Settlement patterns through time - a landscape-archaeological approach for the Rio-Ica-Catchment, Peru

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1 Introduction

The south coast of Peru is a relevant area for both archaeology and earth sciences. This narrow passage between the Pacific and the Andes covers a manifold landscape that is occupied by humans since at least 6000 BC.

Examining precolumbian cultures in the Rio-Ica-Catchment (Fig. 1), the *One River Project*[1] covers the work of several research groups, each concentrating on diverse regional and temporal parts of the catchment. In combination with results of other projects in the area, a detailed picture of multiple but partly separate cultural and environmental aspects of the region was captured recently (Beresford-Jones, 2011; Carré et al., 2013; Nanavati et al., 2016). Following Tobler's first law of geography[2], this study blends these results to 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 differences in occupation from the Early Horizon (1000 to 200 BC) to the Inca Late Horizon (1450 to 1532 AD).

Due to the central role of the Rio Ica as the main fresh water source in a largely arid landscape between the Rio Grande de Nazca and the Rio Pisco (Fig. 1), 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 and to assess the significance of natural location factors of settlements.

We follow a quantitative approach to analyse the manifestation of *Horizons* and *Intermediate Periods* (*sensu* Rowe, 1963) in the Rio-Ica-Catchment. The developed methods and the resulting observations help, to quantify the differences in spatial organisation and functional composition of prehistoric societies in the study area. Likewise we introduce a novel approach that expands the information potential of survey data.

1.1 Study area

The area of interest covers the catchment of the Rio Ica, located at the south-western coast of Peru. The catchment covers an area of 8162 km^2 having its upper headwater areas in the high Andean cordillera with peak elevations above 4500 m a.s.l.. Small streams that drain the highlands generate the Rio Ica, which runs for nearly 300 km, before entering the Pacific Ocean at the northern margin of the hyper-arid Atacama coastal desert. Due to its topography and in combination with the climatic and hydrological properties, the catchment can be subdivided into three sub-basins: the *upper*, *middle* and *lower* valley. These sub-basins differ greatly in terms of vegetation, relief and water regime (Fig. 1, 2 and Tab. 1).

The *upper valley* lies in the Andean highlands and higher parts of the western flanks of the Andes. The prevailing climate is classified according to Koeppen as *Tundra climate* (ET) with short and dry summers (JJA) and long and cold winters. Annual precipitation typically exceeds 500 mm (Fig. 2). In large parts, here, the Rio Ica has cut steep gorges into the landscape, leading to steep inclined slopes, which are intensively used for agricultural terracing.

[1] University of Cambridge, Division of Archaeology - http://www.arch.cam.ac.uk/research/projects/one-river-project

[2] '[...] everything is related to everything else, but near things are more related than distant things' (Tobler, 1970)

