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Inter-visibility between settlements in pre-Hispanic Sierra Nevada de Santa Marta, Colombia. The relation between hierarchy and control of distant communications

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ABSTRACT

The pre-Hispanic *Tairona* society of Sierra Nevada de Santa Marta, in northern Colombia, adapted to their natural surroundings for the development of their culture, economy and architecture. The mountainous environment determined the location and shape of their settlements and roads, the use of construction materials and the way to adapt to the terrain. The location of these ancient villages coincides with the proximity to freshwater sources and usually takes advantage of ridges between watersheds or river basins, for possible strategic reasons of communication and defence. This research is based on computational experiments and fieldwork to explore the relationship that can be interpreted between the hierarchy of individual sites and their privileged position in the territory. Through viewshed analysis, multiple points were taken on the ground to assess the visual domain of some villages over others and the surrounding landscape.

1. Introduction

This paper uses quantitative data to address the possible relationship between the strategic location and the hierarchy of pre-Hispanic settlements in an area of Sierra Nevada de Santa Marta (SNSM), Colombia. For this purpose, an inter-visibility analysis was carried out between the sites and terrain visibility between each site and the surrounding territory. Major ceremonial centres stand out for their visual domain but also a few smaller and peripheral dwellings reveal characteristics that allow the interpretation of strategic functions regarding defence, surveillance and economic control.

The irregular topography of the upper *Buritaca* River basin, with steep slopes and deep river canyons, is the location of at least 30 archaeological sites belonging to the *Tairona* culture. Archaeological research conducted in the region allows quantitative data to be extracted for the comparison of sites, regarding the occupied area of each, the number of structures in them and the estimated population at the time of habitation. Each of these ancient sites has a particular visibility over the surrounding territory and towards other sites' ruins. Digital topographic and hydrographic information can be used to describe the location of archaeological sites and to experiment with viewshed analysis. This method helps the understanding of the relationship between location and hierarchy, regarding visual domain and territory control. The above is supported by previous ground truthing fieldwork over the past seven years, with these questions in mind.

Since their arrival, Spanish conquerors recognized differences amongst the indigenous groups located in SNSM and classified them into provinces. This was due not only to village locations within the territory, but also to manifestations of cultural homogeneity within each polity (Reichel-Dolmatoff, 1951; Giraldo, 2000). This classification by the Spaniards might not refer to a constituted *cacicazgo* or chiefdom's political unit, but to a group that shared cultural characteristics (Langebaek, 2005). This research focuses on the province of *Tairona*, specifically in the upper basin of the *Buritaca* River in SNSM. Here, a concentration of former sites with quantifiable characteristics allows the establishment of relationships between the parts of the polities' built system (Fig. 1).

The Spanish chroniclers of the 16th and 17th centuries described a

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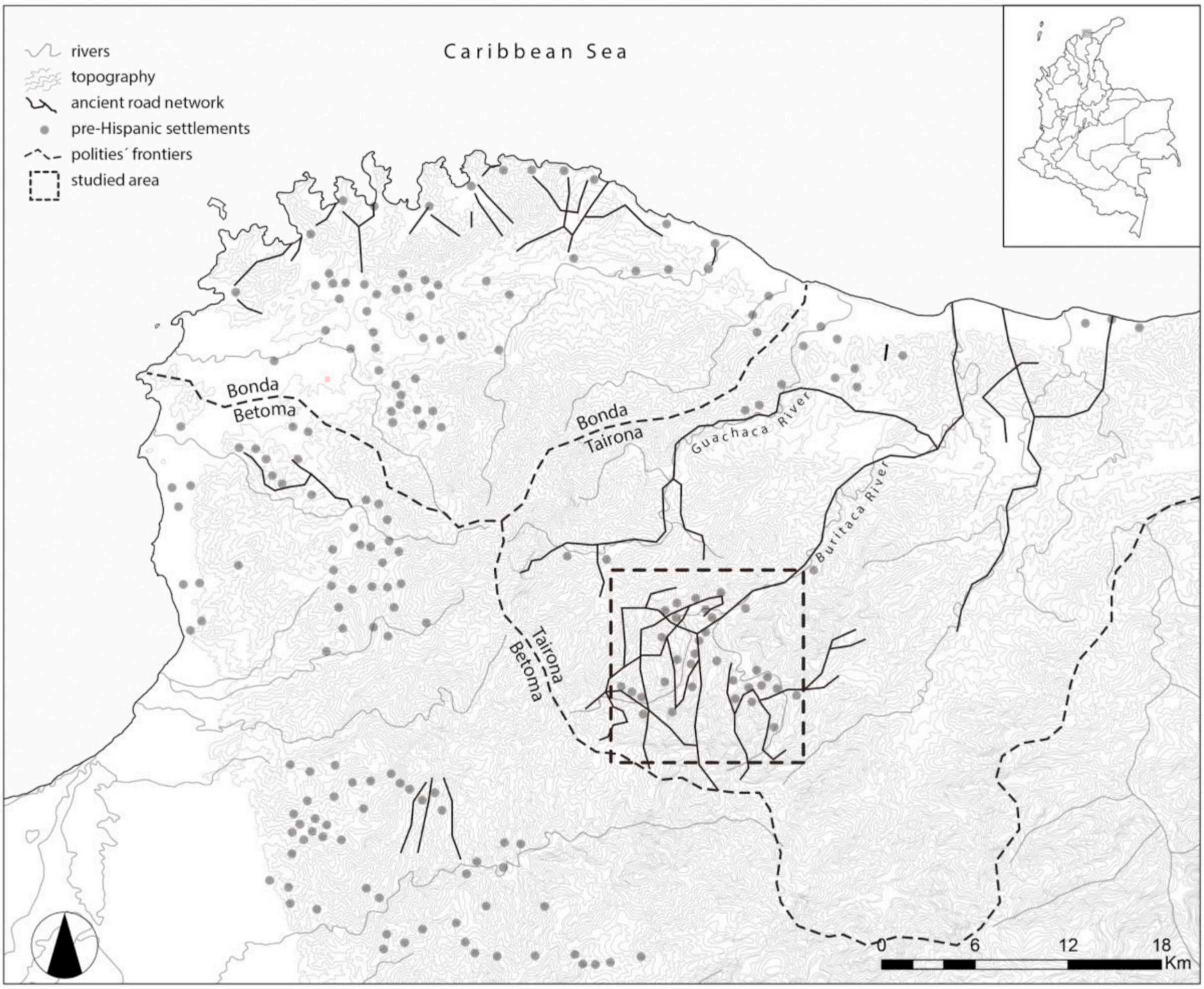

