Revisiting settlement contemporaneity and exploring stability and instability: case-studies from the Indus Civilization

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Abstract

'Map overestimation' or 'the contemporaneity problem' derives from the assumption that settlements identified during surface surveys were occupied throughout individual periods. Inductive and simulation analysis have been used to ascertain the degree of contemporaneity in surface survey data sets, as variation in settlement location is critical for understanding population density and demography, which inform social, economic and political interpretations. This paper revisits the inductive approach to interrogating survey data developed by W.M. Sumner, and the simulation model approach developed by R.E. Dewar to explore the survey data from two regions within South Asia's Indus Civilization. This analysis demonstrates the strengths and weaknesses of these approaches. It also highlights the variability in settlement systems in different areas within the Indus Civilization, and shows that consideration of stability and instability within settlement systems is an important factor when considering dynamics of resilience and sustainability.

Keywords

Settlement survey, contemporaneity, stability, instability, Indus Civilization

Introduction

Archaeological prospection is fundamental to the reconstruction of ancient and more recent landscapes, and encompasses methods including aerial image and historic map analysis, remote sensing, data integration, and a range of more or less intrusive surface and sub-surface surveying (Banning 2002; Wilkinson 2003; Carver 2009, 63-112; Lawrence 2012; Tapete 2018; Green and Petrie 2018; Petrie et al. 2019). Each aspect of prospection has distinct limitations, and it has long been recognised that chronological resolution is one of the fundamental challenges for surface survey methods, particularly the degree to which it is possible to ascertain which features and sites were contemporaneous (e.g. Adams 1965, 124; Plog 1974; Schacht 1984; Chapman 1999). Establishing contemporaneity is critical for assessing synchronic and diachronic variation in settlement location, which is important for assessing population density and demography. All of these factors inform and constrain social, economic and political interpretations. An important aspect of the interpretation of settlement survey data that is not always considered is the degree to which evidence for contemporaneity informs consideration of stability and instability within settlement systems.

Due to the lack of contextual information, survey data is typically less chronologically precise than excavation data. In some regions of the world, however, styles of material culture changed quickly in the past and have been sufficiently well-studied to enable the attribution of occupation phases at sites identified during surface survey to relatively short periods, in particular cases to spans of one century or less (e.g. Roman Italy: Verreyke and Vermeulen 2009; Minoan Crete: Whitelaw 2012). It is far more common, however, for chronological resolution to be less precise, and material collected might only be attributable to periods that extend for up to five (or more) centuries (e.g. Near East, Adams 1981; Sumner 1994; Wilkinson 2000, 2003; Oaxaca Valley, Mexico, Blanton et al. 1982; South Asia, Joshi et al. 1984; Mughal 1997; Possehl 1999). Attempts have been made to separate some of these longer spans into shorter blocks (e.g. 100-year intervals; Lawrence 2012, Figs. 5.41-5.44, 6.38-6.39; Lawrence et al. 2012, 355-6), but these divisions are typically artificial. Although differentiation of shorter time spans of occupation is desirable, the nature of the evidence may mean that this is not feasible. Coarse chronological resolution can be the result of many factors, including both conservatism of material culture in the past and intensity of research in the present, but it can also mask important behavioural dynamics.

Several attempts to interpret settlement data have assumed that if material belonging to a particular period is attested on the surface of a site, then that site was occupied throughout the entire period (e.g. Plog 1974; Weiss 1977; Schacht 1984). There are, however, numerous examples of archaeological settlement sites that were not occupied for the full duration of every (five hundred year) period identified in surface assemblages. 'Map overestimation' (Ammerman 1981, 71; Plog and Hartman 1990) or 'the contemporaneity problem' (Schacht 1984) has long been recognised as an issue that produces maximal estimations of the number of sites occupied in individual periods, and increases the likelihood that landscapes are 'overpopulated' (e.g. Adams 1965, 124; see Wossink 2009, 49; Lawrence 2012, 74-76). Lawrence (2012, 75) has succinctly noted that "the imprecision implicit in the lumping together of sites exhibiting broadly similar ceramic styles masks the possibility that individual sites within a phase may have been occupied at different times". Ideally, archaeologists want to ascertain the degree to which survey data is a robust and accurate reflection of changing settlement dynamics over time, and with this aim in mind, different approaches have been used to ascertain contemporaneity of occupation within individual periods. Relatively simple inductive methods (based on 'reasoned probable cause') have occasionally been used to identify sub-phases of occupation within longer chronological spans, largely based on whether settlements appear to have been occupied in consecutive periods (e.g. Sumner 1988, 1990, 1994). Similar parameters have also been used in more sophisticated attempts to simulate site contemporaneity using statistics (Dewar 1991, 1994; Kingtigh 1994; Kouchoukos 1998; Wilkinson 2000; Wossink 2009). Even more sophisticated assessments of temporality are possible with sizable collections of radiocarbon dates (e.g. Bocquet-Appel et al. 2009; Timson et al. 2014; Crema 2015; Crema et al. 2016), but such precision is not possible with surface survey data.

Here, inductive and simulation approaches are used to assess the levels of settlement contemporaneity over time in two regions within the broad geographical expanse occupied by the populations of South Asia's Indus Civilization: Cholistan in eastern Pakistan and the hinterland of the site of Rakhigarhi in northwest India. The cities and settlements of the urban phase of the Indus Civilization (*c*.2600/2500-1900 B.C.) were distributed across the Indus River basin and adjacent areas in modern Pakistan and India, and were contemporaneous with the late Early Dynastic, Akkadian, and Ur III periods in Mesopotamia and the Old Kingdom and First Intermediate period in Egypt (reviewed in Wright 2010; Petrie 2013, 2017). It has been argued that a global climate change event at *c*.4.2 ka BP (*c*.2200 B.C.) affected all three of these regions, and disrupted Indus urbanism (e.g. Weiss 2017, 100), though this interpretation is likely too simplistic. The subsistence practices of rural Indus populations appear to have been adapted to the climatic, hydrological, and ecological diversity of the Indus River basin, suggesting that they may have been resilient and sustainable in the face of such processes (e.g. Petrie et al. 2017). The case study regions explored here provide insight into the variation in settlement trajectories that characterise the different regions in the environmentally and culturally diverse context of the Indus River Basin. They also enable exploration of the dynamics of stability and instability in settlement systems in a context that is both variable over short time spans and changeable over longer ones. These findings have important ramifications for how we interpret Indus Civilization settlement data, and also for how we should assess settlement data more broadly, contemporaneity, and dynamics of stability and instability within settlement systems.

