Geo-statistical methods to analyse changes in pre-Hispanic settlement patterns in the Río Ica catchment, Peru

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Abstract

Within arid regions allochthonous rivers as a main source of fresh water play a significant role in the spatial organisation of human occupation.

This study aims at a comprehensive view on changes in the prehistoric occupation patterns within the Río Ica catchment on the southern coast of Peru. Results of different research projects are integrated. The heterogeneous character of the catchment allows us to define three sub-sections which differ greatly in terms of vegetation, relief and water regime.

Based on quantitative geo-statistical methods we analyse spatio-temporal changes in human occupation from the Early Horizon (c. 1000 - 200 BC) through to the Inca Late Horizon (AD 1450 - 1532) in the context of environmental conditions, as well as socio-economic processes. Examining known archaeological sites we are able to assess the significance of environmental location factors for pre-Hispanic settlements. In addition, areas of high human interaction are identified on the basis of a classification of archaeological sites according to their function (craft/industry, cult, cooperation and trade). We thereby transfer the concept of central place theory to the spatial distribution of archaeological remains, introducing a novel approach to identifying central functions in a spatially explicit way.

Our results crystallise the changing character of occupation in the study area over more than two millennia. They contribute to the ongoing debate on the decline of the Nasca culture, endorsing a complex combination of natural and socio-economic reasons. Furthermore, the results support the concept of a more widespread exchange and cooperation during 'Horizon' periods in the study area and likewise indicate that the disappearance of a supra-regional administrative polity during 'Intermediate' periods might have led to higher human activity in smaller scale societies, as reflected in a more diverse spatial organisation in terms of geomorphometric units and central areas.

Keywords: central place theory, human-environment realations, landscape archaeology

1. Introduction

The south coast of Peru offers unique perspectives for both archaeology and earth sciences. This narrow strip between the Pacific Ocean and the Andean Cordillera incorporates manifold landscapes that have been occupied by humans since at least the beginning of the Holocene. The adjacent Andean Highlands demonstrate evidence for contiguous human occupation from the so called *Early Horizon* onwards (c. 1000 - 200 BC) (e.g. Lanning, 1967).

The *One River Project*[1], based at the University of Cambridge, studies pre-Hispanic archaeological remains across the Río-Ica-Catchment (Fig. 1) and entails several research groups, each concentrating

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on diverse regional and temporal aspects. Together with the results from other projects in the area, these studies are beginning to present a detailed picture of multiple but partly separate cultural and environmental aspects of the region (e.g. Beresford-Jones et al., 2011; Carré et al., 2013; Nanavati et al., 2016). The study presented here follows Tobler's first law of geography - '[...] everything is related to everything else, but near things are more related than distant things' (Tobler, 1970, p.236) - to blend these diverse results and thus gain a more holistic view of changes in prehistoric occupation within the catchment through time. In the context of recent research results, spatial changes of settlement points are examined quantitatively through time, allowing us to analyse shifts and differences in human occupation from the Early Horizon (c. 1000 - 200 BC) through to the Inca Late Horizon (AD 1450 - 1532). The underlying chronology is based on Rowe (1962) and further discussed below (see Section 2).

Because of the critical role of the Río Ica as the main source of fresh water in a mostly arid landscape between the Río Grande de Nazca and the Río Pisco (Fig. 1) rivers, special attention is given to the spatial variations of settlement points in relation to the main course of the river. By using geo-statistical methods, we are able to define the character of occupation for each of the examined periods:

We analyse the manifestations of *Horizons* and *Intermediate Periods* in the Río Ica catchment (*sensu* Rowe, 1963). To avoid the often associated problem of spatial and temporal generalisation (cf. Beresford-Jones & Heggarty, 2010; Rice, 1993), we offer a quantified view on the changes of (i) environmental location factors of pre-Hispanic settlements (e.g. distance to the Río Ica) and (ii) the human interaction within the study area (e.g. central areas). The results help us to address differences in the spatial organisation and functional composition of pre-Hispanic societies in the study area, introducing a novel approach to expand the information potential of survey data.

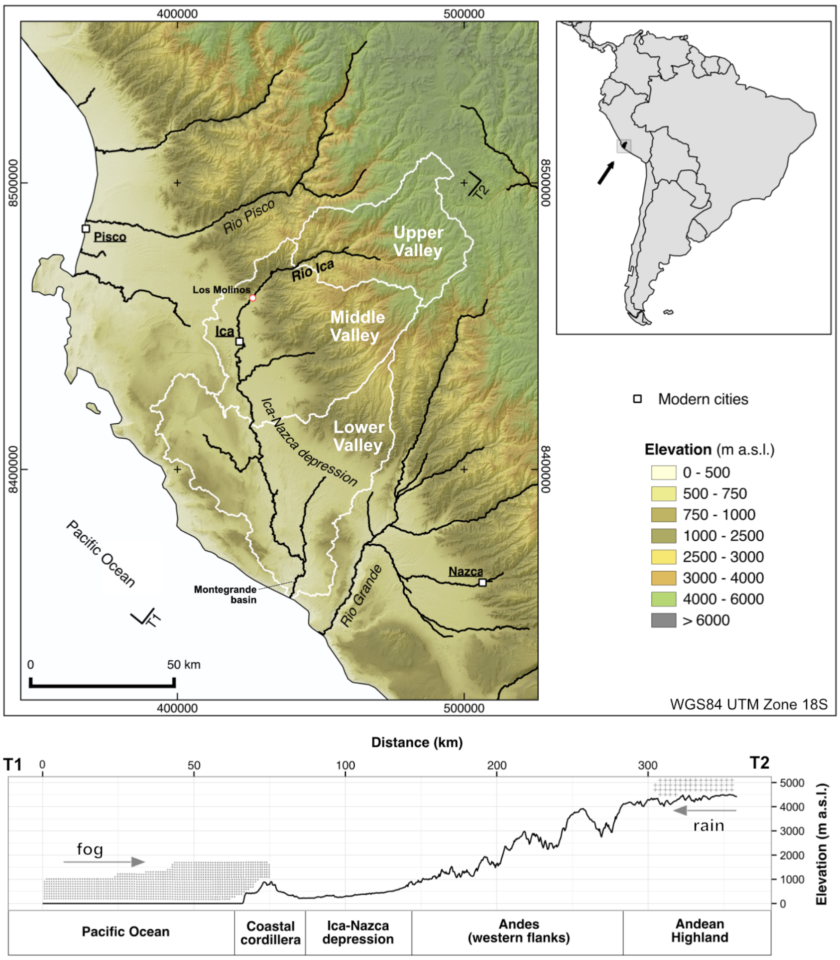


Figure 1: Study area. ***Top:*** Topographic map of the study area. The Río Ica catchment is marked white, generated runoff lines are black. ***Bottom:*** Section through the study area (T1 to T2). Landscape units within the study area are marked. Fresh water occurs in the north-east (precipitation, andean highland) and in the south-west (fog, Lomas). The coastal mountains (Lomas) keep the humid air from advancing into the arid Ica-Nazca depression (elevation data: ASTER GDEM v2).

	Elevation [m]		Area		Prevailing modern	Prevailing climate zone
	min	max	km^2	%	cultivation	(Koeppen climate class)
Lower Valley	0	320	3486.4	42.7	Restricted to the river floodplain, sometimes extended by irrigation	Hot desert climate (BWh)
Middle Valley	320	1020	2905.6	35.6	Extended irrigation agriculture	Cold desert climate (BWk)
Upper Valley	1020	4652	1768.8	21.7	Extended agricultural terracing, pastoralism	Cold semi-arid climate (BSk)

Table 1: Study area. Landscape character and properties of the three sub-basins of the Río Ica Valley.