Fig. 1. *Map of the indigenous polities (Betoma, Bonda and Tairona) during the* 16th *century. The square indicates the studied area, in the upper Buritaca River basin. Elaborated by the authors based on historical and archaeological research* (Reichel-Dolmatoff, 1951; Cadavid and Herrera, 1985; Herrera, 2000; Soto, 2006).

sizeable indigenous population established within the region of Santa Marta in settlements of various sizes. These went from the edge of the Caribbean Sea coast at the foothills of SNSM, up to 1000 m above sea level (MASL). Archaeological studies carried out during the twentieth century have identified sites located up to 2000 MASL and only a few above this elevation (Reichel-Dolmatoff, 1951, 1997). Most of the ancient settlements are found between 0 and 1200 MASL. From 1300 to 1600 MASL, there was low site density, and even less when getting close to 2000 MASL (Herrera, 1985). The area studied in this research contains settlements located between 380 and 1750 MASL.

More than 200 archaeological sites that date back to the 4th century, were documented in this region during archaeological explorations between 1973 and 1976 (Cadavid and Herrera, 1985; Giraldo 2018). In the upper basin of the *Buritaca* River, intensive work was carried out at the end of the 1970s in *Ciudad Perdida* ("Lost City"). Other work fronts were opened in the early 1980s at 30 archaeological sites in the area (Soto, 2006). The old houses and temples have disappeared, as they were built with perishable natural materials. However, the stone architecture of foundations, terraces, walls, roads and stairs is still preserved (Reichel-Dolmatoff, 1997). The ceremonial importance of some constructions is embodied not only in the chronicles of the Conquest but in the large human-made platforms that archaeology has identified as the foundations of sacred temples (Serje, 1984; Giraldo, 2010). The largest structures of this type are found in archaeological sites known as *Ciudad Perdida* and *Koskunguena* (Fig. 2).

The climatic diversity found amongst the complementary coastal and mountain regions allowed the exchange of products from one area to another, within the same province (Langebaek, 1995; Giraldo, 2000). This exchange was a fundamental practice for indigenous groups to guarantee access to goods from different areas. It is considered that the social complexity of pre-Hispanic cultures established in the north-western region of SNSM is reflected in the extensive network of roads. These connected the different formerly populated areas and organized urban centres according to the hierarchy of terraces and stone paths (Groot, 1990; Giraldo, 2018). The roads connected different settlements, usually large towns with smaller ones located at different elevations above sea level and with distinct ecological characteristics. In these complementary regions, climatic diversity allowed a 'micro--vertical' exchange of products from one area to another.

It is claimed that the vast network of roads was of great significance, as it was used for generalized exchange amongst the pre-Hispanic chiefdoms of SNSM. Valuable and difficult-to-obtain products were traded, such as salt, fish, seashells and probably cotton and coca leaves; as well as ceramic, stone artefacts, gold and textiles (Oyuela, 1990). However, the trade of subsistence goods was restricted (except for salt and fish), because greater importance was given to the transport of luxury objects (Langebaek, 1996). It is believed that there were three types of goods' exchange: regional, interregional and long-distance. The first type indicates the commercial exchange of objects within a given region, for example, with the coast or with the mountain region, but not between them. This local exchange is supported by the productive variability of the different areas (lowlands and highlands). The

Fig. 2. Central terraces in Ciudad Perdida (left) and Koskunguena (right), upper Buritaca River basin. Photographs by E. Mazuera.

interregional exchange implies a further commercial relationship where there is a dependency created between regions (Cárdenas, 1988; Giraldo, 2000). In the long-distance trade, the exchange is essential from the political point of view, rather than from the economic one. The movement of luxury products and rituals was significant to establish a political relationship with another distant but accessible group, with which alliances could be maintained. Political feuds and commercial tensions resulted in rivalry, conflict and ever warfare at times.