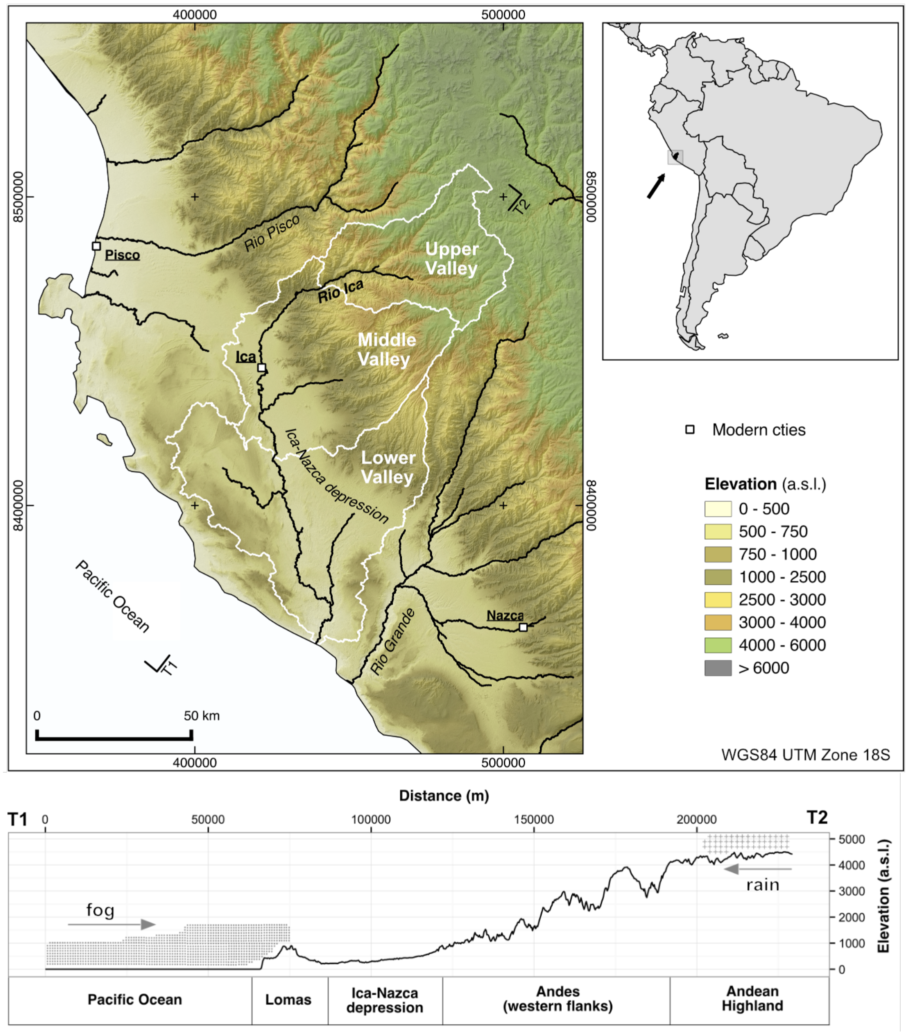


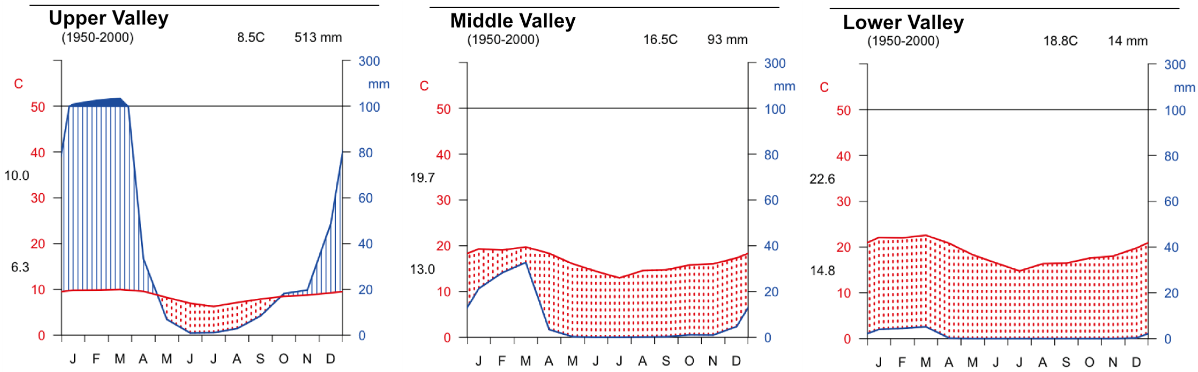
Figure 1: ***Top:*** Topographic map of the study area. The Rio-Ica-Catchment is marked white, generated runoff lines are black. ***Bottom:*** Section through the study area (T1 to T2). Landscape units within the study area are marked. Fresh water occurs in the north-east (precipitation, andean highland) 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).

The prevailing initial soils allow for shrub vegetation and the cultivation of e.g. potatoes, maize and other grains (Murra, 1972).

The seasonal rainfall from October to April generates nearly all runoff of the Rio Ica, which continues through the *middle* and *lower* valley as an autochtone river (c.f. Mächtle et al., 2012). The vegetation in the *upper* valley is dominated by alpine tundra (*puna*) in the higher parts (4000 to 6000 m a.s.l.) followed by shrub vegetation (*kiwicha*) (3200 - 4000 m a.s.l.) and continuing into dryer parts with cacti and grasses (*pajonales*) before leaving the highlands at a river height of about 1000 m a.s.l..

Below it continues into the *middle valley*, characterized by a flat and mostly arid landscape part, called the *Ica-Nazca depression* (Montoya Ramírez et al., 1994). The prevailing climate is classified according to Koeppen as *Cold desert climate* (BWk) with annual precipitation bareley reaching 100 mm (Fig. 2). Around the local capital Ica an extensive agricutural 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 Rio Ica continues into the hyper-arid *lower valley* classified



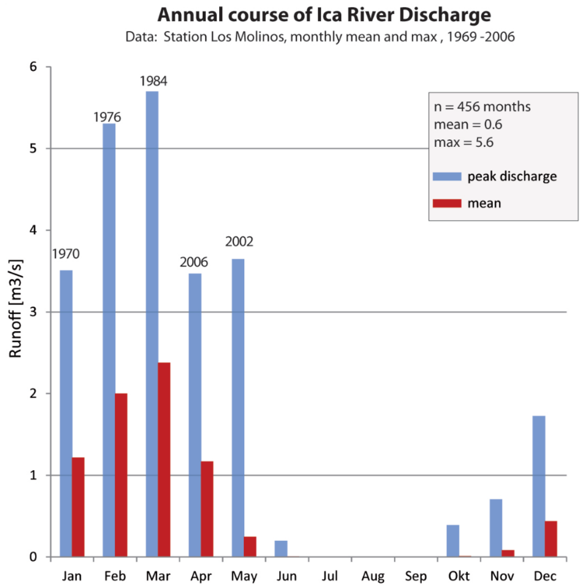


Figure 2: ***Top:*** Climate diagrams of the upper, middle and lower valley. Mean temperature and precipitation values from 1950 to 2000 (climate data: WorldClim 1950-2000). ***Left:*** Annual course of Rio Ica discharge (Station Los Molinos 1969-2006). Peak discharge years are marked (1970, 1976, 1984, 2006, 2002).

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 this riverine oasis and agriculture is possible here during the runoff season. Due to the intensive water usage in the upper parts of the valley and high evaporation rates, a very limited amount of fresh water reaches the lower valley. In some years the Rio Ica even dries up before it reaches the mouth of the river at the cost line. Before entering this delta area the Rio Ica cuts though the coastal cordillera, the mountain barrier with elevations up to 1000 m a.s.l., that stretches parallel to the pacific coast (Fig. 1). These mountains prevent humid air of the sea from reaching the Ica-Nazca depression, but allowing a fog-fed Lomas-vegetation to occur seasonally on their slopes (Beresford-Jones et al., 2015).

This short description of the upper, middle and lower valley shows the diversity of the study area. Since the Early Horizon (1000 BC) a repeated shift of occupation is recorded in the Rio-Ica-Catchment (Lanning, 1967). The described environmental diversity in connection with the limited fresh water suggests a connection of these spatial changes with the location factors of the settlements.

	Elevation min	Elevation max	Area km^2	Area %	Prevailing modern cultivation	Prevailing climate zone (Koeppen climate class)
Lower Ica Valley	0	320	3486.4	42.7	Restricted to the river-adjacent alluvium	Hot desert climate (BWh)
Middle Ica Valley	320	1020	2905.6	35.6	Extended irrigation agriculture	Cold desert climate (BWk)
Upper Ica Valley	1020	4652	1768.8	21.7	Extended agricultural terracing	Tundra climate (ET)

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

	regional sequence	**sites** (settlements)	**distance to Rio Ica (metres)** median	mean	σ (s)	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: Examined chronological stages (see text for references), absolute number of sites and settlements. Distance of settlements to stream network of the Rio 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.

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 suggested by Rowe (1962) and extended by Unkel and Kromer (2009), Beresford-Jones (2011) and Cadwallader et al. (2012). Location and character of the sites are provided by survey data of Engel (1981), Williams and Pazos (1979), Cook (1991), Carmichael (1998) and recent field-work of the *One River Project*. Differences in spatial resolution and methods of the surveys are considered by Zeki (2014): the heterogeneous data basis limits the applicable methods. Since in many cases, the spatial extent of the recorded archaeological sites is missing and some coordinates vary slightly between the different surveys, an area-weighted approach could not be carried out. To minimize discrepancies, dated sites are examined as punctual data in this study. To counteract this loss of information, a novel approach was developed to simulate the spatial extents of central functions in the study area on the basis of a systematic classification of archaeological sites (see 2.2). Thus we are able to record changes of settlement patterns between five chronological stages (Tab. 2), allowing a generalized interpretation of spatial change for a period of around 2500 years. To acquire a more holistic view of the occupation, natural location factors are examined as well as the functional composition of interactions concentrated in the settlements. In order to detect changes between the upper, middle and lower valley, the spatial distribution of these functions are analysed.