1.1. Study area

Our area of interest comprises the catchment of the Río Ica, on the south coast of Peru. This covers an area of 8,162 km^2 having its upper headwater areas in the high Andean Cordillera with peak elevations above 4,500 m a.s.l.. Small streams that drain the highlands form the tributaries of the Río Ica, which runs for nearly 300 km, before entering the Pacific Ocean at the northern margin of the hyper-arid Peruvian coastal desert (together the 'Río Ica catchment' herein). Based on its topography and in combination with the climatic and hydrological properties, the catchment can be broadly subdivided into three sub-sections: the *upper*, *middle* and *lower* valley. These sub-sections differ greatly in terms of vegetation, relief and water regime (Fig. 1, 2 and Table 1):

The *upper valley* lies in the Andean highlands and higher parts of the western flanks of the Andean Cordillera. The prevailing climate is classified according to Köppen (1918) as *Cold semi-arid climate* (BSk) with short and wet summers (JFM) and long and dry winters. Annual precipitation typically exceeds 500 mm (Fig. 2). In large parts here, below around 3,700 m a.s.l. the Río Ica has cut steep gorges into the landscape, producing steep inclined slopes, which have been used for agriculture in the past through terracing. The prevailing soils allow for shrub vegetation and the cultivation of e.g. potatoes, maize and other grains (Murra, 1972).

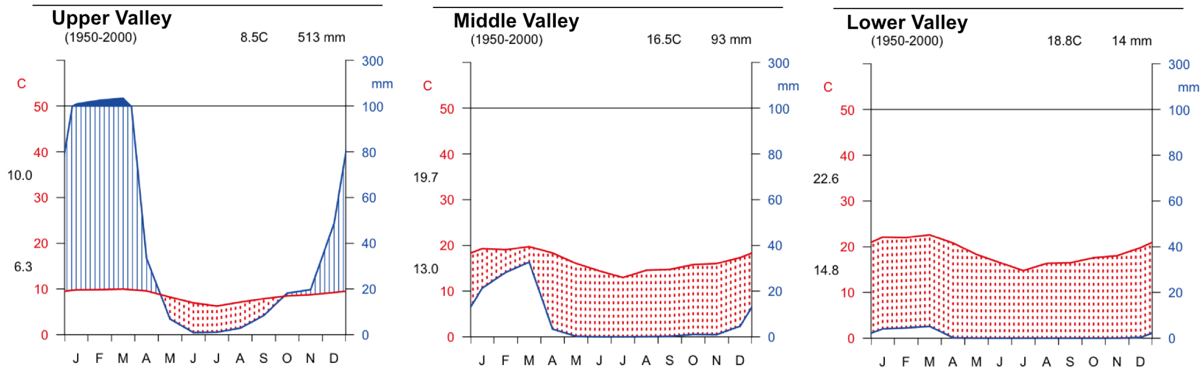
Seasonal rainfall during austral summer from October to April generates almost all the runoff of the Río Ica, which continues through the *middle* and *lower* valley as an allochtonous river (c.f. Mächtle & Eitel, 2013). The vegetation in the *upper* valley is dominated by alpine tundra (*puna*, cf. Custred, 1977) in its higher parts (4,000 - 6,000 m a.s.l.), descending into shrub vegetation (*kichwa*) (3,200 - 4,000 m a.s.l.) and continuing down into dryer parts with cacti and grasses (*pajonales*), before emerging onto the coastal plain at around 1,000 m a.s.l. (cf. Olson, 1994; Running et al., 1995, data available from the U.S. Geological Survey.).

Below it continues into the *middle valley*, characterized by a flat and mostly arid landscape, called the *Ica-Nazca depression* (Montoya Ramírez et al., 1994). The prevailing climate is classified according to Köppen (1918) as *Cold desert climate* (BWk) with annual precipitation barely reaching 100 mm (Fig. 2). Around the modern provincial capital Ica an extensive agricultural region has been established by systematic water management in modern times. Thereby the flat parts of the *middle* valley today are dominated by the influence of modern society, allowing for instance the intensive cultivation of fruits and vegetables.

The remaining water of the Río Ica continues into the hyper-arid *lower valley* classified according to Koeppen as *Hot desert climate* (BWh) with virtually no precipitation. Here any vegetation and cultivation is restricted to some fertile river reaches, which offer protection from the strong winds and intensive insolation. Riparian vegetation, characterized in its natural condition by *Prosopis*-dominated dry forest is restricted to these riverine oases and agriculture is possible here during the runoff season (Beresford-Jones, 2011). Due to the intensive water usage in the upper parts of the valley and high evaporation rates, a limited amount of fresh water reaches the lower valley, although like most dryland rivers, much of the Río Ica's flow is sub-surface. In some rare years the river's surface flow may not even arrive at its mouth on the Pacific coast.

Before reaching this estuary area the Río Ica cuts through the Coastal Cordillera, a mountain barrier with elevations up to almost 2,000 m a.s.l., stretching parallel to the Pacific coast and the inland Andean Cordillera (Fig. 1). These mountains prevent humid air of the sea from reaching the Ica-Nazca depression, but thereby support fog-oasis 'lomas' vegetation seasonally along their seaward slopes (Beresford-Jones et al., 2015).

This brief description of our study area reflects the environmental diversity across the upper, middle and lower valley sections. The archaeological record since at least the advent of agriculture and the start of the the Early Horizon (c. 1000 BC), captures repeated shifts of occupation in the Río Ica catchment, while the catchment's environmental diversity and prevailing limited water supplies suggest a *prima facie*



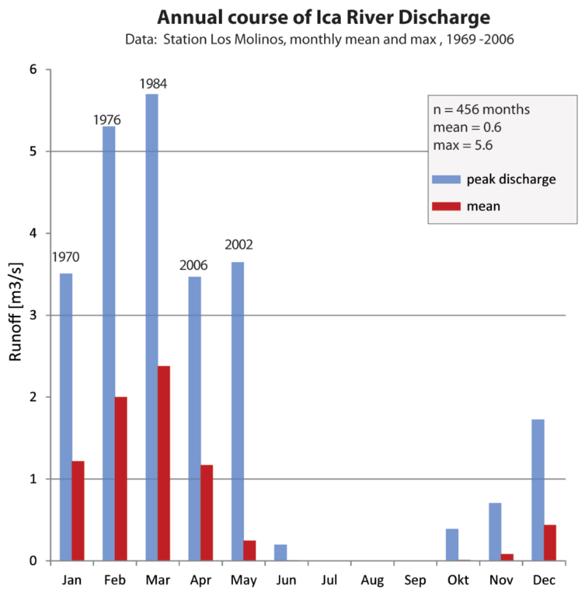


Figure 2: Climatic conditions. ***Top:*** Climate diagrams of the upper, middle and lower valley. Mean temperature and precipitation values from 1950 to 2000 (climate data: Hijmans et al., 2005). ***Left:*** Annual course of Río Ica discharge (Station Los Molinos 1969-2006, see Fig. 1). Peak discharge years are marked (1970, 1976, 1984, 2006, 2002).

connection with those spatial settlement changes.

	regional sequence	**sites** (settlements)	**distance to Río Ica [m]** mdn	mean	sd	min	max	p
Early Horizon (1000 – 200 BC)	Ocucaje, Nasca	**112** (96)	1346	5814	8856	30	47888	8.4e-07
Early Intermediate Period (200 BC – 550 AD)	Nasca	**190** (152)	710	1500	1975	30	10823	4.8e-29
Middle Horizon (550 – 1000 AD)	Nasca, Huari	**137** (104)	649	1594	2635	30	16158	3.5e-17
Late Intermediate Period (1000 – 1450 AD)	Ica-Chincha	**325** (220)	1141	3247	6356	30	34254	2.7e-24
Inca (1450 – 1532 AD)	Inca	**54** (40)	2361	7061	10278	43	33747	1.6e-02

Table 2: Chronology and results. Examined chronological stages (see section 2 for references), absolute number of sites and settlements. Distance of settlements to stream network of the Río Ica in meters, the statistical results and results of Wilcox-Mann-Whitney test. Due to the wide dispersion of the results, the Median values are seen as most representative. Statistical significance of the results is displayed by the p-value of the Wilcox-Mann-Whitney test. Spatial site distribution is shown in Fig. A.1.