Assessing transitions and contemporaneity in settlement distribution data

Excavations often demonstrate that long chronological periods can be divided into coherent sub-phases. However, while period specific material culture may be distinctive, material used only in individual sub-phases is not always easy to recognise in surface assemblages. Many attempts to identify settlement contemporaneity within individual phases of extended periods have therefore been based on inference, and are of necessity, relatively unsophisticated. Researchers must rely on the data on the periods during which individual sites were occupied and make calculations based on the number of sites occupied during periods of interest. Typically, calculations are then modified based on whether sites were also occupied in the preceding, the succeeding, or the both preceding and succeeding periods.

Sumner's inductive approach to transitions in settlement sequences

William M. Sumner (1972) carried out extensive 'full-coverage' archaeological surveys in the Kur River Basin in Fars, in the late 1960s and early 70s that revolutionised our understanding of the rise of early complexity and urbanism in highland southwest Iran. In analysing the results, he attempted to tackle a range of methodological issues originating from the desire to identify sub-phases within extended chronological periods (Sumner 1988, 1990, 1994). He developed a method for identifying contemporaneous settlement that made assumptions about the nature of the occupation based on the presence or absence of material that indicates that the site was occupied in other periods (Sumner 1988, 1990, 1994; also Petrie et al. 2009, 195).

The pre-historic archaeology of the Kur River Basin is divided into periods named after sites or areas where distinctive cultural assemblages were first documented (Sumner 1972, 1990). In order to break up the 1000-year long Bakun period (c.5000-4000 B.C.), Sumner (1994) suggested that 'Early Bakun' phase sites were those with evidence for occupation during the Bakun and the preceding Shamsabad period. 'Middle Bakun' phase sites were those with only Bakun material or with Shamsabad, Bakun and the succeeding Lapui period in evidence. Lastly, 'Late Bakun' phase sites were those that have Bakun and Lapui period material. This approach is illustrated graphically in Figure 1:

Sumner (1994, 49) was wary of the limitation of his inductive approach, and noted that "the accuracy of this method of constructing contemporaneous settlement systems cannot be demonstrated without a refined ceramic chronology and large surface collections". Although his approach appears logical when considering the sub-phases of one specific period, problems become apparent when it comes to the identification of sub-phases for occupation in the preceding (in this case the Shamsabad) and the succeeding (Lapui) periods. For example, using the 'rules', the number of sites occupied in the 'Late Shamsabad' phase should be the same as those occupied in the 'Early Bakun' phase, as both would have evidence for Bakun and the preceding Shamsabad period occupation. This is illustrated schematically in Figure 2, which shows that there is no in built way to differentiate occupation in 'late Period A' and 'early Period B'. This pattern continues into each subsequent phase (e.g. 'late Period B'='early Period

C′, 'late Period C′='early Period D′). Wossink (2009, 49-50) has pointed out that this problem results from the assumptions about occupation during transitions between periods that are built into Sumner's approach. The implications that this approach to survey data has for the interpretation of data sets with unusual structures are explored below.

'Dewar model' simulations and the settlement contemporaneity conundrum

While Sumner was interrogating his Bakun period survey data, Robert E. Dewar (1991, 604, 1994) set out to create a contemporaneity simulation model to address the assumption made by the majority of archaeological settlement distribution models that "components assigned to each phase or period" are normally "treated as contemporaneous". He combined this doubt about levels of contemporaneity with the potential that standard archaeological settlement methods have for 'double counting', resulting from villages being abandoned and relocated within a period, and where the same group of people are responsible for the creation of new similar-sized villages in the same area (Dewar 1991, 605). Dewar (1991, 605) was clear that any interpretations derived from such models are open to legitimate criticism and acknowledged that he was not the first to identify these potential problems (e.g. Plog 1974; Schacht 1984), but distinguished his own approach by arguing that it allowed for single period occupations, which had been less successfully afforded by the earlier attempts. Kintigh (1994) responded to Dewar's original paper and suggested that a different approach to estimating spans of occupation should be used, but in reply, Dewar (1994) noted that this would result in a conceptually different model and associated statistics, and advocated using his model unaltered.

Dewar's contemporaneity simulation model is similar to Sumner's approach in requiring the analyst to have access to settlement data for the target period/phase itself and for the periods/phases immediately preceding and succeeding it (Figure 3). This means that his model cannot be used to assess dynamics of contemporaneity in the first or last phases within a local settlement sequence, but it can be used for all intervening phases.

Using the data from three consecutive phases, Dewar's model calculates a mean settlement *abandonment rate* and an *establishment rate* for the target phase using Monte Carlo simulations

(Dewar 1991, 608-9). The model takes the *abandonment rate* to be equal to (a+d)/p where 'a' equates to the number of sites occupied during both the target and preceding phases, 'd' is equal to the number of sites occupied only during the target phase, and 'p' is the length in years of the target period. For the *establishment rate*, it uses (c+d)/p, where both 'd' and 'p' are as in the previous equation, and 'c' is equal to the number of sites that were occupied during both the target and the succeeding periods (Figure 3).

Dewar's model then uses 'a+b' to calculate the *initial number of sites occupied* at the start of the simulation (i.e. at t_1). The core algorithm takes that input and calculates whether it should be increased and/or decreased by 1 by checking the probability of site creation and abandonment using the *establishment rate* and *abandonment rate* formulae. It then takes this output and re-enters it into the algorithm as the new input, and does this once for every 'p' years, running the analysis an arbitrary number of times (Figure 4). Although noting little change after 100 iterations, Dewar (1991, 610) suggested that 500 was a reasonable number. He also argued that the most interesting aspect of the iterative running of the algorithm was the standard deviation of the result (Dewar 1991, 610). The range of these values represents what Dewar (1991, 609) called the activity or 'flux' of settlement, which was a feature that he argued more accurately represents the dynamism of settlement activity, and is something that is absent from the traditional snapshot methods that he critiqued.

Dewar (1991, 612-616) demonstrated the potential impact of his simulation model using Blanton's 1969 survey in the Ixtapalapa region of the Basin of Mexico (Blanton 1972). The most significant result of Dewar's reanalysis on this dataset was that his model estimates for simultaneous occupations for each of the periods in question were significantly lower than the total count of sites at which any material culture of that period was found (Dewar 1991, 612).

Dewar Model Simulation web app: an online portal for implementing the Dewar model

In order to create a user-friendly interface for carrying out analysis using the Dewar model, one of the authors (Lynam) created an Open Access web interface using the guidelines provided by Dewar (1991) (Figure 5). The web authoring and some of the associated analysis presented below were carried out as part of an extended essay for the MPhil in Archaeology at the University of Cambridge in 2011.

The web app is built on a standard JavaScript-HTML client stack, which means that each simulation initiated by the user is calculated by code that runs within the client's web browser. The first version of the code base was designed to run on a server operating in the cloud because at the time web clients and their operating system hosts would have struggled to run simulations requiring in the order of 100,000 iterations. With recent advances in processing power and the availability of cheaper memory, running algorithms that involve this number of iterations can be achieved with relative ease by most modern personal computer configurations.