Given the rugged geography of SNSM, multiple obstacles can interrupt visual communications between different parts of the territory from one settlement to another. However, from specific points of the terrain, it is possible to observe settlements in sections of valleys and surrounding canyons, as well as other archaeological vestiges in more distant highlands. Although there is no visual domain of the entire region from a single point, it is possible to establish a chain of visual relationships between different formerly occupied places. Currently, the existing vegetation makes it more challenging to observe the surroundings. However, the farmland described by the Spanish conquerors at that time likely allowed visuals with fewer obstructions.

It is thought that the indigenous communities took advantage of the topography, climate, vegetation and demanded access to villages as defensive strategies (Reichel-Dolmatoff, 1997; Serje, 1984; Giraldo, 2018). The settlement's defences likely relied on the ability to monitor their environment and to detect anomalies such as fires or other signs in nearby villages, which warned them about the presence of invaders. This is comparable to concepts in military surveillance architecture studies where fundamental defensive characteristics of such buildings are a strategic elevated position from which to monitor the surroundings and obstacles in the surrounding terrain to hinder the approach of enemies (Devries, 2003; Toy, 1985; Vilar, 1991). Amongst these surveillance constructions were the *atalayas* or fortified watchtowers built by the Arabs during their occupation of the Iberian Peninsula between 711 and 1492. These buildings were located in strategic places of connection with other settlements or political units in the territory. They functioned as part of a system where short distances, below 10 km, separated the towns or beacons to allow visual communication between them by means of fire and smoke signals (Pavón, 1999; Grabar, 1985).

The above considerations are applicable in the case of SNSM ancient settlements. From specific points of the SNSM topography, there are unobstructed views connecting sectors of any single settlement and others a few kilometres away. The irregular topography provided natural defences, and the proximity to freshwater supplied the village's needs. The road network allowed communication between visible settlements and led to others further away. Even when physical displacements from one village to another could take several hours, the visual connectivity or viewshed could be immediate.

A viewshed can be used to determine what parts of a terrain are visible from a location. The viewshed describes the set of points (observed) in a geographical area visible by line-of-sight from a single location (observer). In a computer-generated map or model, a total or cumulative viewshed is obtained when every location in a geographical area is treated as an observer and its viewshed is calculated. A cumulative score is assigned to each point, describing the total number of points observed (Wheatley, 1995; Jones, 2006). The topography of a geographical area can be represented as a grid of points each with latitude, longitude and elevation values. The Digital Elevation Model (DEM) is typically the basis for viewshed analysis.

The study of this visual relation between sites in the SNSM coincides with recent research that also inquires how ancient communities in other parts of the world shaped landscapes, spatial relations and social contact. This analysis can contribute to understanding the significance of settlement patterns that may have determined the way territory was occupied (Giraldo, 2010; Kosiba, 2010; 2011; Kosiba and Bauer, 2013; A. Smith, 2003; Llobera et al., 2011; Ogburn, 2006).

Archaeology in the 21st Century has benefitted around the world with the increasing application of computer technologies for the analysis of ancient landscape occupation and social organisation (Richards-Rissetto 2017; Richards-Rissetto and Landau 2019). In tropical environments such as SNSM, with abrupt topography and dense vegetation, digital model interpretations allow new approaches to archaeological discussions formerly limited by cost, time and fieldwork possibilities. For decades, regional scale occupation studies of past societies in remote landscapes have been subject to misconceptions or theories that lack concrete evidence. Hence, research on this topic has concentrated on monumental site centres in more compact areas, leaving territorial analysis under attended (A. Chase et al., 2014; D. Chase and Chase

2017). A rapid transition is occurring in the way 3D models of archaeological objects and their surroundings are used in solving archaeological questions, shifting from basic visualization to deeper observations and interpretations of cultural phenomena that integrate diverse scales and perspectives (Galeazzi 2016; Tapete 2019).

The insights gained from viewshed analysis can be used to understand patterns of settlement. Cumulative viewsheds are tools for exploring the visibility characteristics of a landscape and can help understand how users experience or assign meaning to the spaces they occupy. For O'Sullivan and Turner (2001), the cumulative viewshed is a 'visibility graph' which using mathematical theory of graphs can be employed to determine connections between settlements and the landscape. Llobera (2003) describes these methods as supporting a 'visualscape' which in the case of archaeology is believed (Bongers et al., 2012) to help understand the decision making in selecting settlement locations. Several archaeological applications have applied viewshed analysis to develop theories of settlement patterns and site selection. Wheatley (1995) investigated if Long Barrow sites in Southern England were established based on the number of other visible sites. Kay and Sly (2001), as did Lambers and Sauerbier (2006), undertook similar studies to examine the distribution of medieval beacons on the Isle of Wight in the UK and Nasca geoglyphs in Peru. Wright et al. (2014) examined inter-visibility between archaeological sites in Northern Cameroon and defined a method where randomly generated settlement patterns are evaluated for inter-visibility and compared to the existing configuration. Murphy et al. (2018) used an extended set of visibility tools to attempt to establish if a topographical location was part of the Roman communication network in Scotland.

The studies noted above are based on the analysis of sites in a landscape represented by a single point. Our analysis is concerned with analysis of viewshed from a set of points contained within the boundary of each site. An area-based approach avoids oversimplification of the analysis through the reduction of each settlement to a single location. The area-based approach offers the ability to represent how inhabitants could observe their surroundings as they go about daily tasks from anywhere within their village and not by viewing from a predefined advantage point. This representation may provide better understanding of decision making in site selection. To our knowledge this approach of analysing the viewshed of the area of each village within a larger settlement is novel. This provides the opportunity to compare sites to each other and account for the area covered by each site.