2. Methods

The spatio-temporal changes of occupation within the study area are examined by using quantitative geo-statistical methods. Known archaeological sites are classified chronologically using the stages originally defined by Rowe (1962) and subsequently refined by Unkel & Kromer (2009), Unkel et al. (2012) and Cadwallader et al. (2015). The location and character of the sites are determined by compiling the survey data of Beresford-Jones (2011), Carmichael (1998),Cook (1991), Engel (1981), Massey

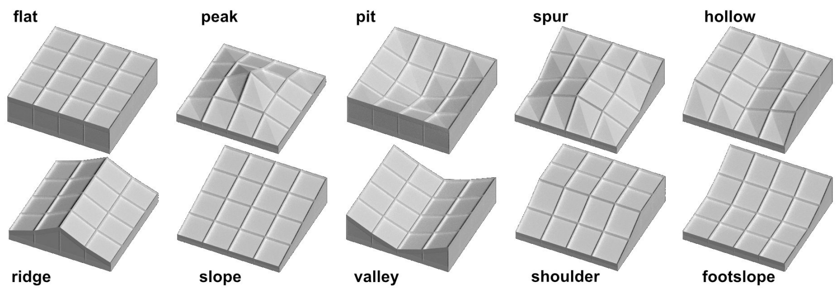


Figure 3: Geomorphometric units - concept. Concept of used geomorphometric units (*geomorphons*), after Jasiewicz & Stepinski (2013).

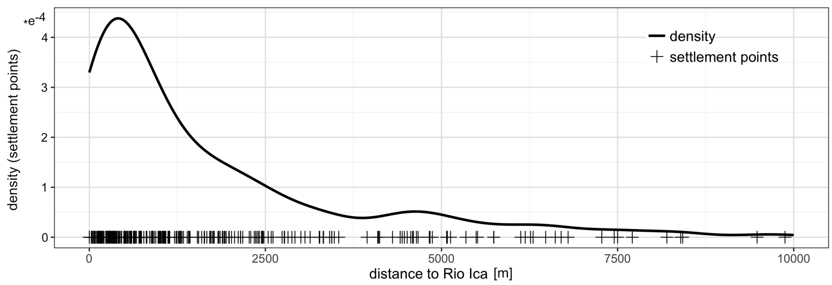


Figure 4: Distance to Río Ica. Correlation of settlement point density and the distance of settlement points to the Río Ica.

(1991), Williams & Pazos (1979) and the recent field-work of the *One River Project*. Differences in the spatial resolution and methods of the surveys are discussed by Zeki (2014) and their heterogeneous data limits the applicable methods. Since in many cases the spatial extent of the recorded archaeological sites is missing and in others the locational co-ordinates of sites vary slightly between different surveys, an area-weighted approach could not be carried out. To minimize such discrepancies, dated sites are examined as point data in this study (Fig. A.1). Meanwhile, to counteract the resultant loss of information, a novel approach was developed to simulate the spatial extent of central functions in the study area on the basis of a systematic classification of archaeological sites (see Section 2.2). We are thereby able to record changes of settlement patterns between five chronological stages (Table 2), allowing for a generalised interpretation of spatial change over a period of around 2,500 years: environmental location factors are examined (see Section 2.1) as well as the functional composition of interactions concentrated in the archaeological sites (see Section 2.2). In order to detect changes between the *upper*, *middle* and *lower* valley, the spatial distribution of these functions is analysed.

2.1. Environmental location factors of settlements

The spatial location of the settlements is acquired by processing a digital elevation model (ASTER GDEM v2, spatial res.: 30 x 30 m). Following the work of Jasiewicz & Stepinski (2013) a classification is carried out to extract geomorphometric units (*geomorphons*, Fig. 3, 5). Furthermore *aspect*, *distance* to the Río Ica and *height* above the Río Ica are calculated. The GrassGIS (v.7.0) add-on *r.geomorphon* and the *R.stream.** and *r.slope.aspect* modules are used for these analyses. Spatial calculations and data acquisition are carried out using the packages *sp*, *raster* and *rgeos* (Pebesma et al., 2015; Hijmans et al., 2015; Bivand et al., 2015) for R (v.3.2.2).

By comparing the location factors of settlements to those of random points, we are able to determine the significance of the results. As the settlement density is strongly connected to the course of the Río Ica and its tributaries - the main water source in the study area - and most human activity concentrates on an area within 2 km reach of the river (Fig. 4), random points are therefore generated on the basis of the kernel smoothed intensity of real settlement points (*rpoint()*, R-package: *spatstat* (Baddeley & Rubak, 2015)). This allows the implication of the orientation of occupation along the river as an effect of first order of spatial organisation (Wiegand & A. Moloney, 2004). We are thereby able to determine the significance of the examined location factors as factors of spatial organisation (Knitter & Nakoinz, in press; Wiegand & A. Moloney, 2004). The Wilcox-Mann-Whitney test is used for the estimation of the required significance values (R-package: *stats* (R-Core-Team, 2016)). Significant differences between the settlement points and the corresponding random points are observed for the factors *geomorphometric units* and *distance* to the Río Ica. The comparison of the associated results with the general distribution of these factors within the whole study area also supports their relevance. Certain *geomorphometric units* and *distances* to the river are therefore interpreted as being intentionally chosen by prehistoric societies, thus allowing us to discuss possible reasons for their changing over time.

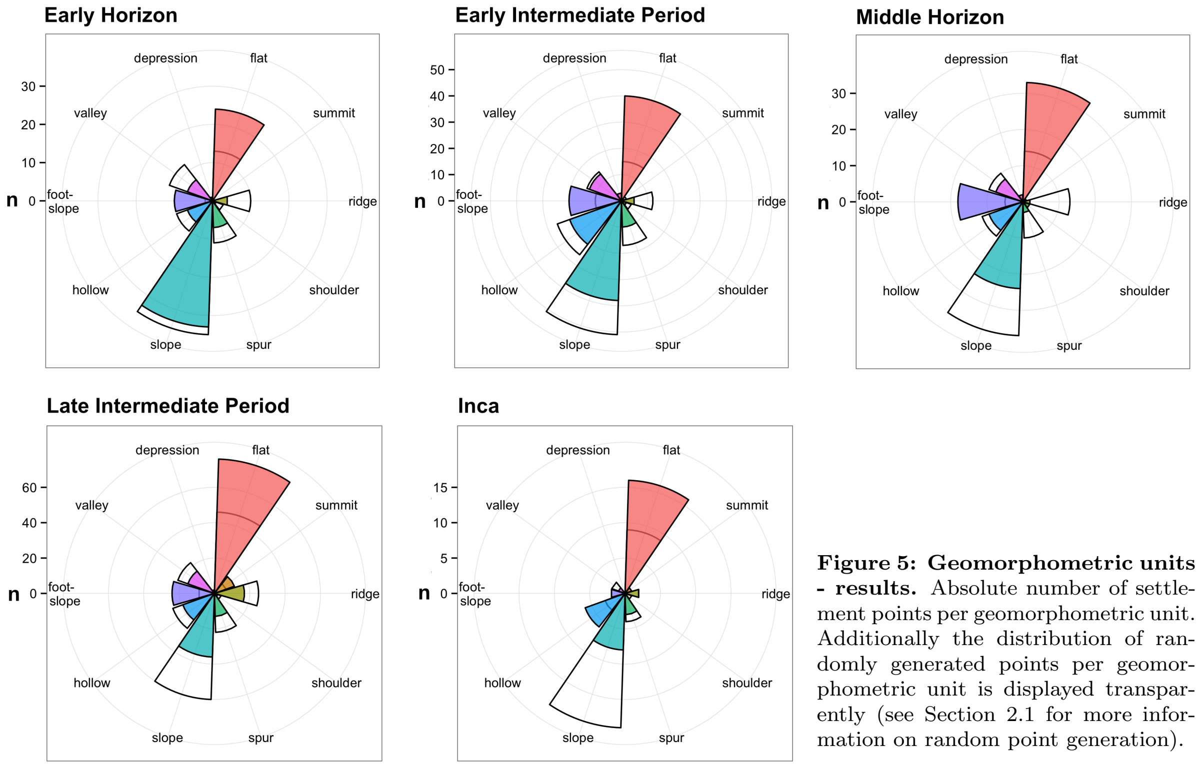


Figure 5: Geomorphometric units - results. Absolute number of settlement points per geomorphometric unit. Additionally the distribution of randomly generated points per geomorphometric unit is displayed transparently (see Section 2.1 for more information on random point generation).