The web app is relatively simple in design. Its sole function is to output a single value representing the calculated simultaneous site occupancy rate alongside its accompanying standard deviation. This is calculated within the *runSimulation function*, which takes the target period length in years, the a, b, c, d values as set out in the description of the Dewar model detailed above, and the number of iterations that the user wishes to run the simulation as parameters. This function effectively translates the logic illustrated in Figure 4 into JavaScript code and prints the result as a web page text output. The simulation can be accessed at https://franklynam.com/dev/dewarmodel. The source code for the project is available for re-use under the Creative Commons Attribution 4.0 International license, and downloadable from https://bitbucket.org/franklynamteam/dewarmodel-app.

Sumner's induction approach and Dewar's simulation model are both useful methods for interpreting structure within survey data sets, and they can also be used as heuristic devices for assessing the robustness of interpretations of survey data. In this latter respect particularly, Dewar's model is clearly capable of producing provocative results that provide particular insight into the nature of settlement dynamics across long periods. It is, however, important to consider the nature and limitations of the interpretations it throws up. For instance, its simplicity means that it is not suited to modelling sophisticated scenarios, and Lawrence (2012, 75) has noted that the assumption of a continuous rate of founding and abandonment over time means that Dewar's model is not able to account for relatively extreme instances of mass abandonment or settlement. The same assessment could be made of Sumner's inductive approach. As Wossink (2009, 50) has noted, the Dewar and Sumner approaches both make use of the same parameters, but the two methods deploy this data in different ways, and produce distinct results. Here, we directly compare the results generated using the Dewar and Sumner methods to interrogate survey data from two regions within South Asia's Indus Civilization. This analysis allows us to assess the implications of the types of data output by each method, which in turn makes it possible to explore and assess dynamics of settlement contemporaneity in different data sets, and highlight other dynamics in settlement systems that are revealed.

Interrogating Indus settlement distribution using simulation and induction approaches

Since the 1950s, there have been a proliferation of archaeological surveys throughout different parts of the Indus River Basin in western South Asia (e.g. Stein 1942; Suraj Bhan 1975; Surah Bhan and Shaffer 1978; Joshi et al. 1984; Possehl 1999; Wright et al. 2001, 2003; Singh et al. 2008, 2010, 2011, in press a, in press b; Chakrabarti and Saini 2009; Dangi 2009, 2011; Kumar 2009; Parmar et al. 2013; Pawar et al. 2013; Sharan et al. 2013). These surveys have typically been based around a 'village to village' method that is broadly akin to 'full-coverage survey' approaches, which attempt to survey an entire region and record all of the sites that are discovered (Green and Petrie 2018; *cf*. Sumner 1990). The resulting data has had direct impact upon current interpretations of the Indus Civilization (e.g. Chakrabarti 1995, 1999; Lal 1997; Kenoyer 1997; Possehl 1999, 2002; Wright 2010; Cork 2011; Coningham and Young 2015). Important surveys that have been carried out in Cholistan in eastern Pakistan and the area around the Indus urban site of Rakhigarhi in northwest India will be considered here (Figure 6).

Settlement dynamics in Cholistan

Between 1974 and 1977, M. Rafique Mughal oversaw an extensive settlement survey of the region of Cholistan, in Punjab, Pakistan (Figure 6; Mughal 1997; also Mughal et al. 1996). Today, Cholistan is a barren semi desert zone delineated by the Thar Desert to the east, the alluvial plains of the Indus, Chenab and Sutlej rivers to the west and north, and Sindh province to the south (Mughal 1997, 20-21).

Mughal's team mainly used random surface collection to ascertain their periods of occupation at the sites they identified (Mughal 1997, 27-28, 32-33). They supplemented the surface collections by sinking occasional test trenches to have a cursory look at site stratigraphy, which became particularly important for establishing the relative position of Hakra ware (Mughal 1997, 32-33), which was in use before the Early Harappan or Kot Diji period. Mughal (1997, 32-33) proposed a date of *c*.3500-3100/3000 B.C. for Hakra ware, and used conventionally accepted dates of *c*.3100/3000 B.C. for the Early Harappan period, *c*.2500-2000/1900 B.C. for the Mature Harappan period, *c*.2000/1900-1500 B.C. for the Late Harappan period, which effectively represent the pre-urban, urban and post-urban phases in typical Indus chronologies (Possehl 1999, 2002; Wright 2010). None of the periods have been chronologically constrained locally.

Mughal's team paid particular attention to tracing settlement along the relict channels of the Ghaggar-Hakra River (Mughal 1997, 21-22), which is the subject of ongoing debate about its morphology, date, historical identity, and archaeological importance (e.g. Lal 2002; Saini et al. 2009; Danino 2010; Clift et al. 2012; Giosan et al. 2012; A. Singh et al. 2017).

Although there are numerous publications on the results of the Cholistan survey (see Mughal 1997), the final publication was designed to incorporate data on all of the sites found during the survey, including the site name, associated cultural assemblage(s), size of the area covered, type of site (camp site, industrial, etc.), and location (Mughal 1997, 139-56; SI, Table SI.1). It also included summary tables assessing site size frequency in various ways (Mughal 1997, Tables 11-14). Additional sites in the region were published in a report on a more extensive archaeological survey of Pakistani Punjab (Mughal et al. 1996), and sites in Cholistan identified by Sir M. Aurel Stein (1943) were included in Gregory Possehl's (1999, Appendix A) collated list of sites. These publications include sites dating to all cultural periods documented in the region, but the majority of sites had occupation dated to the Hakra and the Early, Mature and Late Harappan periods. A summary of the total site count for Cholistan, the total area of all sites and a calculation of the average area/site per period is shown in Table 1 (full details in Table SI.1).

Size data on a number of sites is not presented in the publications. Specifically, two of the sites listed as containing Hakra material, one sites listed as containing Early Harappan material, and three sites listed as containing Mature Harappan material have no associated site size data. If the major urban site of Ganweriwala is excluded from the Mature Harappan calculations, the average site area is 5.60ha.

Mughal (1997, 31-62, Tables 1-10, 139-148) assigned periods and maximum occupation extents to the sites compiled in his catalogue, and also attributed sites to typologies based on interpreted use. These categories included temporary camp sites, industrial sites, settlements with kilns, residential settlements, and cemeteries (Mughal 1997, 53, Table 11). Mughal's (1997, 59; Table 11) inclusion of a camp site category is of particular importance for our overall understanding of Indus settlement, as it showed the first indications that aspects of the population engaged in pastoral and potentially nomadic lifeways, particularly during the Hakra and Late Harappan periods. The Cholistan data support the claim that there were substantial numbers of small/rural sites, but Cork (2011, 172) made the prescient point that the numbers of sites may be misleading because there is no differentiation within very long chronological phases.