The precedent studies are typically dependent on existing software applications. Our approach to analyse visibility of settlements represented as groups of points introduces processing complexity. We considered dependency on existing software too constraining for our needs and chose to develop a set of analytical tools in response to our analytical and data processing needs. We extend Wright et al.'s (2014) random settlement approach generating settlements based on the observed elevation range. Our process adds to the single elevation constraint the expected ranges of proximity to water source and slope gradient observed in the actual settlements.

Murphy et al. (2018) analytical approach is based on comparison of results of different forms of viewshed analysis this contrasts with other precedent studies that are dependent on statistical analysis using Kolmogorov-Smirnov tests and Bayesian logistic regression. In our study, like Murphy et al., we do not rely on statistical analysis but simply compare results. However, unlike Murphy et al., our results come from a set of studies that attempt to generate multiple alternative settlement configurations. The scale and location of our analysis led us to reject the need of fuzzy viewsheds. The geographic scale in our study is within what Murphy et al. consider the limit of perfect visibility and visibility difficulties due to weather conditions at the equator are much less significant than in Scotland.

2. Materials and methods

2.1. Hypothesis

For the pre-Hispanic settlements in SNSM, the two forms of cumulative viewshed are thought to be potential, partial hypotheses for the actual patterns of settlement. Inter-visibility describes how visible sites are from one another. Terrain-visibility indicates how visible the surrounding landscape is from selected locations.

Good inter-visibility would enable viewing of public activities and ceremonies between sites and provides communication which may have defined the socio-political hierarchy of the settlements. Good terrain-visibility would have offered a defensive advantage and made monitoring movements and activities possible. This study considers two hypotheses that examine inter-visibility (the visibility of neighbouring sites) and terrain visibility (the visibility of the surrounding landscape). Randomly generated settlements were used in the present work to test these hypotheses, undertake cumulative viewshed analysis and compare them to the existing settlement. For the two hypotheses this study investigates the following null hypotheses:

$H1_0$. The existing settlement will not score significantly higher than random settlements in inter-visibility tests.

$H2_0$. The existing settlement will not score significantly higher than random settlements in terrain visibility tests.

A tertiary hypothesis is that the documented social hierarchy within the existing settlement should correlate with the inter-visibility and terrain visibility scores for individual sites. Sites with higher visibility scores are expected to be those that sit higher in the local hierarchy.

This study uses the term *settlement* to refer to a collection of individual sites. The resolution of the base DEM means that a site is not a single point but a collection of points defining an area. The random settlement configurations used in this study have characteristics found through evaluation of the existing settlement. These studies captured permitted ranges for elevation, proximity to a source of water and slope gradients. For this study one thousand settlement configurations were generated, each containing the same number of individual sites as the existing settlement.

2.2. Computational approach

To undertake the analysis the authors chose to develop a customized piece of software using the C#.Net Framework 4.5.2. An alternative approach could have involved viewshed analysis functionality and representation of results found in commercial geographic information systems (GIS). The choice not to use an existing GIS application was made based on our goals of transparency of process and representation of results and the need for performance, task automation, task control and flexibility in generating input data.

The source code for our software is opensource and available here, together with all input data and methods for visualizing the results.[1] The transparency offered by this approach provides others with the opportunity to critique our methodology and potentially build on it. Furthermore, working in this way we were able to leverage other opensource software that supported our data preparation and analysis. The transparency of our method and integration of other open tools would not be possible if we had used proprietary GIS software. Graphical representation of the results supported the interpretation of the analysis and conclusions of the study. Developing our own software provided the freedom to convert between different data formats and use a variety of representations that directly assisted interpretation.

Our analysis involved two experiments involving 1000 randomly

[1] https://github.com/rolyhudson/LostCityApp.