2.2. Functional classification of archaeological remains

Areas of high human interaction are identified on the basis of the classification of archaeological sites according to their function. Function was determined by ground-proofing during archaeological surveys. The approach used is based on the concepts of central place theory (Christaller, 1933), understanding the interaction potential of a place as the sum of its central functions in the settlement pattern.

Central place theory in archaeology is mostly used to assess the centrality of ancient cities and settlements. This study transfers the concept to the spatial distribution of archaeological sites. By assigning the central functions of *craft/industry, cult, cooperation* and *trade* (based on the functions proposed by Gringmuth-Dallmer, 1996 and discussed further by Knitter et al., 2014) to the examined sites, depending on findings and artifacts, we are able to assess the spatial distribution of these functions within the study area. We do so as follows: the function of *craft/industry* is assigned to sites such as quarries, terraces, canals, lithic scatters animal bone agglomerations, etc; *cult* is assigned to, for instance geoglyphs, cemeteries and individual graves; *cooperation* covers complex structures and buildings; *trade* is captured with respect to the distances between the sites and, for instance the Pacific (as source of marine shells) or the lomas fog meadows (land snails), or special exotic finds like *Spondylus* and obsidian. The distribution of these functions is measured with the kernel smoothed intensity (*density.ppp()*, R-package: *spatstat* (Baddeley & Rubak, 2015)) of each functional group of sites.

In addition this approach allows us to calculate the interaction potential within the study area from the sum of functions (*r.stack()*, R-package: *raster* (Hijmans et al., 2015)), thus simplifying the spatial identification of areas of high human interaction (we suggest the term *central areas* over *central places* in this case, see Fig. 6). The repeated shift of these *central areas* over time illustrates the character of prehistoric occupation in the study area.

Moreover, the spatial character of the generated results allows us to evaluate the connection between human interactions and the environment. To analyse the spatial distribution of the central functions examined, generalised swath profiles (Hergarten et al., 2014; Telbisz et al., 2013) for the upper, middle and lower valley are generated and modified on the basis of the kernel smoothed intensity of the interaction potential (Fig. 7; see Haburaj, 2016 for R code). Thus we introduce a novel approach to identifying the distribution of central functions in a spatially explicit way, thereby allowing us to derive central areas of human interaction.

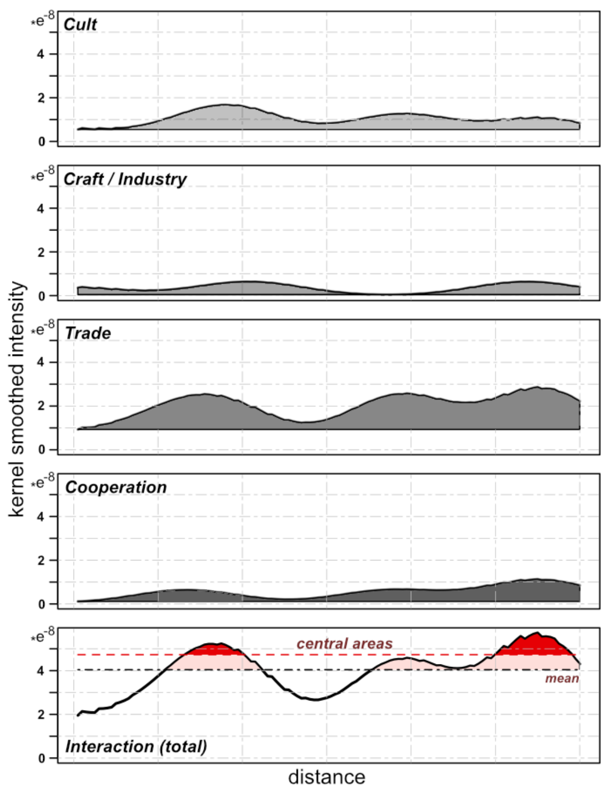


Figure 6: Concept of interaction estimation. Kernel smoothed intensity of examined functions (number of sites with function x) and their sum (total interaction) along a linear section through the study area. *Central areas* (areas of high interaction) are identified by filtering the total interaction twice. Areas with a lower intensity than the mean are excluded. The intensity within *central areas* is higher than the mean of the remaining values.

3. Results

The results show clearly recurring changes in the spatial relation of settlement points to the Río Ica beginning with the Early Horizon (c. 1000 - 200 BC) and reaching into the Inca Late Horizon (AD 1450 - 1532). From the Early Horizon to the Middle Horizon flat areas adjacent to the river are clearly preferred (Fig. 5, A.2 - A.6). Except for *craft* all central functions clearly concentrate on these regions. Compared to the later periods, the distance of settlements from the Río Ica is relatively high during the Early Horizon (Table 2). Most settlements of this period are situated on slopes and flat areas (Fig. 5). During the succeeding two periods (Early Intermediate Period and Middle Horizon) the distance to the river decreases significantly. At the same time a shift towards the landscape unit *footslope* (and *hollow* during Early Intermediate Period) can be observed.

During the Early Intermediate Nasca Period (c. 120 BC - 600 AD) a concentration of *central areas* in the fertile river basins is evident. During the following Middle Horizon, a high intensity of the function *craft/industry* is identified in the Montegrande basin and at the mouth of the river (Fig. 1, A.3).

In the succeeding Late Intermediate Period and the Inca Late Horizon settlement points are located slightly further away from the Río Ica. This is accompanied by the extensive spread of the central function *trade* during these periods, together with a general shift of *central areas* towards the middle valley (Fig. A.5, A.6) is observed. Simultaneously, a shift of *central areas* into steeper areas of the upper valley takes place (Fig. A.5).

4. Discussion

These results in the context of our understanding of socio-economic and environmental processes at play over this two and a half millennia on the south coast of Peru, allow for a far more detailed view of the prehistoric occupation of the Río Ica catchment. While the basis of our data is not as uniform, nor as chronologically refined, it nonetheless makes for some interesting comparisons with the comprehensive survey data recently published for the Palpa Valley, just to the south (Sossna, 2015). The most distinctive observations can be interpreted as follows:

4.1. The Nasca Period (c. 120 BC - 600 AD)

The greater distance of settlements from the Río Ica during the Early Horizon (Table 2) and their location mostly on slopes and higher flat areas (Fig. 5) recorded by this study reflects wider evidence for

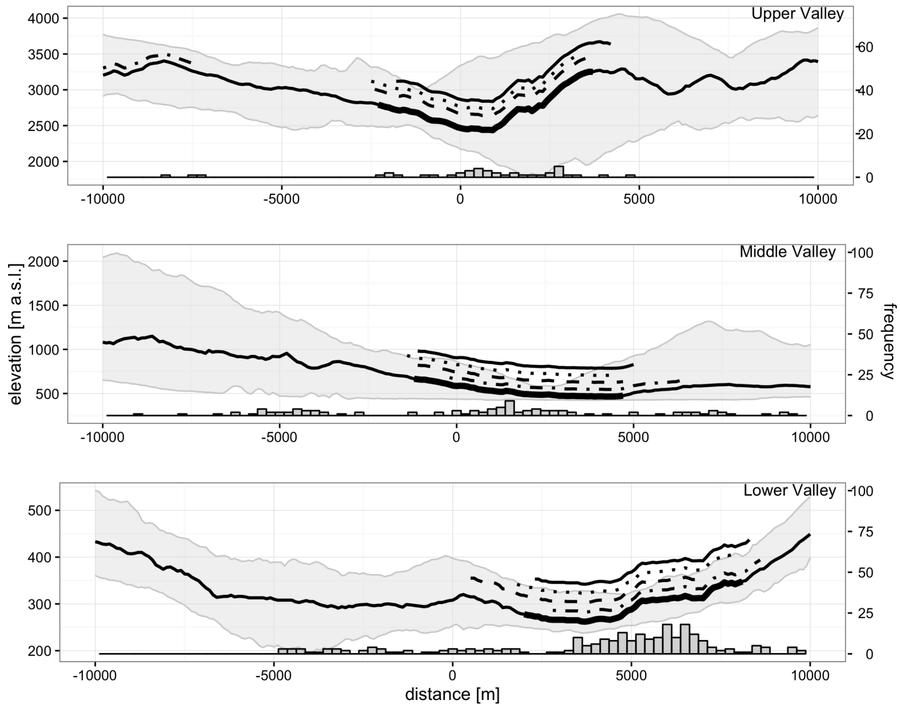


Figure 7: Topographic correlation. Overall distribution of sites (histogram) in relation to the topography (swath profiles: black = median, grey = quantile(25, 75)) and distribution of central functions (fat = *central areas*, dotdash = *cooperation*, dashed = *craft/industry*, dotted = *cult*, solid = *trade*). See Appendix for temporally resolved results (elevation data: ASTER GDEM v2).

the occupation of easily defensible locations towards the end of the Early Horizon (e.g. Sossna, 2015), and other evidence for conflict at this time. It may also reflect changes in river valley geomorphology taking place as a consequence of increasing agriculture and consistent with the interpretation of Beresford-Jones et al. (2009) that these riparian river basins were then far more densely forested than today with *Prosopis*-dominated leguminous woodlands, which protected floodplains and supported agricultural fertility.