The settlement distribution dataset from Cholistan provides sufficient information to calculate estimated simultaneous site occupancy rates for the region during the Early, Mature and Late Harappan periods, as they are flanked by data from both preceding and subsequent periods. The Late Harappan period is somewhat problematic as Mughal suggests that it was followed by a hiatus of around 400 years before the emergence of the Painted Grey Ware (or PGW) period sites at the end of the second millennium B.C. (Mughal 1997, 35). For the purposes of this analysis, the PGW period is assumed to directly succeed in the Late Harappan occupation, but as will be seen below, the settlement data itself suggests that a specific type of displacement occurred between these two periods in Cholistan.

Table 2 lists the inputs calculated using the complete Cholistan dataset and the results of the Dewar simulation model are shown in Table 3. The calculations of settlement contemporaneity in the Early Harappan period use the following parameters: a = sites occupied in the Hakra Ware and Early Harappan periods; b = sites occupied in the Hakra Ware, Early Harappan and Mature Harappan periods; c = sites occupied in the Early Harappan and Mature Harappan periods; and d = sites occupied in the Early Harappan period only. The calculations of settlement contemporaneity in the Mature Harappan period use the following algorithm parameters: a = Early Harappan and Mature Harappan periods; b = Early Harappan, Mature Harappan and Late Harappan periods; c = Mature Harappan and Late Harappan periods; and d = Mature Harappan period only. The calculations of settlement contemporaneity in the Late Harappan period, the algorithm parameters are as follows: a = Mature Harappan and Late Harappan periods; b = Mature Harappan, Late Harappan and PGW periods; c = Late Harappan and PGW periods; and d = Late Harappan period only. Table 3 also includes calculations for the total occupied area and a standard deviation for each period, which should be considered with caution, as it is not clear which sites were occupied at any one time. Wossink (2009, 54-55) suggests performing simulations for each site size class, but this has not been attempted here, because of the limited number of sites occupied in consecutive periods. The site size statistics are included simply to provide a means of comparing data from different periods within Cholistan, and to make speculative comparisons with the data from the area of Rakhigarhi.

There is a dramatic difference between the number of sites attributed to each of the Early, Mature and Late Harappan periods (Table 1), and the number of sites likely to have been occupied contemporaneously, as calculated using the Dewar model (Table 3; Figure 7). This is a product of both the logic behind the Dewar model and the specifics of the settlement data, which attest to minimal continuity of occupation between each of the three of the Indus periods, as highlighted by the low numbers for parameters 'a', 'b', and 'c' shown in Table 2. For example, of the 57 sites reported as having Early Harappan material, only two also included Hakra Ware material and three different sites contained Mature Harappan material (Table 2). No sites were occupied in all three of the Early, Mature and Late Harappan periods, which is significant as the ‘rules’ of the Dewar model stipulate that the existence of a site for an entire period is only guaranteed if it also shows evidence of occupation in the preceding and subsequent periods (Dewar 1991, 608, 1994; see also Kintigh 1994). The lack of continued occupation is an important aspect of the data.

Dewar (1994, 150) and Wossink (2009, 51-2) both note that the Dewar model is unable to detect multiple phases of occupation within a single period, and Wossink (2009, 53) argued that this creates a “floating reconstruction of contemporaneous sites”. Importantly, abandonment and resettlement within the same period has been identified at cognate settlements excavated in northwest India (Petrie et al. 2016). This factor is significant for the Cholistan data, as the lack of Early Harappan sites that were also occupied in the preceding and succeeding periods ensures that the model attributes the majority of the sites to only a single sub-phase within the overall Early Harappan period. The results of the analysis thus suggest that of the 57 sites that Mughal lists, fewer than ten were occupied at any one time during the Early Harappan period, with the simulation estimating the number between 2.471 and 9.249 (rounded to 2-9; 4-16%). These patterns are repeated for the Middle and Late Harappan periods. Of the 186 sites occupied in the Middle Harappan period, the simulation estimates simultaneous occupation at between 3.793 and 14.267 sites (rounded to 4-14; 2-7.5%), and of the 56 sites occupied in the Late Harappan period, the simulation estimates simultaneous occupation at between 1.825 – 8.035 sites (rounded to 2-8; 4-14%). Taken together, the output from the Dewar model for these three periods suggests that contemporaneous occupation at any point during each period was significantly lower than the total number of sites for any one period (Figure 7). It is notable that the figures cited here are different to those listed by Petrie et al. (2017, 13), as more sites have been added to the data set.

If we use the criteria outlined by Sumer (1994) to assess the settlement dynamics of the same sites and the same periods (as per Figure 2), we again see a different pattern (Table 4), which is also distinct from the results of the Dewar analysis shown in Table 3. Sumner’s approach shows marked shifts from concentrations of occupation in the middle of each period (e.g. early-mid Hakra ware phase: 122 sites; the mid-Early Harappan phase: 52 sites; mid-Mature Harappan:

179; mid-Late Harappan: 52 sites), to minimal occupation in the transitional periods (late Hakra/early Early Harappan: 2 sites; late-Early/early Mature Harappan: 3 sites; the late-Mature/early Late Harappan: 4 sites) (Figure 7).

The ostensibly transitional sites shown in Table 4 are also identified in the Dewar model parameters shown in Table 2, and highlight the limited continuity of occupation between periods in Cholistan (Figure 7). The Sumner approach therefore challenges the traditional interpretation in a similar way to the Dewar model, with both analyses serving to highlight underlying issues within the dataset, which will be explored further below.

Settlement dynamics on the plains of northwest India

The plains of northwest India have been subjected to archaeological surveys of varying intensity since the early 1970s (e.g. Suraj Bhan 1975; Suraj Bhan and Shaffer 1978). A reconnaissance of known sites in 2008 demonstrated that there are significant errors in the published locations, that knowledge of site distribution and density is dictated by the intensity and extent of previous surveys, and that large numbers of sites of all periods have not been recorded (R.N. Singh et al. 2008; Petrie et al. 2017). These limitations prompted two targeted surveys under the auspices of the *Land, Water and Settlement* project. The first focussed on settlement distribution in the hinterland of the Indus urban site of Rakhigarhi (the Rakhigarhi Hinterland Survey; R.N. Singh et al. 2010), while the second focussed on the settlement distribution around the Ghaggar-Hakra palaeochannel in northern Haryana and southern Punjab (the Ghaggar Hinterland Survey; R.N. Singh et al. 2011). Other researchers have since carried out surveys in neighbouring areas (e.g. Parmar et al. 2013; Pawar et al. 2013; Sharan et al. 2013). A reassessment of a sub-set of the settlement data for northwest India has identified important patterns, but also highlight ongoing problems caused by inaccuracy in site location and attribution, and incomplete coverage (Green and Petrie 2018). Surveys have also now been carried out by the *TwoRains* project in the areas between and around the *Land, Water and Settlement* surveys (R.N. Singh et al. in press a, in press b). Here we will consider the results of the Rakhigarhi Hinterland Survey as a means of providing contrast to the data from Cholistan (Figure 6).