2.1 Location factors

The spatial location of the settlements is acquired by processing a digital elevation model (ASTER GDEM v2, resolution: 30 x 30 m). Following the work of Jasiewicz and Stepinski (2011) a DEM classification is carried out to extract geomorphometric units (*geomorphons*, Fig. 3). Furthermore *aspect*, *distance* to the Rio Ica and *height* above the Rio Ica are calculated.

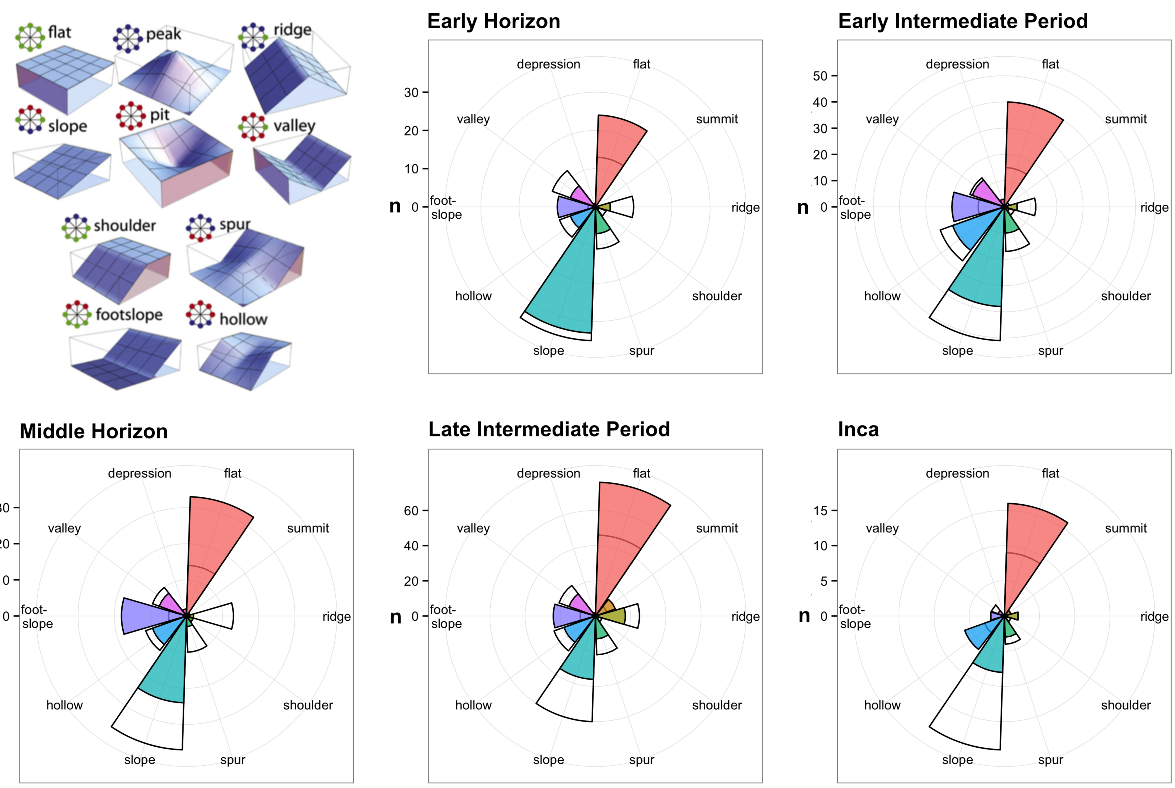


Figure 3: Absolute number of settlement points per geomorphometric unit. Additionally the number of random points per geomorphometric unit is displayed transparently. ***Upper Left:*** Concept of used geomorphometric units (*geomorphons*), see Jasiewicz and Stepinski (2011).

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. The settlement density is strongly connected to the course of the Rio Ica (main fresh water source in the study area) and most human activity concentrates on an area within 2 km reach of the river (Fig. 4). Therefore the random points are generated on the basis of the kernel smoothed intensity of real settlement points (`rpoint()`, R-package: `spatstat` (Baddeley and Rubak, 2015)), allowing the implication of the orientation of occupation along the river as an effect of first order of spatial organization (Wiegand and A. Moloney, 2004). Thus we are able to determine the significance of the examined location

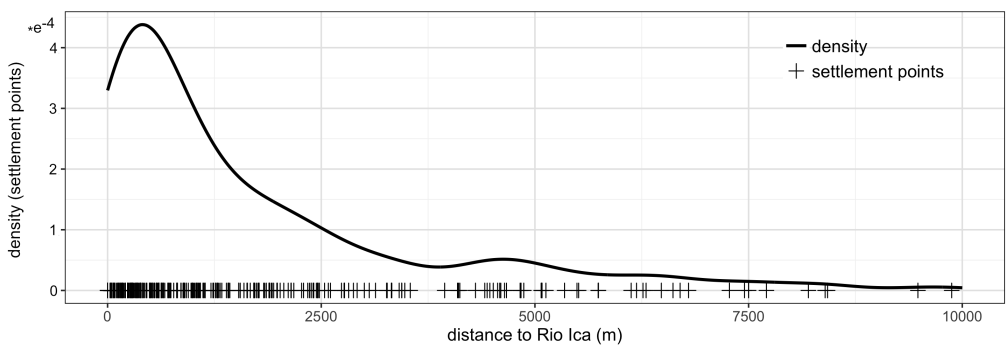


Figure 4: Correlation of settlement point density and the distance of settlement points to the Rio Ica.