Evidence suggests that agriculture on floodplains expanded by canal systems began during the Early Horizon (Hesse & Baade, 2009), attaining full development by the Early Intermediate Period, when land under irrigation in the lower valley exceeded that of today (Beresford-Jones et al., 2011). The study shows that, during the Early Intermediate Nasca Period, populations in the Río Ica catchment became concentrated mostly in the fertile river basins of the lower valley, and that this concentration of occupation was reflected in the predominance of *central areas*, persisting here from the Early Horizon through to the Middle Horizon (Fig. A.2, A.3, A.4).

The gradual intensification of agriculture throughout the Early Intermediate Period (cf. Beresford-Jones et al., 2011; Piacenza, 2005; Silverman, 1993), led to a significant growth of the population (Fehren-Schmitz et al., 2009), while the limited availability of irrigable agricultural land in the lower valley may have led to a considerably higher population density (Cadwallader et al., 2012; Sossna, 2015). In turn this may explain the observed shift towards a less explicit distribution of settlement points on the geomorphometric units during the Early Intermediate Period (Fig. 5). Spatial limitations may have led to the colonization of diverse landscape units within the same region.

Beresford-Jones et al. (2011) argue that widespread social and settlement changes evident on the south coast by the Middle Horizon were human-induced: precipitated by this intensification of irrigation agriculture and associated deforestation, exposing the lower valley to ENSO climatic perturbations. Others see such changes as the consequence of long-term climate changes at the desert margin (Eitel et al., 2005; Mächtle & Eitel, 2013). While the results of this study cannot distinguish between these two interpretations, they do confirm their equifinal outcome, suggesting that perhaps the most satisfying explanation may lie in self-enhancing feedback mechanisms in a complex combination of both environmental and socio-economic factors (cf. Sossna, 2015), leading to a gradual reduction of natural habitat and social cooperation, *viz.* increased aridity reduces woodlands; reducing woodlands increases aridity (cf. Beresford-Jones, 2011).

4.2. Horizons and Intermediate Periods

By quantifying changes in occupation through time, the results also allow us to asses the manifestations of *Horizons* and *Intermediate Periods* in the study area. Broadly speaking, Rowe's (1963) concept of 'Horizons' entails homogeneity in the archaeological record over large areas suggesting widespread expansions of ideas, goods and/or people; whereas 'Intermediate Periods' entail a more fragmented, localized archaeological record reflecting the collapse of *Horizons* into regional diversity. Though widely influential the concept has not been without its critics: Hill Boone (1993, p.vii), for instance, asserting that 'the horizon concept is too broad and simple for the scholar, but that it is useful for the student'.

Yet this study's results clearly reflect increased interactions during each of the Early, Middle and Late (Inca) Horizons in the Río Ica catchment. Higher interactions are observed particularly in the fertile basins of the lower and middle valleys, though for the Inca Late Horizon, these extend also into the upper valley. We see these as evidence that the Río Ica catchment was integrated, at these times, into larger networks of ideas and/or trade and exchange. Especially for the Middle Horizon apparent increases in the functions of *craft* and *cooperation* must be interpreted in the context of an expansionist Wari Empire (Fig. A.4), not least in growing cotton here to supply demand in the southern highlands heart of the empire (Beresford-Jones et al., 2011). During the Middle, and other, horizons flat areas and slopes are preferred over other geomorphometric units congruent with high agricultural activity in the river basins (Fig. 5).

By the Late Intermediate Period a shift towards steeper areas and ridges in the upper valley is observed in general (Fig. 5, A.5): characteristic of the emergence of acephalous, splintered, small-scale societies across the southern sierra at this time (e.g. Arkush, 2011; Bauer & Kellett, 2010; Reindel, 2009; Parsons & Hastings, 1988). Yet, at this time too, the lower valley and middle valley appear shaped by a high general interaction, and a concentration in the function of *trade*, thereby supporting a model of network of the movement of goods all articulated by camelid caravans under the aegis of the Ica-Chincha polity. Indeed, the extension of *trade* function from the coast into the middle valley likely reflects the transport of marine resources upstream to where, by the Late Intermediate, population was now concentrated (Cadwallader, 2012).

The shift of *central areas* onto steeper areas of the upper valley (Fig. A.5, A.6) suggests that the vast extensions of agricultural terraces that characterize that landscape today might have been constructed during the Late Intermediate Period and Late Horizon. Nevertheless, evidence from other areas of the Andes show that terrace construction has a long pedigree, with substantial terracing already prevalent during the Middle Horizon (Denevan, 2001). Moreover, the strong variations of topography in this part of the swath profile should be considered. Ongoing research in the upper valley will show the reliability of these observations.

By the following Inca Late Horizon settlement points in the middle valley have become located slightly further from the Río Ica (Table 2). This likely reflects the opening up of the middle valley to agriculture by the building of new canal systems (Massey, 1991) and the associated rise of a flourishing Ica-Chincha ceremonial centre at Ica Vieja (Conlee, 2003; Menzel, 1976) and the integration of the catchment into the enormous network of goods and exchange that was the Inca Empire. Indeed, this hypothesis is further supported by the extensive spread of the central function *trade* (or better *movement of goods*, cf. Hirth & Pillsbury, 2013) during the Inca Late Horizon together with a general shift of *central areas* into the middle valley (Fig. A.5, A.6).

Limitations of the used geo-statistical methods are mentioned in Section 3 and further discussed in Apendix *A. Limitations.*

5. Conclusions

We were able to analyse changes in settlement patterns across the Río Ica catchment over almost two and half millennia, from the beginning of the Early Horizon (c. 1000 BC) to the end of the Inca Late Horizon (AD 1532), by developing and using quantitative methods of spatial analysis. Together with the recent, extremely comprehensive survey coverage of the Palpa Valley (e.g. Sossna, 2015) and the Ingenio Valley (Silverman, 2002), our data mean that changing archaeological patterning through time can probably now be studied in greater resolution for the south coast than anywhere else in the Andean region.

The results of this study support the hypothesis that spatial changes of settlement patterns are accompanied by changes in the environmental location factors of settlements. Moreover, we were able to capture changes in the character of occupation for each of the examined periods. This was achieved by an analysis of central functions developing upon Knitter et al. (2013), to offer a novel approach to the identification of distributions of central functions in a spatially explicit way. Our approach also offers a way to mitigate the often problematic situations surrounding archaeological data (such as incomplete knowledge of spatial extent of sites, incompatible survey bases, etc.): relatively low quality of input data (site location and site functions) allows for a quantitative socio-political interpretation.

Our results support the concept of much more widespread exchange and cooperation during *Horizons* in the study area. On the one hand, this may be unsurprising since Rowe (1967) used the Ica Valley ceramic sequence to define his widely used chronology for all Andean prehistory. On the other, the comparatively high number of sites during *Intermediate* periods shows that general interactions and thus human activity in the Río Ica catchment was not necessarily greater during *Horizons*. Rather, we suggest that the disappearance of a supraregional administrative polity during *Intermediate* periods might have led to higher human activity in smaller scale societies, as reflected in a more diverse spatial organisation in terms of geomorphometric units and *central areas*.