The Rakhigarhi Hinterland Survey data provides evidence for occupation in the Early, Mature and Late Harappan periods, as well as the PGW period, and while it is broadly cognate with the data from Cholistan, it lacks evidence for Hakra Ware period occupation (Table 5, SI: Table S2; R.N. Singh et al. 2010). Petrie et al. (2017, 14) have pointed out that there is no clear evidence for a large paleochannel on the surface in the vicinity of Rakhigarhi, but many of the sites dating to the different Indus periods are in a linear arrangement, suggesting that there may be a watercourse that is now hidden beneath the subsurface (also R.N. Singh et al. 2010, 46). The survey data suggests that the area around Rakhigarhi was first occupied during the Early Harappan phase (R.N. Singh et al. 2010), and there is also evidence for Early Harappan occupation on at least one of the mounds at Rakhigarhi (Nath 1998, 1999, 2001). The expansion of Rakhigarhi into an urban centre in the Mature Harappan period appears to have partly depopulated the surrounding area, including the abandonment of sites that are 'upstream' and 'downstream' from Rakhigarhi along the putative watercourse (R.N. Singh et al. 2010, 46, Figs 3-4). Many sites in these areas were re-occupied in the post-urban Late Harappan period (R.N. Singh et al. 2010, 46). In contrast to the Cholistan data, a significant number of the Indus settlements in the hinterland of Rakhigarhi were occupied in consecutive periods. These data appear to indicate broad continuity in occupation over time from the pre-urban through urban to post-urban phases, with little change in the overall population within the hinterland of Rakhigarhi (Table 5; Petrie et al. 2017, 14). As for the Cholistan data, there is evidence that the major change in settlement distribution in the Rakhigarhi area appears to come with the PGW period. The alignment of sites that are oriented on Rakhigarhi in all of the Indus periods disappears, and the main concentration of settlement in the PGW period appears to shift to the southeast where there is a complex network of modern canals (R.N. Singh et al. 2010, 46, Figure 6).

The patterns in the survey data for the hinterland of Rakhigarhi make it a useful candidate for comparison and contrast to Cholistan. Both regions have been subject to extensive survey, and appear to have concentrations of settlement around an urban-scale centre. However, each is environmentally distinct and situated in a different rainfall zone (Petrie 2017; Petrie et al. 2017), so each has the potential to reveal different insights into the development of Indus urbanism. It should be emphasised, however, that the area surveyed in Cholistan is much larger, so it is not appropriate to directly compare the raw numbers of sites in each region, but it is feasible to compare patterns in the data. The period-wise data from the Rakhigarhi Hinterland Survey are shown in Table 5.

The inputs for the Dewar model as calculated for the Rakhigarhi Hinterland Survey data are listed in Table 6 and the results are given in Table 7. It is not possible to produce a simulation for the Early Harappan period. The calculations of settlement contemporaneity in the Mature Harappan period use the following parameters: a = sites occupied in the Early Harappan and Mature Harappan periods; b = sites occupied in the Early Harappan, Mature Harappan and Late Harappan periods; c = sites occupied in the Mature Harappan and Late Harappan periods; d = sites occupied in the Mature Harappan period only. The calculations of settlement contemporaneity in the Late Harappan period use the following parameters: a = Mature Harappan and Late Harappan periods; b = Mature Harappan, Late Harappan and PGW periods; c = Late Harappan and PGW periods; d = Late Harappan period only.

The analysis of the Rakhigarhi Hinterland Survey data using the Dewar model reveals a significantly high degree of contemporaneity of occupation at settlements during the urban Mature Harappan period, with 10.18-13.82 (rounded to 10-14) of the 17 settlements in occupation at any one time (59.8-81.2%). However, the model suggests that there was a dramatic decrease in site contemporaneity during the post-urban period, with only 6.04-13.24 (rounded to 6-13) of the 33 settlements in occupation at any one time (18.3-40.1%) (Figure 8). Keeping in mind the differences in the size of the area surveyed, it is notable that these summative statistics are markedly different to those for Cholistan. As for Cholistan, the figures cited here are different to those listed by Petrie et al. (2017, 13), as more sites have been added to the data set.

If we use the criteria outlined by Sumer (1994) for the Rakhigarhi Hinterland Survey data, we see a different pattern once again. These data are summarised in Table 8. The mid-phase occupations in each period are the most abundant (early-mid Early Harappan: 15 sites; mid-Mature Harappan phase: 11 sites; mid-Late Harappan: 16 sites), whereas the transitional phases have fewer sites (late-Early/early Mature Harappan phase: 4 sites; the late-Mature/early Late Harappan: 2 sites; late Late Harappan/early PGW: 7 sites) (Figure 8).

It is notable that the number generated for the mid-Mature Harappan sub-phase (Table 8) using the Sumner method is within the range of the mean simultaneous occupation generated by the Dewar model (Table 7). There is an increase in the number of sites occupied during the mid-Late Harappan period, which reflects an overall increase in the number of sites in that period. However, the Dewar model suggests that not all of these sites were occupied simultaneously *within* that phase, which is backed up by the Sumner analysis that suggests that only half of the 33 known sites were occupied. As with the Cholistan data, the distinctive patterns that are shown by the analyses for the Rakhigarhi Hinterland Survey data highlight underlying issues with the dataset, which will be explored further below.

Contemporaneity, stability and instability in Indus settlement systems

The results generated by the Dewar model simulations and the Sumner inductive analysis are significant for our understanding of the Cholistan and Rakhigarhi Hinterland Survey data and have implications for the stability and instability of settlement in each context. In addition to being data from different regions, the Cholistan data set is over three times the size of the Rakhigarhi Hinterland Survey data, and the area that it encompasses is more substantial. Furthermore, the level of interpretation for the Cholistan data is considerably more developed, as the dataset has been in hand for over 40 years, while the Rakhigarhi Hinterland Survey data is still being assessed, so there are differences in the degree to which the new results impact existing interpretations.

Extant interpretations

Based on the density of sites in the region, Possehl (1997, 462; see Cork 2011, 185) argued that Cholistan was the most important area of settlement concentration in the Mature Harappan period. Mughal accepted his survey data at face value, and his interpretations were based on the assumption that each settlement was occupied throughout each of the periods attested in their surface material. Significantly, Mughal (1997, 26; Cork 2011, 160) postulated that the Hakra River ceased to flow perennially sometime in the latter half of the third millennium B.C., and that by the mid-second millennium B.C. the flow had become so minimal as to result in the devastation of the regions viability as a zone of agricultural exploitation.