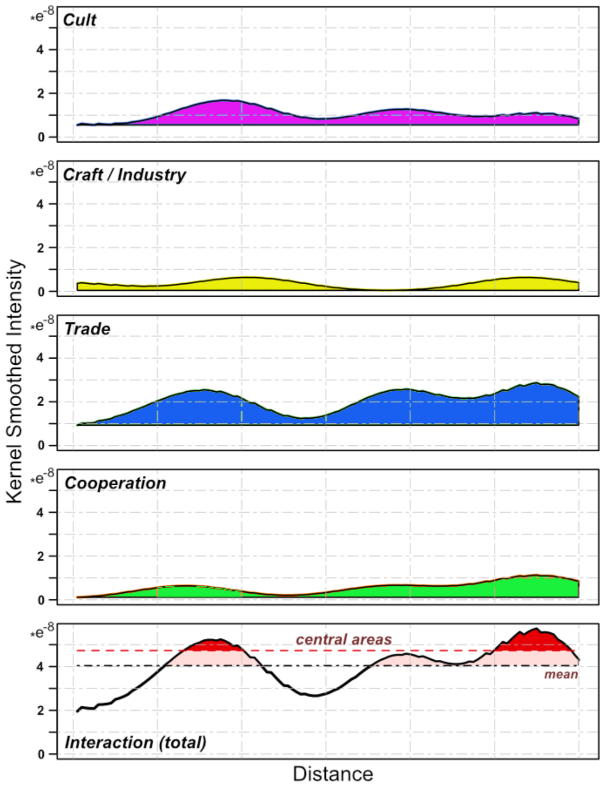


Figure 5: Concept of interaction estimation. Kernel smoothed intensity of examined functions (number of sites with function x) and their sum (total interaction) along a linear section through the study area. *Central areas* (areas of high interaction) are identified by filtering the total interaction 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.

factors as factors of spatial organization (Knitter and Nakoinz, 2016; Wiegand and 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 Rio Ica. The comparison of the associated results with the general distribution of location factors within the whole study area also supports the relevance of these factors. Therefore *geomorphometric units* and *distance* to the river are interpreted as intentionally chosen by prehistoric societies, allowing us to discuss possible reasons for their changing over time.

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. The used approach is based on the concepts of central place theory (Christaller, 1933), understanding the interaction potential of a place as the sum of its 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 this concept to the spatial distribution of archaeological sites. By assigning the central functions *craft/industry, cult, cooperation* and *trade* (based on the functions proposed by Gringmuth-Dallmer (1996) and further discussed 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: the function *craft/industry* is assigned to e.g. quarries, terraces and canals (furthermore lithic scatters and animal bones were con-

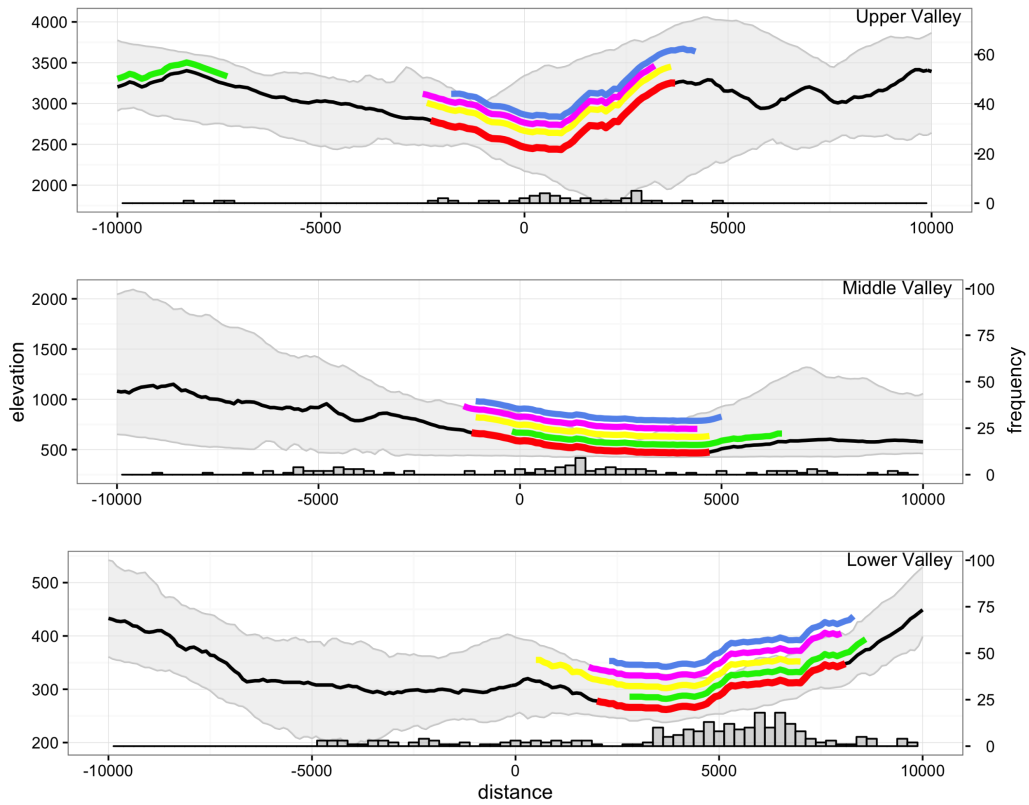


Figure 6: Overall distribution of sites (histogram) in relation to the topography (swath profiles: black = median, grey = quantile(25, 75)) and distribution of central functions (red = *central areas*, green = *cooperation*, yellow = *craft/industry*, magenta = *cult*, blue = *trade*). See Appendix for temporally resolved results (elevation data: ASTER GDEM v2).

sidered); *cult* is assigned to e.g. cemeteries, geoglyphs and graves; *cooperation* covers complex structures and buildings; *trade* is captured with respect to the distance of the sites to the Pacific (marine shells, corral) or the Lomas (land snails) while special finds like Spondylus are always considered. The distribution of these functions is measured with the kernel smoothed intensity (`density.ppp()`, R-package: `spatstat` (Baddeley and Rubak, 2015)) of each functional group of sites.

In addition this approach allows us, to calculate the interaction potential from the sum of functions (`r.stack()`, R-package: `raster` (Hijmans et al., 2015)) and thus simplifies the spatial identification of areas of high human interaction (we suggest the term *central areas* over *central places* in this case, see Fig. 5). The repeated shift of these *central areas* over time concretises the character of prehistoric occupation in the study area.

Moreover the spatial character of the generated results allows the connection of human interaction with the environment. To analyse the spatial distribution of the examined central functions, generalised swath profiles (Hergarten et al., 2014; Telbisz et al., 2013) of the upper, middle and lower basin are generated and modified on the basis of the kernel smoothed intensity of the interaction potential (Fig. 6, see supplemental material for R code). Thereby we introduce a novel approach to identify the distribution of central functions in a spatially explicit way, allowing us to derive central areas of human interaction.