This study thereby contributes to the ongoing debate on prehistoric occupation of the Ica-Nazca region whilst also supporting the applicability of the various methods used for the analysis of settlement patterns in general. By including both environmental factors (location factor analysis, swath profiles) *and* cultural factors (central functions of archaeological sites), our approach promotes a more holistic understanding of spatio-temporal changes of settlement patterns.

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Appendix

Appendix A. Limitations

Although our results help to crystallise changes in pre-Hispanic occupation patterns in the study area, there are clear restrictions of what the used methodology can show.

A critical issue remains the neglection of site extents: Implication of the actual size of archaeological sites through an area-weighted approach would clearly increase the validity of our socio-poilitical interpretations. Due to data limitations (e.g. destroyed archaeological sites) we suggest the proposed simulation of spatial extent of central functions as a method to compensate for this loss of information.

Strongly connected to this topic are the vast systems of terraces and water management in the upper valley. While the lack of information on their dating and spatial extent is responsible for their neglection in this study, the used methods clearly show potential for integrating them into future studies.

Moreover, several points have to be considered when interpreting our geo-statistical results: (i) ground proofing confirmed most of the results that were derived from the 30 metre digital elevation model (ASTER GDEM v2); (ii) the used methodology for interaction estimation (Fig. 6) proposes usage of the mean value as a reference. The mean value has turned out to be useful in deriving areas of high human interaction, while usage of median or mode would produce similar results but involve a different understanding of *central areas*.

Appendix B. Figures

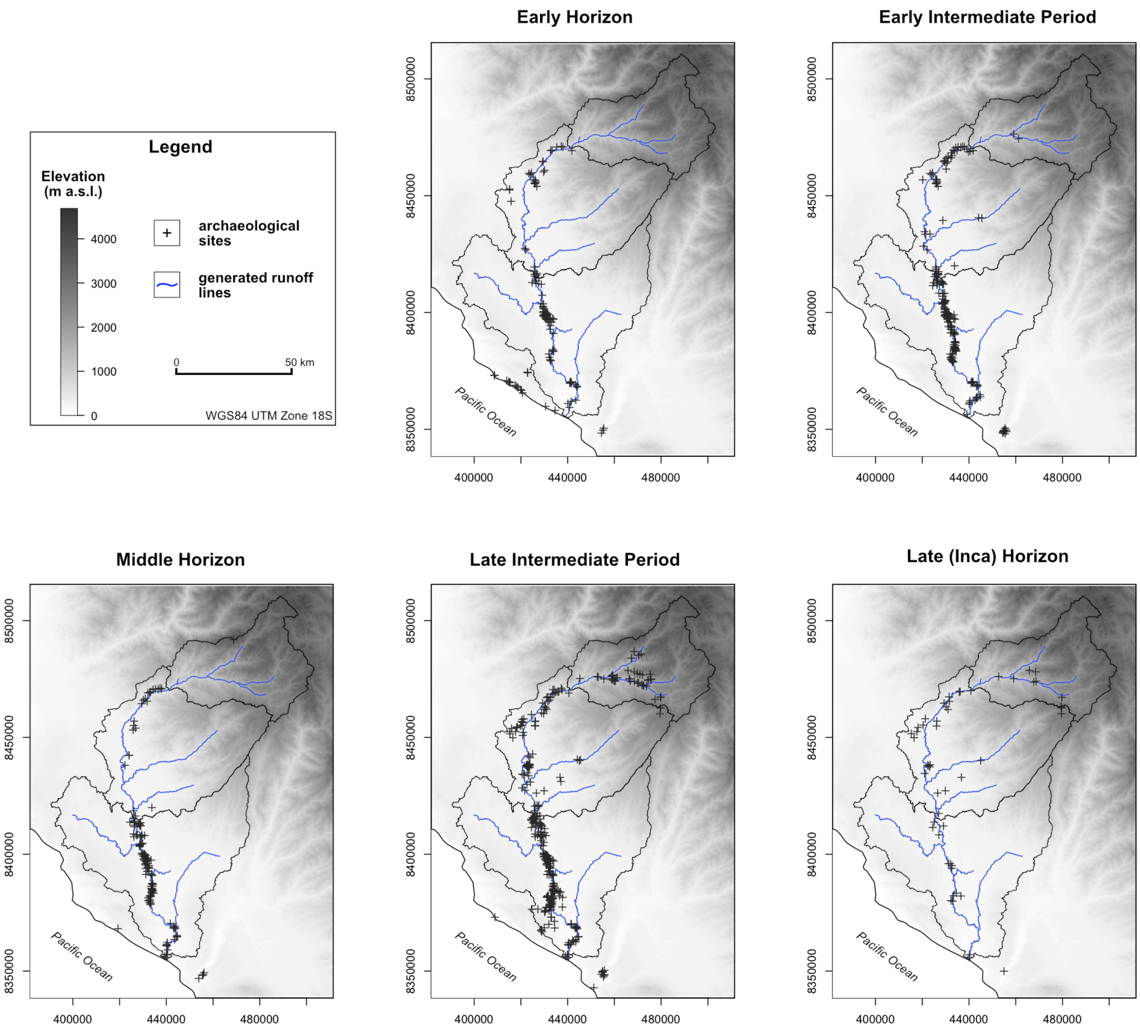

Figure A.1: Site distribution
Spatial and temporal distribution of archaeological sites within the study area. Number of sites: 112 (Early Horizon), 190 (Early Intermediate Period), 137 (Middle Horizon), 325 (Late Intermediate Period), 54 (Late (Inca) Horizon). See Table 2 and Section 2.2 for more information on archaeological sites (elevation data: ASTER GDEM v2; WGS84 UTM 18S).

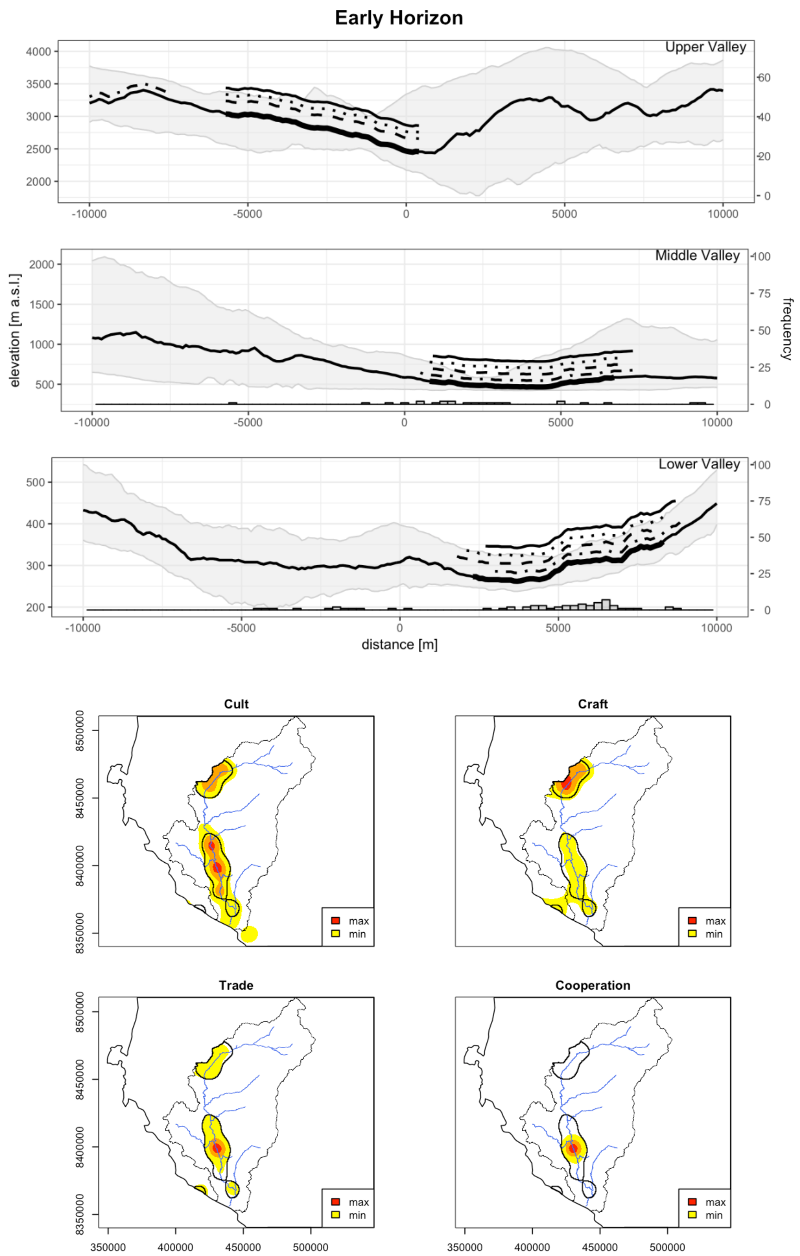

Figure A.2: Early Horizon
Top: Swath profiles of the upper, middle and lower valley. Elevation (black = median, grey = quantile(25, 75)), distribution of central functions (fat = *central areas*, dotdash = *cooperation*, dashed = *craft/industry*, dotted = *cult*, solid = *trade*) and site distribution (histogram). Note that central functions can be independent from site distribution since their spatial extent is simulated and topographic correlation is generalised (elevation data: ASTER GDEM v2). ***Bottom:*** Site density of central functions in the study area (black lines = *central areas*) (WGS84 UTM 18S).