In considering settlement size, Mughal (1997, 55-59, Tables 13-14) proposed a four-tier hierarchy (with six categories: village [small <=5ha and large 5.1-10ha], town [small 10.1-20ha, large 20.1-30ha], small city [30.1-40ha], large city [>=80ha]) for the region, which was in keeping with prevailing approaches to settlement pattern analyses (e.g. Adams 1981; Flannery 1998; see also Chakrabarti 1995, 29-31, 81; Cork 2011, 155-192). While Mughal did not explicitly use the word 'state' to describe the patterns that he observed, his discussion leaves little doubt as to his favoured interpretation, where Cholistan is thus seen as an important 'core centre of the Harappan culture' (e.g. Mughal 1997, 57). The periods preceding and succeeding the urban Mature Harappan period were seen as being either formatively or derivatively related to this central phase (Mughal 1997, 57-8).

Several scholars have followed Mughal's interpretation of a four-tier division, with Wright (2010, 132, 137) noting that the central place model supplemented by that of the city-state are best used to describe the distribution and structure of settlement in what she refers to as the 'urban' Indus phase. Kenoyer (1991, 351, 1997) has similarly referred to a four-part settlement division with the tier-one sites being greater than 50 ha in size, tier-two being 10-50 ha, tier-three being 5-10 ha, and the final tier-four sites being less than 5 ha. Cork (2011) used rank-size analysis to interrogate settlement patterns across the Indus Civilization, and characterised the Cholistan Early Harappan rank-size pattern as being very convex in form, indicating a structure based on independent mid-size towns (Cork 2011, 185). He pointed out that spatially, mid-size towns in Cholistan are clustered around each other, and suggested that this might indicate a need for advanced food redistribution systems to subsidise the needs of the urban populations (Cork 2011, 190). Cork (2011, 191) also suggested that the proximity of these mid-sized sites might point towards a specialisation of site function as has been suggested for sites around Uruk in Mesopotamia. The pattern becomes a primo-convex curve during the Mature and Late Harappan periods, which Cork (2011, 185) argued indicates one of two possible scenarios: a large primate centre with some regional control or a primate system with regional control superimposed onto a system of independent mid-size towns.

Village sized sites increased in number and the percentage of occupied area that they comprise from the Hakra to Mature Harappan periods, while the town sized sites decreased in both these categories during the same periods (Mughal 1997, 57, Table 14). The exception is the site of Ganweriwala, which appears in the Mature Harappan period and at *c*.81ha fits the role of the large first-tier urban city site, though its extent has subsequently been queried (Kenoyer 2008, 188; Petrie 2013, 91). Mughal saw his four-tier model as being most in evidence during this Mature Harappan period, but conceded that perhaps a three-tier system might better suit the Hakra, Early Harappan and even the Mature Harappan periods if the small village and large village categories were combined into a single analytical unit (Mughal 1997, 58). The importance of smaller settlements is suggested by the data in Table 1, which shows that the Mature Harappan period had a combined settled area of 1117.76 ha, and the average site size was 6.01 ha.

Mughal (1997, 55-59, Table 11) also made a specific point of identifying camp sites and sites with evidence of industrial activity, and sought to explain the changing ratios of these types throughout the periods. Referring only to the data included in his 1997 publication, he noted a sharp decline in the number of camp sites with the shift to the Early Harappan (from 52.52% in the Hakra Ware period to 7.50%), and a resurgence of such sites in the Late Harappan (26%) (Mughal 1997, 55-59, Table 11). Sites with industrial activity showed a different pattern, increasing from a minimal occurrence in the Hakra Ware period (two sites, 2.02%), to comprising the majority of sites in the Mature Harappan period (112 sites, 64.36%), where a substantial proportion being purely industrial (79 sites, 45.40%) (Mughal 1997, 54-5, Table 11).

The data produced by the Ragkhigarhi Hinterland Survey (R.N. Singh et al. 2010) has been subject to far less interpretation as it is integrated into the fabric of ongoing field research projects that continue to carry out survey in the surrounding region (e.g. Green and Petrie 2018; R.N. Singh et al. in press a, in press b). Building on the initial preliminary report (R.N. Singh et al. 2010), several observations about these data have been put forward (Petrie et al. 2017, Petrie 2017), but no detailed analysis of site size and occupied area has yet been published, and the figures included here are preliminary. Further, it is not possible to discuss the presence or absence of camp or industrial sites, or settlement hierarchy in a sophisticated way. However, it is possible to compare the relative figures for total and average occupied area, and the way that those figures are modified by the Dewar model calculations.

The urban centre of Rakhigarhi appears to have been first occupied in the Early Harappan period, increased in size during the Mature Harappan period, but was depopulated and then abandoned by the start of the Late Harappan period (Nath 1998, 1999, 2001; R.N. Singh et al. 2010, Table 1; Nath et al. 2014; Shinde et al. 2013). Petrie et al. (2017, 14) have noted that the Rakhigarhi Hinterland Survey data suggests that there was little change in the overall population within the hinterland of Rakhigarhi during the Indus periods, and no substantial increase in the Late Harappan period, at least in this part of the plain (see Table 5).

Petrie et al. (2017, 14) have also pointed out that the pattern of settlement within the area of the Rakhigarhi Hinterland Survey contrasts to prevailing views that suggest a significant increase in settlement numbers on the plains of northwest India during this period (Madella and Fuller 2006; Kumar 2009; Wright 2010, 317–318, 2012). Green and Petrie (2018) have reaffirmed the likelihood that the Late Harappan period saw settlement numbers increase overall across northwest India, suggesting that the increase occurred outside the hinterland of Rakhigarhi.

Implications of the Dewar simulation and the Sumner inductive analysis

Assessing the Sumner inductive and Dewar simulation results presented here against the extant interpretations highlights the utility and limitations of both methods. While Dewar's model helps to overcome 'map overestimation' and 'the contemporaneity problem', which have the potential to skew estimates of past demography, it can only provide an estimate as to the number of contemporary sites during a set period. It cannot determine which settlements were contemporary, where they were located spatially, or what their extent might be, all of which are important criteria for settlement pattern analysis. This limitation means that any new insights will only be abstract rather than concrete. There are similar problems with the Sumner approach, which provides a logic for identifying transitional phases, but is susceptible to 'map overestimation' because of the rules it uses for identifying mid-period occupations.

The Sumner inductive and Dewar simulation analysis data suggest that it may be misleading to assume that the large numbers of settlements recorded for each phase in Cholistan represent concentrated and dense settlement. Rather, the modelled data for contemporaneity, and the fact that there was little continuity of occupation between periods at individual settlements suggest that Cholistan may have been characterized by an unstable settlement system with only a subset of settlements being occupied at any one time during each Indus periods (Petrie et al. 2017, 13).