3 Results

The results clearly show recurring changes in the spatial relation of settlement points to the Rio Ica beginning with the Early Horizon (1000 - 200 BC) and reaching into the Late Intermediate

Period (1000 - 1450 AD). From the Early Horizon to the Middle Horizon flat areas adjacent to the river are clearly preferred (Fig. 3, 7 - 11). Except for *craft* all central functions clearly concentrate on these regions.

Compared to the following periods, the distance of settlements to the Rio Ica is high during the Early Horizon (Tab. 2). Most settlements of this period are situated on slopes and flat areas (Fig. 3). During the succeeding two periods (Early Intermediate Period, 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.

In Nasca times (ca. 120 BC - 600 AD) a concentration of central areas in the fertile river basins is visible. 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. 8).

In the succeeding Late Intermediate Period and the Inca Late Horizon the settlement points are located slightly further away from the Rio Ica. In addition, the extensive spread of the central function *trade* during these periods together with a general shift of *central areas* towards the middle valley (Fig. 10, 11) is observed. Simultaneously a shift of *central areas* into steeper areas of the upper valley takes place (Fig. 10).

4 Discussion

These observations have to be discussed with regard to the socio-economic and environmental processes of each period. In this context they allow a far more detailed view on the prehistoric occupation of the Rio-Ica-Catchment.

4.1 Nasca (ca. 120 BC - 600 AD)

The results for the Early Horizon, the Early Intermediate Period and the Middle Horizon contribute to the ongoing debate on the rise and fall of the Nasca culture (ca. 120 BC - 600 AD) (e.g. Beresford-Jones, 2011; Eitel et al., 2005). The population of Nasca people in the study area focused mostly on the fertile river basins in the lower valley, an area that was far more forest-like than today: e.g. large numbers of *prosopis* protected the soil and supported its fertility (Beresford-Jones et al., 2009). The concentration of occupation in these areas is also reflected in the *central areas* from the Early Horizon to the Middle Horizon (Fig. 7, 8, 9). These fertile soils may have favoured the agricultural productivity during the Early Horizon, allowing humans, to settle in more distant areas from the Rio Ica. The beginning of the Early Intermediate Period is dominated by agricultural intensification (Beresford-Jones, 2011; Piacenza, 2005; Silverman, 1993), leading to a significant growth of the population (Fehren-Schmitz et al., 2009). Simultaneously the limited availability of usable habitat in the lower valley may have led to an significantly higher population density (Cadwallader, 2012). 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. 3). Spatial limitations may have led to the colonization of diverse landscape units within the same region.

According to Beresford-Jones (2011) the ongoing intensification of agriculture - beginning in the Early Horizon - and the connected deforestation may have favoured erosion and deteriorated soil fertility. In connection with the gradual temperature increase and aridification, both proposed for Nasca times in the adjacent Rio Grande de Nazca basin by Eitel et al. (2005), these processes may have changed the landscape of the Rio-Ica-catchment. The increasing human activity may have had a negative influence on the landscape's resilience (Dotterweich, 2008), in turn leading to a greater impact of the changing climate. Furthermore, ENSO-induced *postimpact landscape alterations* (in terms of Dillehay and Kolata, 2004) would have led to the gradual reduction of usable space in the arid lower basin. Against the background of the growing cultural diversity in the study area from the mid-Nazca time (around 400 BC) onwards, we cannot clearly identify one single reason for the observed changes. Rather we suggest a complex combination of both natural and socio-economic reasons, interacting with each other and leading to a gradual reduction of natural habitat and cooperation.

4.2 Horizons and Intermediate Periods

Furthermore the results allow us to quantify the changes in occupation through time and thereby asses the manifestation of *Horizons* or *Intermediate Periods* in the study area. According to Rowe (1963) periods labelled 'horizons' are characterized by an expansion of trade and widespread interaction, whereas a return to regional sequences can be observed during 'intermediate' periods.

The proposed high interaction during the Early Horizon, Middle Horizon and the Inca Late Horizon is clearly reflected in the results of this study. The observed high interaction in the fertile basins and the middle valley (during Inca times also in the upper valley) is seen as a symptom of the integration of the region into a larger trade-network. Especially during the Middle Horizon the increase of the functions *craft* and *cooperation* have to be interpreted in the context of Huari expansion: while cotton was grown here to supply Huari further north, the Huari-characteristic construction of larger buildings (Rowe, 1963) required more cooperation (Fig. 9). At the same time, flat areas and slopes are preferred over other geomorphometric units during these *Horizons*, indicating a high agricultural activity in the river basins (Fig. 3).

In the Late Intermediate Period a shift towards steeper areas in the upper valley and ridges in general is observed (Fig. 3, 10). This development is seen as characteristic for the emergence of acephalous splintered small scale societies in the upper valley (Lane, 2009). At the same time the lower valley and the coast are shaped by a high general interaction and a concentration of the function *trade*, supporting the model of a trade network of camelid caravans in this area under the Ica-Chincha polity. The extension of *trade* towards the middle valley likewise reflects the proposed transport of marine resources to this area (Cadwallader, 2012).

In the following Inca Late Horizon the settlement points are located slightly further away from the Rio Ica (Tab. 2). With regard to the flourishing rise of the ceremonial centre Ica-Chincha (Conlee, 2003; Menzel, 1976) in the middle valley, we interpret this development as a symptom of the building of new agricultural canal systems (Massey, 1991) (beginning in the Late Intermediate Period) and the integration into a larger trade-network, culminating in the Inca Empire. This hypothesis is supported by the extensive spread of the central function *trade* during the Inca Late Horizon together with a general shift of *central areas* towards the middle valley (Fig. 10, 11). The shift of *central areas* into steeper areas of the upper valley supports the hypothesis of a post-Nasca creation of the vast system of agricultural terraces (Fig. 10). On the other hand, the strong variations of topography in this part of the swath profile have to be noted. Ongoing research in the upper valley will show the reliability of these observations.

5 Conclusions

We were able to analyse the differences in settlement patterns in the Rio-Ica-Catchment from the Early Horizon (1000 to 200 BC) to the Inca Late Horizon (1450 to 1532 AD) by developing and using quantitative methods of spatial analysis. The results support the hypothesis, that spatial changes of settlement patterns are accompanied by changes of the natural location factors of settlements. Furthermore, we are able to capture the character of occupation for each of the examined periods. This is acquired by the analysis of central functions in a further development of Knitter et al. (2013), offering a novel approach to identify the distribution of central functions in a spatially explicit way. With regard to the often problematic data situation in archaeology (e.g. single finds, incomplete knowledge of spatial extent of sites), our approach likewise expands the information potential of destroyed archaeological sites.