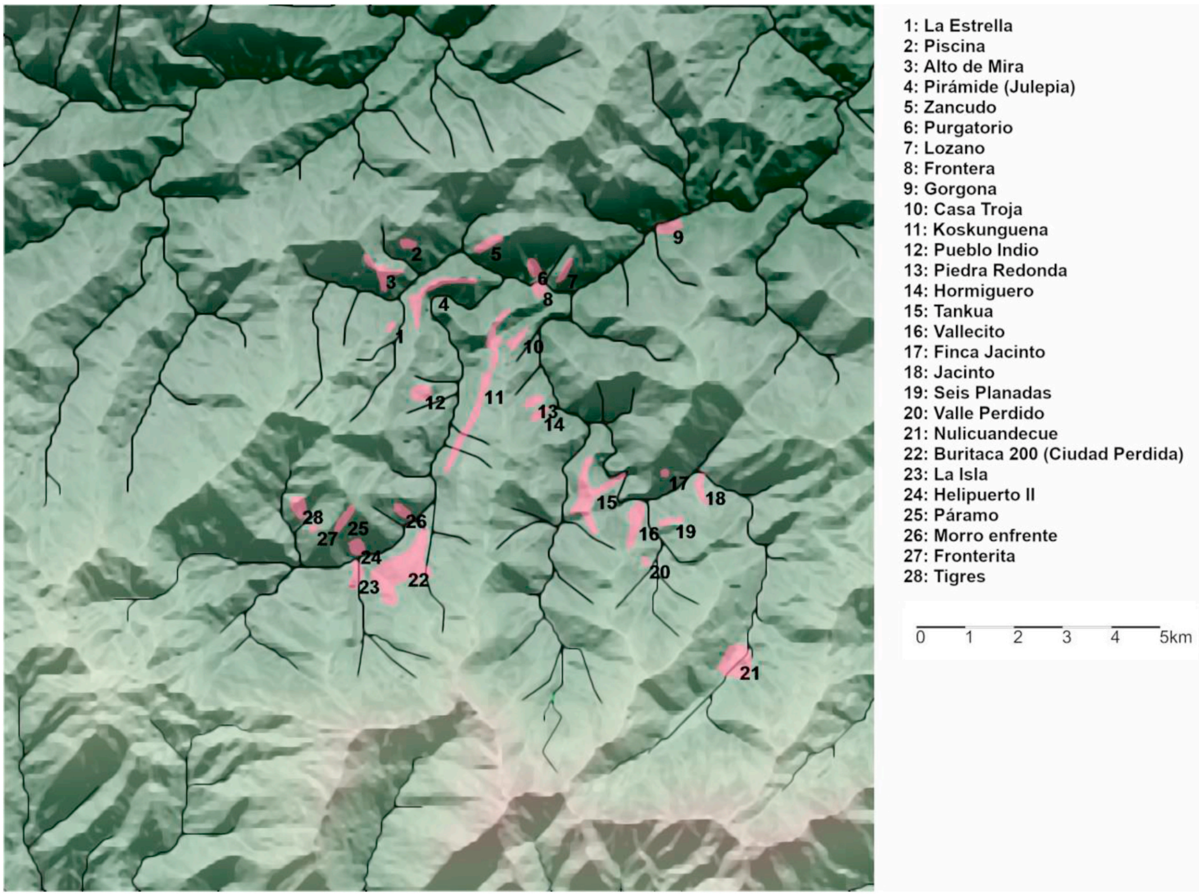

Fig. 3. Area of study, showing ancient settlements, river network and topography. Elaborated by authors.

generated settlements, each with twenty-eight sites. In the first experiment cumulative viewshed is calculated 800,000 times (between each site and all the other sites for each settlement). In the second experiment cumulative viewshed is calculated between each site and the surrounding area DEM (38,000 points) for each of the 1000 settlements. Random generation of sites was implemented as a computationally demanding organic growth algorithm. Our use of custom code allowed us to parallelize the computation and improve performance of the analysis. Developing our own tools allowed fine grained control and automation of the thousands of analytical runs. The customized approach offered the ability to control the inputs to the analysis and generate them through a novel algorithm.

Our requirements that are supported by GIS platforms represent a small subset of tools that these packages provide. The time required to learn enough of a GIS system to access a narrow set of functionalities combined with the time needed to understand the application plugin interface for our processing and data manipulation requirements was considered too great an overhead.

3. Calculation

3.1. Overview

A series of preparatory steps were undertaken before the evaluation of the viewsheds. The process begins with the generation of georeferenced site boundaries and the river network. These are combined with a subset of data from several individual files of DEM in *.hgt format. Elevation ranges and water proximity are measured in the actual settlement and used to generate random configurations of settlements. The existing settlement and the random settlement configurations are evaluated for their inter-visibility and terrain visibility scores. Finally, the scores are plotted for visual analysis and comparison.

3.2. Digital elevation model

The DEM source files (de Ferranti, 2014) are a 'hole filled' version of NASA's SRTM. The resolution of the grid is spaced at three arc seconds which at the equator and for Colombia is a grid of 90 × 90 m. The area of study is 17.6 × 17.6 km, centred at −73.915 longitude and 11.057 latitude. This area provides a buffer zone for viewshed analysis around the settlements. If this buffer is too small, then viewshed analysis can be incorrectly biased. The binary, *.hgt format files cover a 1 × 1° area of the earth's surface. Four of these files are required to define the DEM (N11W075, N11W074, N10W075 and N10W074). The system automatically opens and accesses the relevant elevation data from the files for the area of study and creates the DEM as a 197 × 197 grid of points. The digital elevation model is available as part of the opensource code repository.

3.3. Georeferenced objects

Extensive detailed mapping of the area of study is limited to studies of specific sites, which have subsequently been compiled into maps (Soto, 2006). These maps were digitized and scaled, and boundaries of each site extracted as a set of geospatial points with latitude and longitude coordinates.

The river network in the area is mapped to varying levels of detail in different sources, including the maps documenting settlement locations. The basis of the river network for our analysis is generated using stream network analysis, a geospatial approach based on the topography of the landscape. Stream network analysis of the DEM was undertaken using Whitebox tools, a geospatial analysis platform with a python scripting