By suggesting that many of the sites in Cholistan were not occupied contemporaneously, the Dewar model results challenge Cork's (2011, 172) discussion of clustering during the Hakra and Early Harappan phases. Clusters of sites might represent the movements of the same group of people around the same region during one period (Petrie et al. 2017, 13). We can similarly apply this interpretation to the proliferation of camp sites, particularly where there are clusters of sites around one modern village (e.g. Khiplewal I, II, III, which are all Hakra period sites). Although the total settled area of the 186 sites occupied in the Mature Harappan period was 1117.76 ha with an average site size of 6.01 ha, the Dewar model suggests that only 4-14 of these sites might have been occupied simultaneously. These numbers indicate that the area contemporaneously occupied was 54.27 ha +- 31.47 ha (see Table 4), which is difficult to rationalise, as this was the period when the potentially *c*.81ha site of Ganweriwala was occupied. The abstracted Dewar model data for Cholistan are clearly provocative, but clearly must be tested on the ground through careful assessment of the surface assemblages.

Instability in the Cholistan settlement system may have been a product of various factors. An increasing number of palaeoclimate proxy records from the surrounding region suggest changes in winter and summer rainfall during the mid-Holocene (e.g. Dixit et al. 2014a, 2014b, 2018; Giesche et al. 2019). Mughal (1997, 25) suggested that the flow of the water of the Sutlej system previously flowed into the Ghaggar-Hakra channel, which may have become seasonal as early as the third millennium B.C. and dried up altogether by the mid-second millennium B.C.. There has been debate about the nature of water flow in the Ghaggar-Hakra hydrological system, and the dates at which it changed. Remote sensing analysis has highlighted that this system was very complex (e.g. van Dijk et al. 2016; Orengo and Petrie 2017, 2018), and OSL dates from northwest India suggest cessation of major river flow between ~15-12ka and ~8ka BP (A. Singh et al. 2017). However, other dates suggest parts of the system were active in later periods (e.g. Saini et al. 2009; Saini and Mujtaba 2010; Durcan et al. 2017; also Durcan 2012; Clift et al. 2012; Giosan et al. 2012; Maemoku et al. 2012). Petrie et al. (2017; Petrie 2017) have suggested that it is possible that ephemeral flow continued as a result of the monsoon rain in the catchment, and this is demonstrated by historical floods in the early nineteenth century (Mughal 1997, 131, 134; after Punjab States Gazetteer 1908) and references to flood diversions on historical Survey of India maps.

Stein (1942, 173, 181; Mughal 1997, 26; Possehl 1999, 372-384; Durcan 2012, 260) suggested that an inland delta might have been present around Fort Derawar at some time during the past. Durcan (2012, 260-1) expanded this insight by drawing attention to the similarities of this potential inland delta and the operation of floodout systems, such as those described in Central Australia and elsewhere by Tooth (1999, 2005, 2012). In such situations, water moves from areas with confining upstream terraces, and crosses an emergence point after which floodouts occur as the water spreads out and braids across a plain and dissipates (e.g. Tooth 2005, 638, Figure 3). A braided hydrological system would have been susceptible to the frequent avulsions during the periods of flooding that occur during monsoon rains (Petrie et al. 2017, 13). If the environment was as marginal as it appears, settled populations may have required strategies involving mobility between settlement locales to survive a constantly shifting hydrology. Petrie et al. (2017, 13; Petrie 2017) have suggested that individual families or kin groups might have needed to spread their members between multiple settlements. In different years or generations, individuals or groups might have moved between settlements to access available water in times of shortage or stress.

The Sumner inductive and Dewar simulation analysis results for the Rakhigarhi Hinterland Survey region are markedly different to those for Cholistan, suggesting that there was considerable continuity of settlement between periods, which in turn indicates that there was relative stability in the settlement system within this region. This stability is emphasised by looking at the data for the total settled area in the Mature Harappan period, which is 208 ha, and the average site size of 12.24 ha (Table 5). The Dewar model results suggest that 10-14 of the 17 Mature Harappan sites might have been occupied simultaneously, which indicates that the majority of the settlements were occupied throughout the period, potentially comprising a total area of 146.9 ha +- 22.28 ha, or 59.8-81.2% of the total. A major change appears to have occurred in the Late Harappan period, however, with only 6-13 of the 33 settlements in occupation at any one time, potentially comprising only 63.1 +/- 23.58 ha or 18.3-40.1% of the total settled area of 216 ha being occupied at any one point. These statistics suggest a significant change within the settlement system around Rakhigarhi between the two periods, with the implication being that there was more mobility of the population during the post-urban period, which contrasts to what appears to be a stable settlement system in the Mature Harappan period. This finding is partly a product of the model and partly due to the data, as there is continuity in occupation at a number of sites between the Mature and Late Harappan periods, but less continuity of occupation between the Late Harappan and PGW period (attributes ‘b’ and ‘c’ in Table 6). As noted above, the PGW period occupation shows a more substantial shift, with only seven of the sites occupied in the Late Harappan period continuing into the subsequent period, and significant numbers of new settlements appearing to the south east of the main area of Indus period occupation (R.N. Singh et al. 2010, Figure 6). Remote sensing analysis has attested to the existence of a complex network of palaeochannels in the area around Rakhigarhi (Orengo and Petrie 2017, 2018), and preliminary geomorphological analysis has suggested that this area was situated on a braided river system (Neogi et al. in press). The nature of this system is currently being assess through targeted geomorphological research (Walker in prep).

Conclusions and implications

The differences between the settlement dynamics that operated during the Indus periods in Cholistan and the area around Rakhigarhi that have been identified here have important ramifications for the ways that each set of data can be used to inform our understanding of Indus landscapes and urbanism. Cholistan has long been regarded as a core area for Indus settlement, but the Dewar and Sumner data suggest that the region may have been characterised by an unstable settlement system requiring mobility of the population between settlements. In contrast, the area around Rakhigarhi appears to have been characterised by a more stable settlement system in the Early and Mature Harappan periods, but saw an increase in population mobility during the Late Harappan period, and further changes in the PGW period.

The suggestion that settlement in Cholistan was unstable is provocative, and beyond what is outlined here, we currently lack the data to determine whether it is credible. It is essential to understand the rationale for why such a settlement system might have been in place, and the hydrology of Cholistan and its proximity to the Thar Desert are likely to be critical factors. The nature of monsoon rainfall and its impact upon the hydrology of the Ghaggar/Hakra river system is regarded as an important factor for explaining change in Indus settlement, and Petrie et al. (2017, 12) have suggested that it may not have been perennial during the Holocene. This interpretation has implications for both the settlement systems in both regions considered here.