Furthermore our results support the theory of more widespread trade and cooperation during *Horizons* in the study area. Likewise the comparatively high number of sites during *Intermediate Periods* shows that general interaction and thus human activity in the Rio-Ica-Catchment was not necessarily higher during *Horizons*. Rather we suggest, that the disappearing of a supraregional administrative during *Intermediate Periods* might have led to higher human activity in small scale societies, as reflected in a more diverse spatial organisation in terms of geomorphometric units and central areas.

Thus, this study contributes to the ongoing debate on prehistoric occupation of the Ica-Nazca depression and likewise supports the applicability of the used methods for the analysis of settlement patterns in general. By including natural factors (location factor analysis, swath profiles) and cultural factors (central functions of archaeological sites), our approach follows a holistic understanding of spatio-temporal changes of settlement patterns.

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6 Appendix

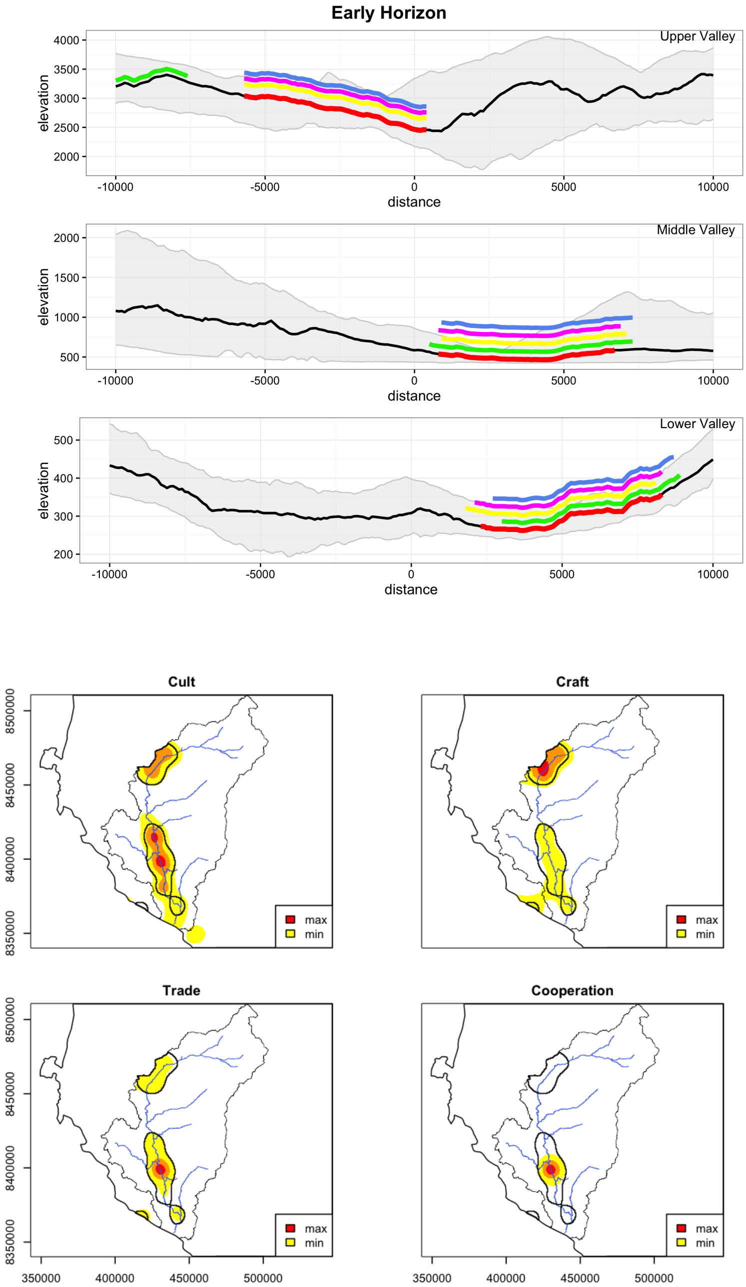

Figure 7: Early Horizon. ***Top:*** Swath profiles of the upper, middle and lower valley. Elevation (black = median, grey = quantile(25, 75)) and distribution of central functions (red = *central areas*, green = *cooperation*, yellow = *craft/industry*, magenta = *cult*, blue = *trade*) (elevation data: ASTER GDEM v2). ***Bottom:*** Site density of central functions in the study area (black lines = *central areas*) (WGS84 UTM 18S).