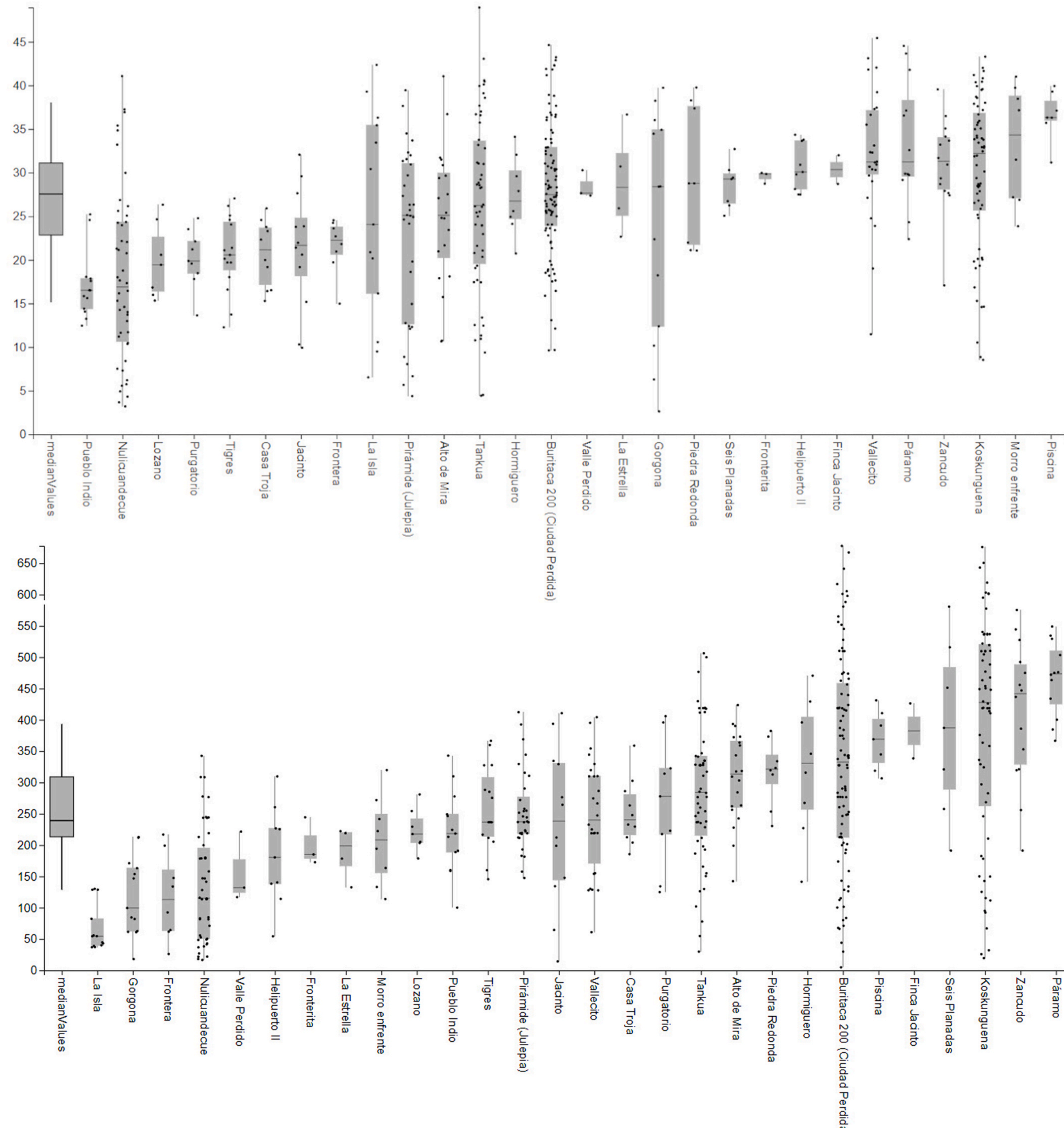

Fig. 4. Analysis of topographic characteristics k of actual settlements. Top: Slope angle in degrees. Bottom: proximity to the river network in metres.

interface (Lindsay, 2018). A python script was developed that prepared the DEM first by filling missing data, filling localized pits and breaching depressions. Once the DEM is prepared, the flow direction and flow accumulation can be defined and finally, streams can be extracted in a vector format. The network was adjusted further using rivers found on google maps and open street maps, and the river network documented with the settlement boundaries (Fig. 3).

3.4. Evaluation of the existing settlement

Site boundaries are read into the system as a list of geospatial points. These are overlaid onto the DEM and then the DEM points within each boundary are recorded. Using these groups of points, the elevation ranges of each site can be evaluated, and the typical surface slopes of sites are determined using Horn’s (1981) 3rd-order finite difference method (Fig. 4). Horn’s method defines slope at a location in the DEM by combining the elevations of the surrounding eight points and the cell size.

The river network is also read into the system as lists of geospatial points. The points in this network are used to construct a k-dimensional tree (KD tree) using Accord.Net (Accord.NET Framework, 2017) to evaluate proximity to water faster. KD tree data structures partition