Instability in the Cholistan settlement system may have been a product of the type of a braided river system susceptible to frequent small-scale avulsions during periods of flooding that appears to have watered the region, which appears to have been distinct from the system operating around Rakhigarhi. Living in such an environment may have required settled populations to be relatively mobile and there may have been high population mobility between settlement locales. Such practices suggest that Indus populations were adapted to a diverse environment, and have implications for the sustainability and resilience of those adaptations (Petrie et al. 2017, 13; Petrie 2017). There is considerable scope for learning more about the life-ways of the people living in these settlements through future investigation of local subsistence practices, and examination of the local geomorphology and hydrology. Although Rakhigarhi did not sit along the most readily visible channel in the Ghaggar/Hakra river system, there was clearly some form of channel in the area of the settlement (Orengo and Petrie 2017, 2018). The continuity of settlement from the Early to Mature and even to some degree into the Late Harappan period suggest that the hydrology of this area was relatively reliable and stable during the Indus period, though the settlement system appears to have seen some change with the shift to the Late Harappan period, and further change with the PGW period.

The reassessments of settlement dynamics and contemporaneity presented here clearly have implications for our interpretation and understanding of Indus Civilization settlement systems, but also of settlement systems more generally. This analysis reaffirms the usefulness of the Dewar model simulations and the Sumner inductive analysis approaches as ways of exploring survey data in new ways, and both have the potential to extract more information from that data. Particularly, these approaches provide insight into *how* settlement distributions change and offer important additions to the toolkit of descriptive statistics that can be used to interrogate survey data. The approach and results presented here are in accord with similar analyses attempted by Wossink (2009) and Lawrence (2012). Importantly, Wossink (2009) builds a specific case for the development of specialised pastoralism in northern Mesopotamia during a similar period where climate and climate change were important parameters. It may be prudent to explore further models for behaviour and lifeways in Cholistan that explore the demographics of mobility of sedentary communities and the relationship between sedentary and pastoral communities operating at different levels of attachment and independence. Understanding of the dynamics of settlement systems and particularly their stability and instability is critical for interpreting a range of processes, particularly when it comes to human response to environmental change, and assessments of resilience and sustainability.

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Figure captions

Figure 1. Schematic representation of Sumner's (1994) approach to identifying sub-phases of extended chronological periods (image C.A. Petrie).

Figure 2. Extension of Sumner's (1994) rules to sequential chronological periods (image C.A. Petrie).

Figure 3. Schematic of the notation used by the Dewar model (image F. Lynam; after Dewar 1991: Figure 3)

Figure 4. The operation of the Dewar model algorithm (image F. Lynam)

Figure 5. Dewar Model Simulation web implementation (image F. Lynam)

Figure 6. Map showing the distribution of Indus settlements and the location and extent of the survey regions in Cholistan (at centre) and the Rakhigarhi hinterland (at right; image compiled by C.A. Petrie)

Figure 7. Comparison between Mughal's Cholistan survey results and the outputs of the Dewar model and the Sumner estimates analysis. Site counts shown on y-axis.

Figure 8. Comparison between the Rakhigarhi Hinterland Survey (RHS) results and the outputs of the Dewar model and the Sumner estimates analysis. Site counts shown on y-axis.

Tables

Period	*Absolute dates*	*Total site count*	*Total area of all sites*	*Average area/site*
Hakra Ware	c.3500-3000 B.C.	122	800.80ha	6.56ha
Early Harappan	c.3100-2500 B.C.	57	389.66ha	6.84ha
Mature Harappan	c.2500-1900 B.C.	186	1117.76ha	6.01ha
Late Harappan	c.1900-1500 B.C.	56	323.62ha	5.78ha
Painted Grey Ware	c.1100-500 B.C.	16	41.6ha	2.60ha

Table 1. Summary of the Cholistan survey data (compiled from Stein 1943; Mughal 1997, Tables 1-10, 139-148; Mughal et al. 1996, Appendix I; Possehl 1999, Appendix A).

Period	*Duration*	*a*	*b*	*c*	*d*
Early Harappan	600 years	2	0	3	52
Mature Harappan	600 years	3	0	4	179
Late Harappan	400 years	4	0	0	52

Table 2. Dewar model input variables (after Mughal 1997).

Period	*Site count*	*Total occupied area*
Early Harappan	5.86 +/- 3.389	40.08 +/- 23.18ha
Mature Harappan	9.03 +/- 5.237	54.27 +/- 31.47ha
Late Harappan	4.93 +/- 3.105	28.49 +/- 17.94ha

Table 3. Estimates for contemporary occupation in Cholistan region derived using the Dewar model. The average site counts and standard deviations were calculated by averaging the results of 20 individual simulations that were run through the MC calculation with 100,000 iterations.

Period	*Sumner*	
early-mid Hakra	122	[Hakra ware only]
late Hakra/early Early Harappan	2	[Hakra/Early]
Mid-Early Harappan	52	[Hakra/Early/Mature, and Early Harappan only]
late Early/early Mature Harappan	3	[Early/Mature]
mid-Mature Harappan	179	[Early/Mature/Late, and Mature only]
late Mature/early Late Harappan	4	[Mature/Late]
mid-Late Harappan	52	[Mature/Late/PGW, and Late only]
late Late Harappan/early PGW	0	[Late/PGW]
mid-PGW	16	[PGW]

Table 4. Sumner estimates of period-wise occupation

Period	*Absolute dates*	*Total site count*	*Total area of all sites*	*Average area/site*
Early Harappan	*c*.3100-2500 B.C.	28	189ha	6.75ha
Mature Harappan	*c*.2500-1900 B.C.	17	208ha	12.24ha
Late Harappan	*c*.1900-1500 B.C.	33	216ha	6.55ha
Painted Grey Ware	*c*.1100-500 B.C.	20	107ha	5.35ha

Table 5. Summary of the RHS survey data (R.N. Singh et al. 2010).

Period	*Duration*	*a*	*b*	*c*	*d*
Mature Harappan	600 years	4	9	2	2
Late Harappan	400 years	10	1	7	15

Table 6. Dewar model input variables for the RHS survey (after Singh et al. 2009)

Period	*Site count*	*Total occupied area*
Mature Harappan	12.00 +/- 1.82	146.9 +/-22.28ha
Late Harappan	9.64 +/- 3.60	63.1 +/- 23.58ha

Table 7. Estimates for contemporary occupation in the RHS survey region derived using the Dewar model. The average site counts and standard deviations were calculated by averaging the results of 20 individual simulations that were run through the MC calculation with 100,000 iterations.

Period	*Sumner*	
Early-mid-Early Harappan	15	[Early Harappan only]
late Early/early Mature Harappan	4	[Early/Mature Harappan only]
mid-Mature Harappan	11	[Mature Harappan, Early/Mature/Late Harappan]
late Mature/early Late Harappan	2	[Mature/Late Harappan only]
mid Late Harappan	16	[Late Harappan, Mature/Late Harappan & PGW]
late Late Harappan/early PGW	7	[Late Harappan and PGW only]
mid PGW	13	[PGW]

Table 8. Sumner estimates of period-wise occupation for the RHS survey region