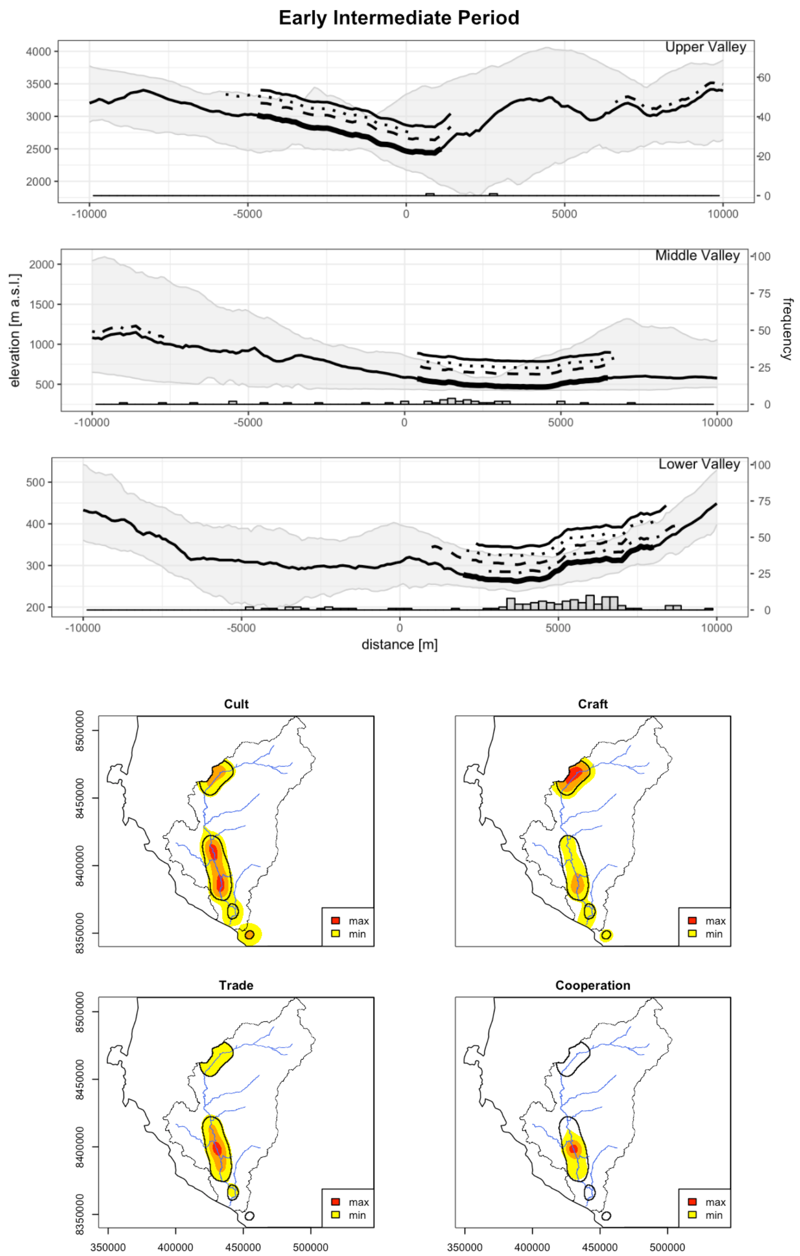

Figure A.3: Early Intermediate Period
Top: Swath profiles of the upper, middle and lower valley. Elevation (black = median, grey = quantile(25, 75)), distribution of central functions (fat = *central areas*, dotdash = *cooperation*, dashed = *craft/industry*, dotted = *cult*, solid = *trade*) and site distribution (histogram). Note that central functions can be independent from site distribution since their spatial extent is simulated and topographic correlation is generalised (elevation data: ASTER GDEM v2). ***Bottom:*** Site density of central functions in the study area (black lines = *central areas*) (WGS84 UTM 18S).

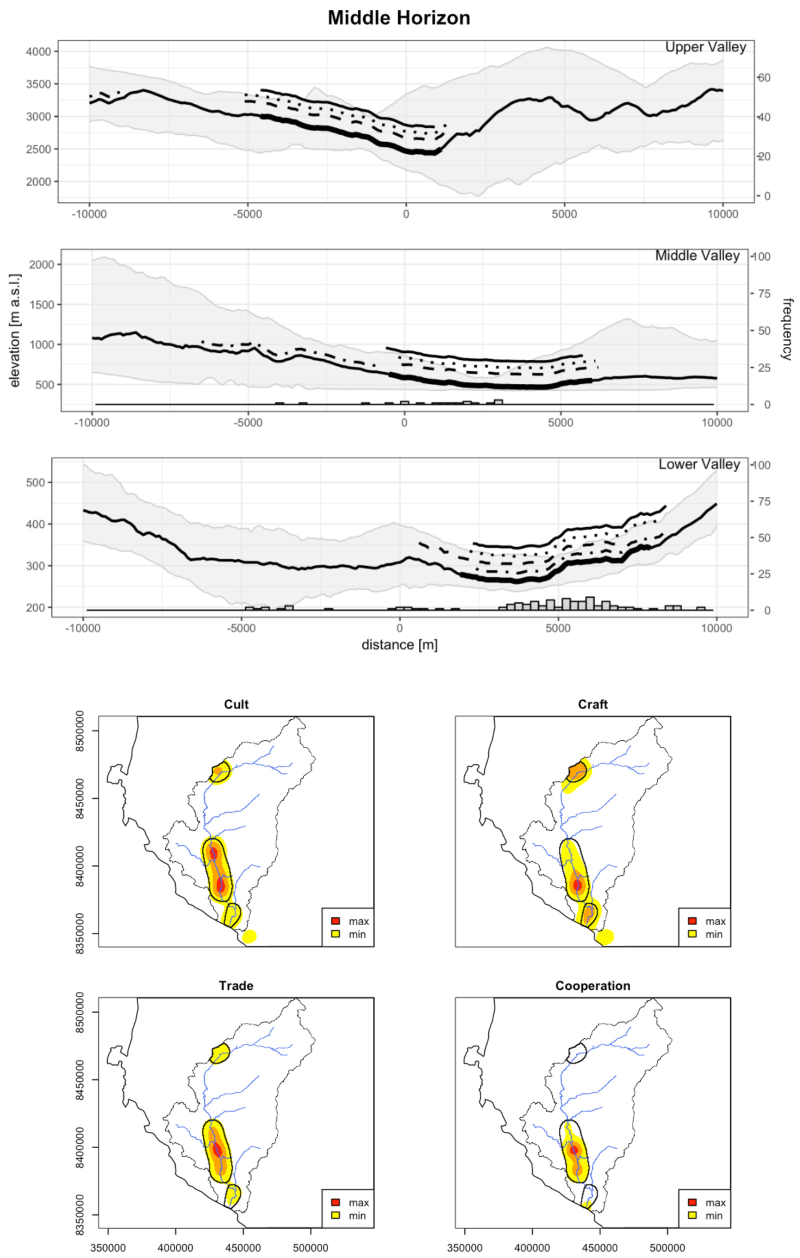

Figure A.4: Middle Horizon
Top: Swath profiles of the upper, middle and lower valley. Elevation (black = median, grey = quantile(25, 75)), distribution of central functions (fat = *central areas*, dotdash = *cooperation*, dashed = *craft/industry*, dotted = *cult*, solid = *trade*) and site distribution (histogram). Note that central functions can be independent from site distribution since their spatial extent is simulated and topographic correlation is generalised (elevation data: ASTER GDEM v2). ***Bottom:*** Site density of central functions in the study area (black lines = *central areas*) (WGS84 UTM 18S).