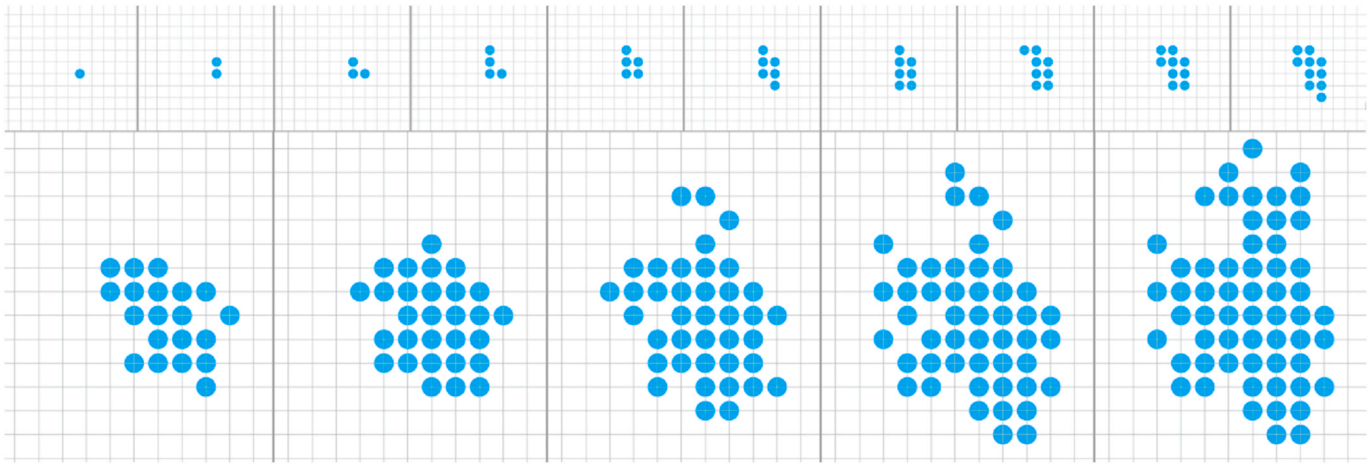

Fig. 5. Site growth by neighbouring points. Top row growth steps 1–10, bottom row growth steps 20–60. Growth stops when the site has as many points as the actual site it references.

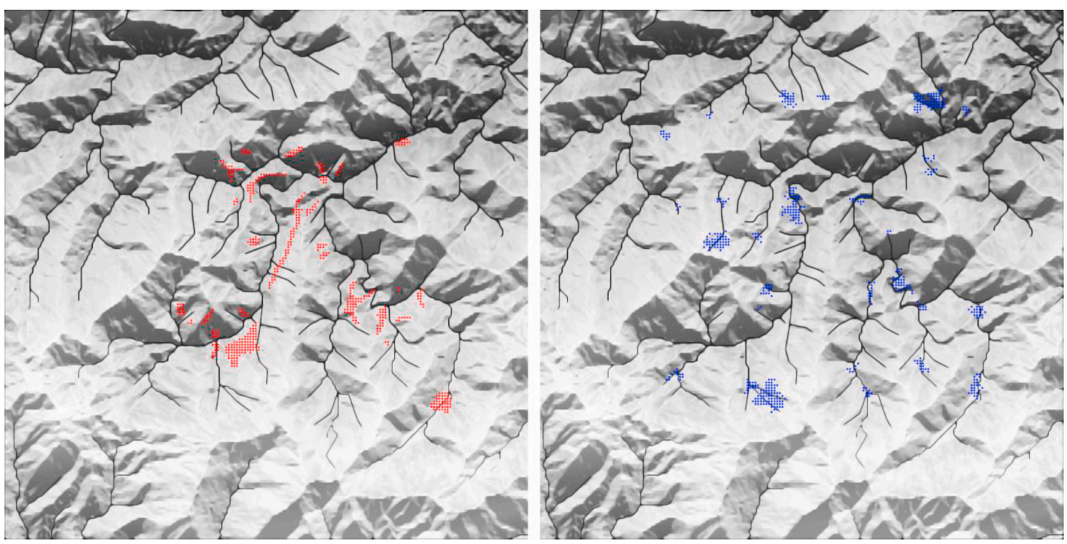

Fig. 6. Comparison of actual settlements (left) with one of the 1000 randomly generated settlement configurations (right). Elaborated by R. Hudson.

space, which makes finding the nearest point on a river to a point in a settlement more efficient than searching the entire river network. Proximity to water is evaluated for each point within each site boundary and mean, median and ranges are defined for each site and the whole settlement.

The box charts in Fig. 4 show the maximum, minimum, interquartile range and median for all sites independently and for the whole settlement. For the proximity to water, the range is 128–390 m and a median of 245 m. For the slope analysis, the range is 16–36° and median 27°.

3.5. Viewshed algorithm

The viewshed analysis is undertaken using Wang, Robinson, and White's (2000) reference plane method, which is computationally faster than methods based on sightlines. Wang et al. provide a lengthy description of the RP algorithm with a minimum of graphical support. Readers requiring a graphically supported description should refer to the website accompanying this paper.[2]

Using the reference plane method, an entire DEM can be processed, and a view score assigned to each point defining a cumulative viewshed. To measure inter-visibility between sites, cumulative viewsheds need to be determined between specific subsets of the original DEM where each subset represents points in the DEM contained by the boundary of an individual site. To measure terrain visibility, cumulative viewsheds are generated between specific subsets of the original DEM and the rest of the DEM. This approach defines a score for both inter-visibility and terrain visibility for the entire settlement which can be compared to randomly generated settlement configurations (see next section). This comparison is used to test the null hypotheses stated. In addition to the global settlement scores each individual site can be scored for inter-visibility and terrain visibility allowing comparison between sites of the existing settlement.

3.6. Randomly generated settlements

Based on the analysis of the existing settlement, the following three rules for defining random settlement configurations were established to investigate the significance of inter-visibility and terrain visibility:

[2] https://rolyhudson.github.io/LostCityApp/Graphics/ReferencePlaneAlgorithm/refPlaneAlgorithm.html.