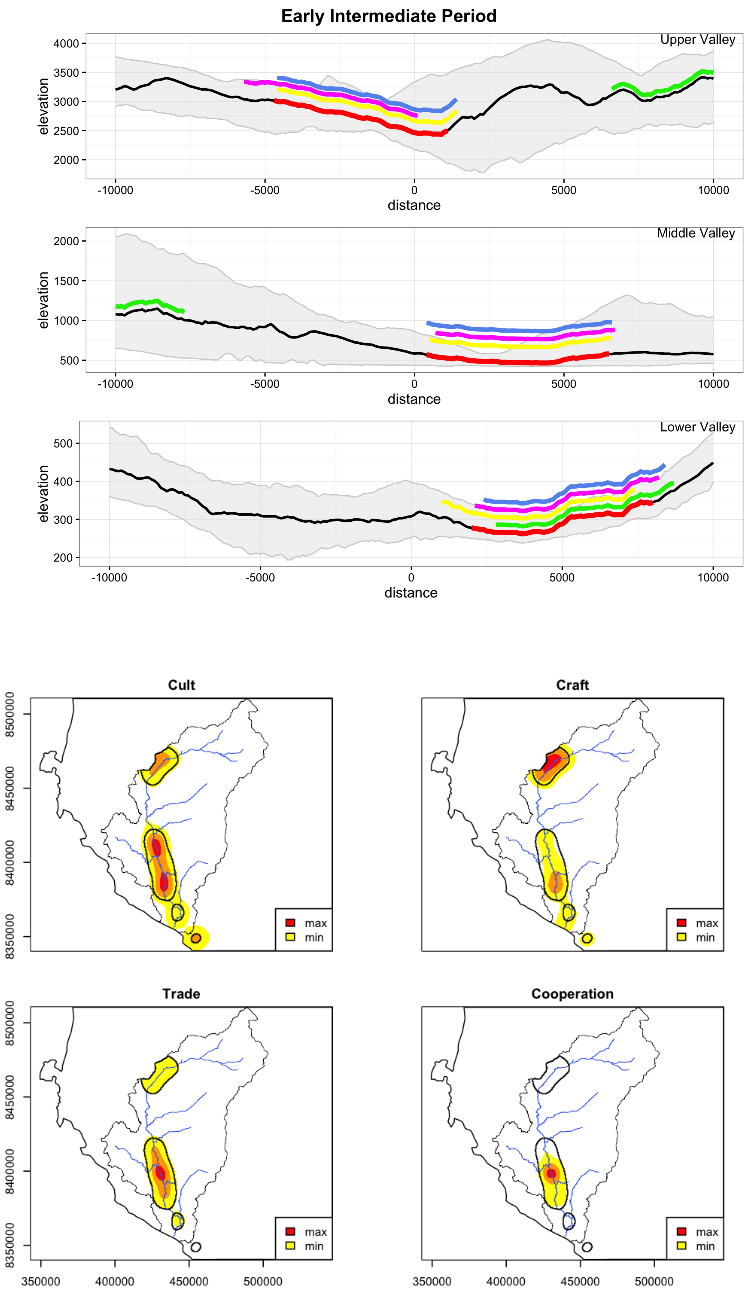

Figure 8: Early Intermediate Period. ***Top:*** Swath profiles of the upper, middle and lower valley. Elevation (black = median, grey = quantile(25, 75)) and distribution of central functions (red = *central areas*, green = *cooperation*, yellow = *craft/industry*, magenta = *cult*, blue = *trade*) (elevation data: ASTER GDEM v2). ***Bottom:*** Site density of central functions in the study area (black lines = *central areas*) (WGS84 UTM 18S).

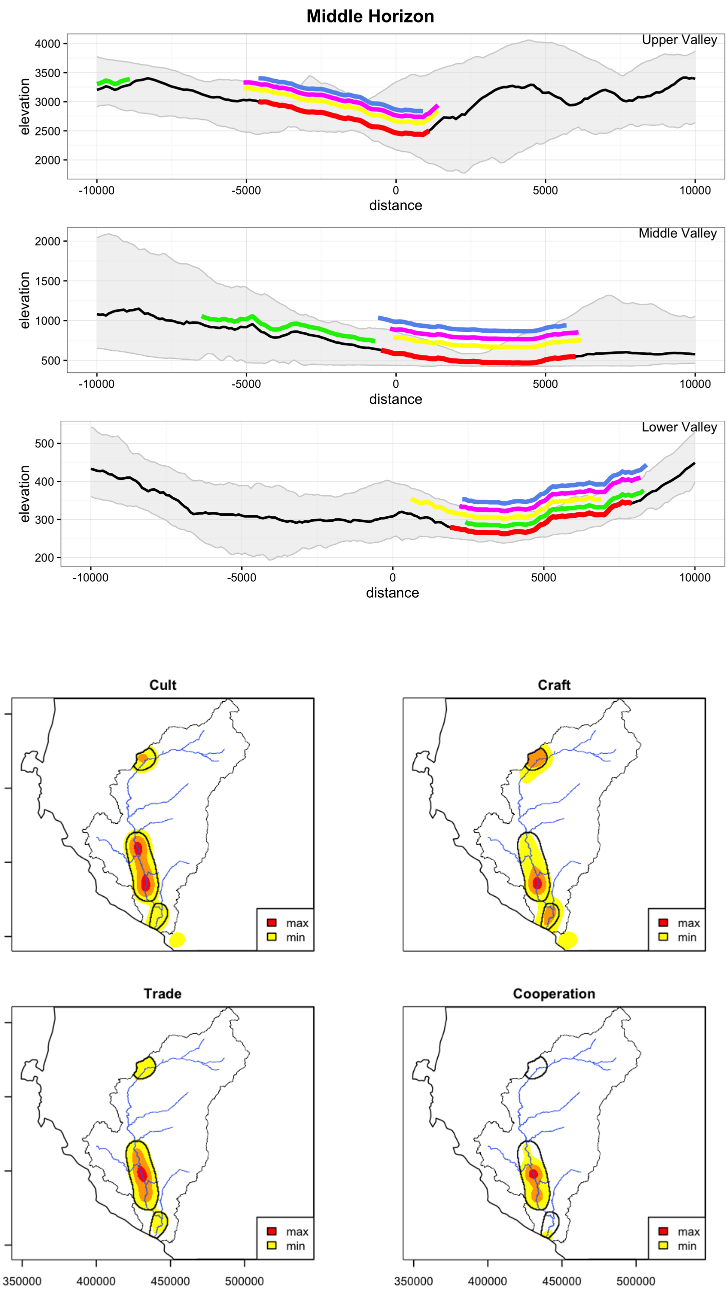

Figure 9: Middle Horizon. ***Top:*** Swath profiles of the upper, middle and lower valley. Elevation (black = median, grey = quantile(25, 75)) and distribution of central functions (red = *central areas*, green = *cooperation*, yellow = *craft/industry*, magenta = *cult*, blue = *trade*) (elevation data: ASTER GDEM v2). ***Bottom:*** Site density of central functions in the study area (black lines = *central areas*) (WGS84 UTM 18S).