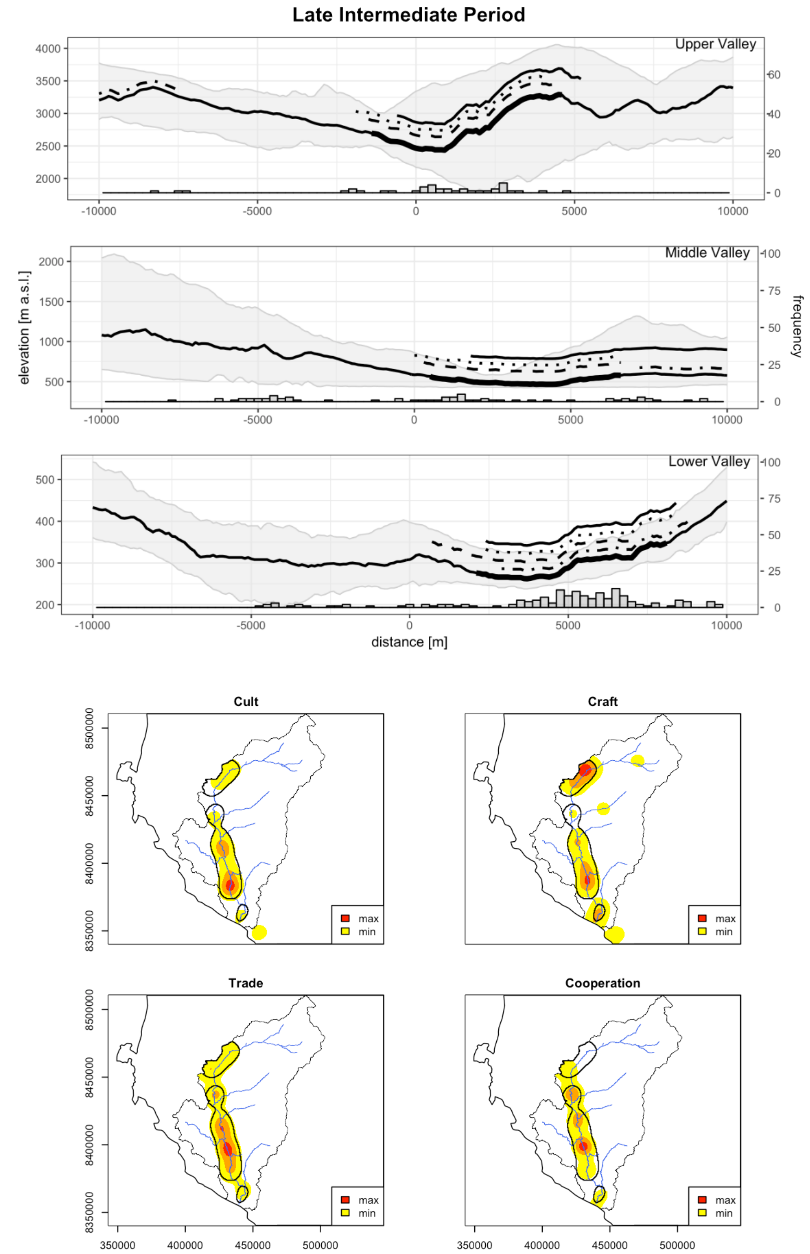

Figure A.5: Late Intermediate Period
Top: Swath profiles of the upper, middle and lower valley. Elevation (black = median, grey = quantile(25, 75)), distribution of central functions (fat = *central areas*, dotdash = *cooperation*, dashed = *craft/industry*, dotted = *cult*, solid = *trade*) and site distribution (histogram). Note that central functions can be independent from site distribution since their spatial extent is simulated and topographic correlation is generalised (elevation data: ASTER GDEM v2). ***Bottom:*** Site density of central functions in the study area (black lines = *central areas*) (WGS84 UTM 18S).

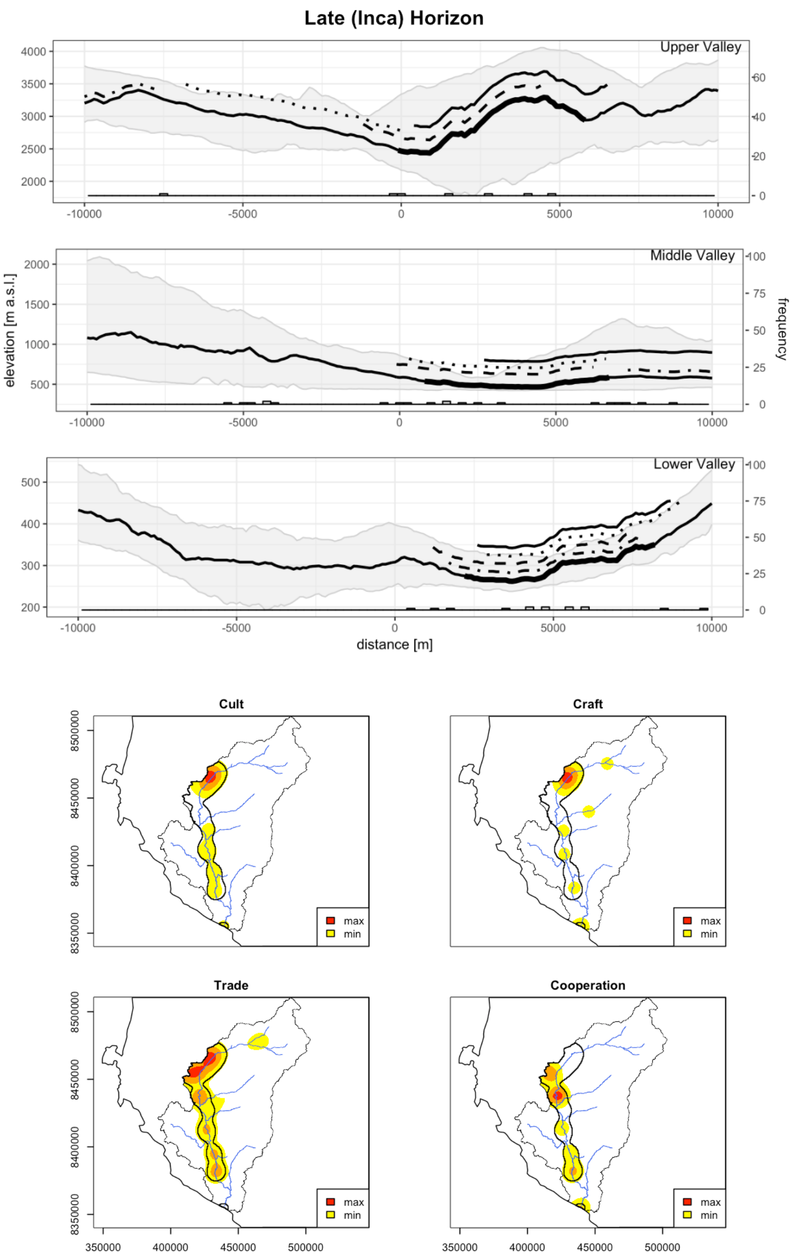

Figure A.6: Inca Late Horizon
Top: Swath profiles of the upper, middle and lower valley. Elevation (black = median, grey = quantile(25, 75)), distribution of central functions (fat = *central areas*, dotdash = *cooperation*, dashed = *craft/industry*, dotted = *cult*, solid = *trade*) and site distribution (histogram). Note that central functions can be independent from site distribution since their spatial extent is simulated and topographic correlation is generalised (elevation data: ASTER GDEM v2). ***Bottom:*** Site density of central functions in the study area (black lines = *central areas*) (WGS84 UTM 18S).