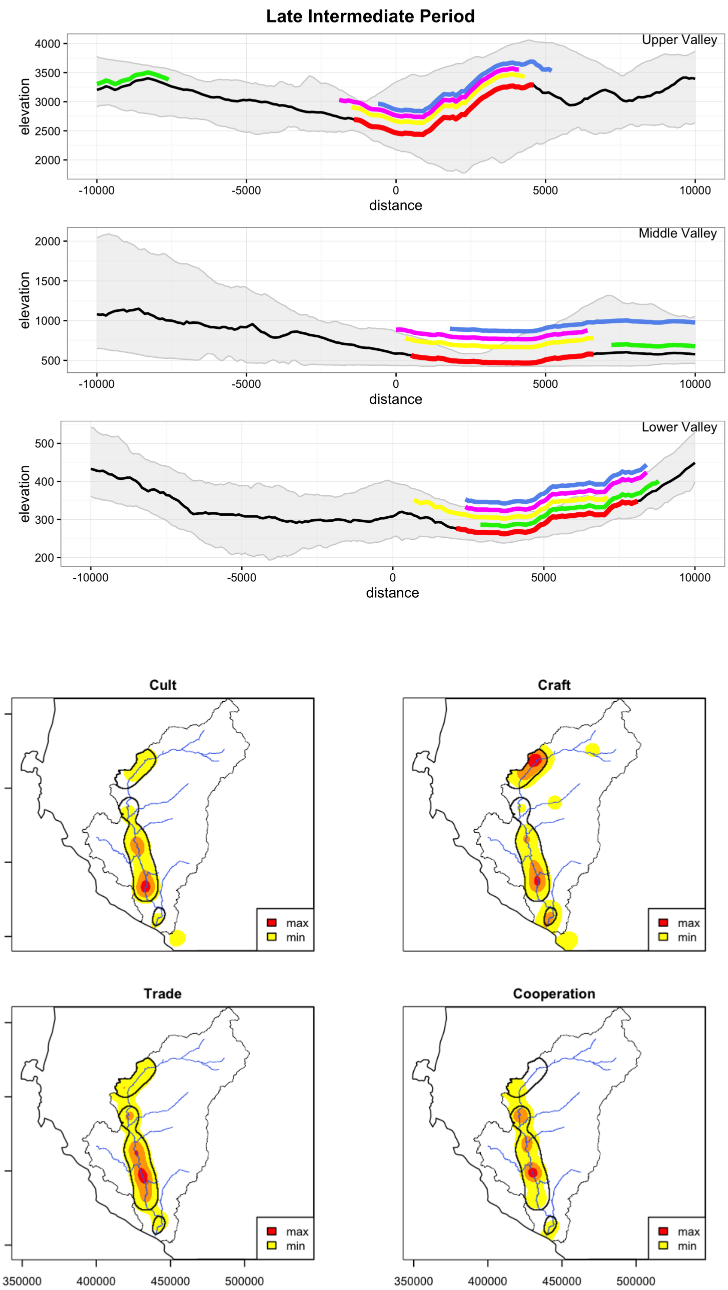

Figure 10: Late Intermediate Period. ***Top:*** Swath profiles of the upper, middle and lower valley. Elevation (black = median, grey = quantile(25, 75)) and distribution of central functions (red = *central areas*, green = *cooperation*, yellow = *craft/industry*, magenta = *cult*, blue = *trade*) (elevation data: ASTER GDEM v2). ***Bottom:*** Site density of central functions in the study area (black lines = *central areas*) (WGS84 UTM 18S).

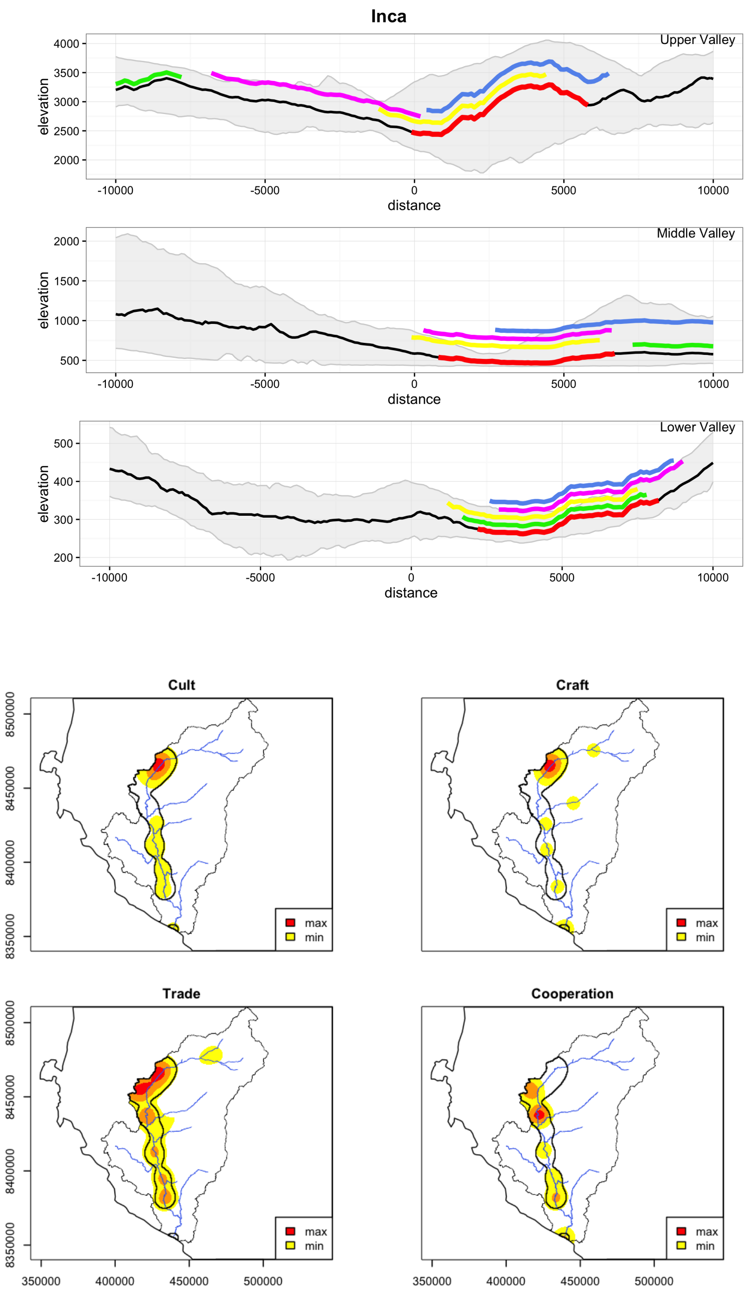

Figure 11: Inca Late Horizon. ***Top:*** Swath profiles of the upper, middle and lower valley. Elevation (black = median, grey = quantile(25, 75)) and distribution of central functions (red = *central areas*, green = *cooperation*, yellow = *craft/industry*, magenta = *cult*, blue = *trade*) (elevation data: ASTER GDEM v2). ***Bottom:*** Site density of central functions in the study area (black lines = *central areas*) (WGS84 UTM 18S).