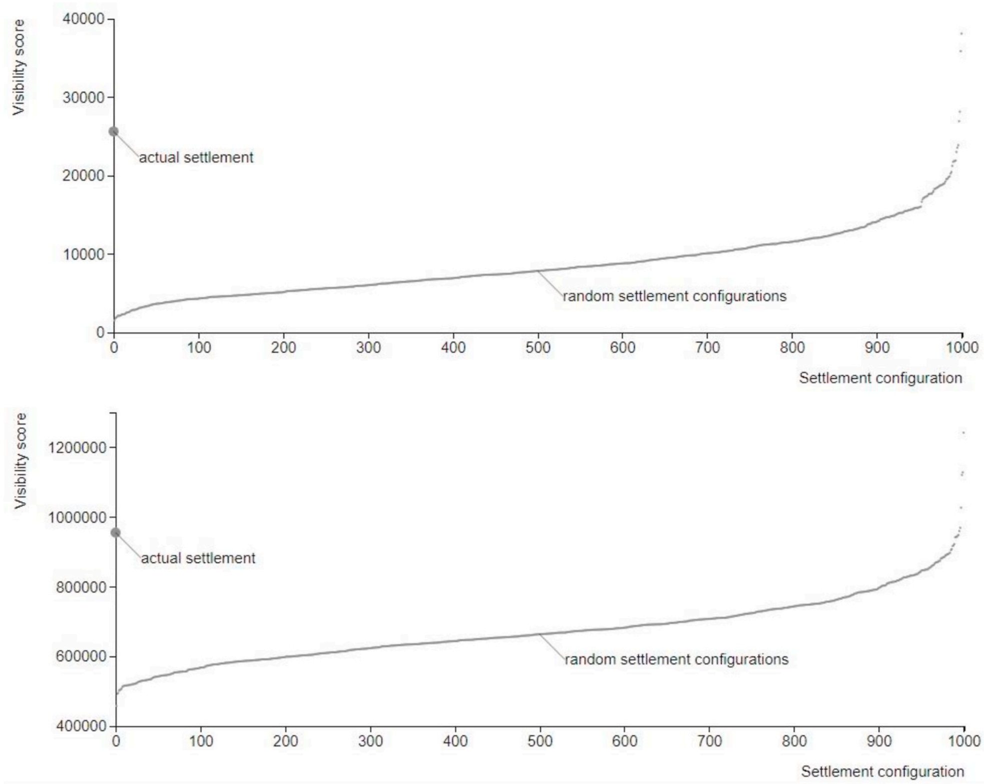

Fig. 7. Scores for the two experiments showing randomly generated settlement configurations, and comparison to the actual settlement. Top: Inter-visibility scores. Bottom: Terrain visibility scores.

1. Points defining an individual site must lie with the observed elevation range of 380–1750 m.
2. The distance from at least one point in an individual site must be less than the observed median minimum of 125 m.
3. Points defining an individual site must lie within the observed slope range of 16–36°.

Table 1
Site terrain and intervisibility scores ranked by population. Population data from Soto (2006).

Map number	site name	population	terrain visibility score	inter-visibility score
22	Buritaca 200 (Ciudad Perdida)	1710	162,575	4328
11	Koskunguena	1518	125,233	3864
4	Pirámide (Julepia)	1330	83,473	2406
21	Nulicuandecue	855	48,069	0
3	Alto de Mira	640	70,843	1495
15	Tankua	522	79,103	1285
10	Casa Troja	275	21,583	558
16	Vallecito	237	44,781	1739
12	Pueblo Indio	237	22,761	682
18	Jacinto	237	15,481	304
8	Frontera	237	6019	189
7	Lozano	178	20,289	538
5	Zancudo	145	56,266	2283
6	Purgatorio	145	13,775	179
13	Piedra Redonda	145	10,463	158
9	Gorgona	140	6678	0
28	Tigres	107	23,984	40
27	Fronterita	95	6026	40
14	Hormiguero	82	7480	71
19	Seis Planadas	76	14,528	725
2	Piscina	72	33,546	1207
25	Páramo	72	38,267	1365
24	Helipuerto II	72	11,879	791
23	La Isla	46	9566	354
1	La Estrella	35	6486	272
20	Valle Perdido	31	2626	12
17	Finca Jacinto	29	4172	101
26	Morro Enfrente	25	9391	652

One thousand settlement configurations were generated, and inter-visibility and terrain visibility were evaluated for each configuration. Each random settlement configuration is generated using the actual settlement as a reference. Each random configuration contains the same number of sites as the actual configuration. Each of the sites in the random configuration contains the same number of DEM points found in the referenced site.

The start point in a single site is defined by randomly selecting a point within the DEM and is considered valid if it is not already 'occupied' by another site and if it satisfies the three rules listed above. If the start point is rejected, the process continues until a valid starting point has been found. Once a valid start point has been defined, it is marked, and the process of site growth begins.

From this *growth point,* the system seeks a new neighbouring point. From the eight points surrounding the *growth point*, those that are vacant and comply with the three rules are selected as candidates for a new neighbour. One of the candidates is selected at random and is marked as part of the new site. This process continues until the new random site comprises as many points as the actual site it references, after a series of steps in the growth process (Fig. 5). The actual settlement's configuration is compared with a single randomly generated settlement configuration (Fig. 6).

There is a probability that the settlement cannot grow further if an unoccupied neighbour that complies with all three rules does not exist. Therefore, to guard against this situation, the site is rejected once all the neighbouring points have been tested and no candidate neighbours have been found. The process returns to seeking a new site start point.

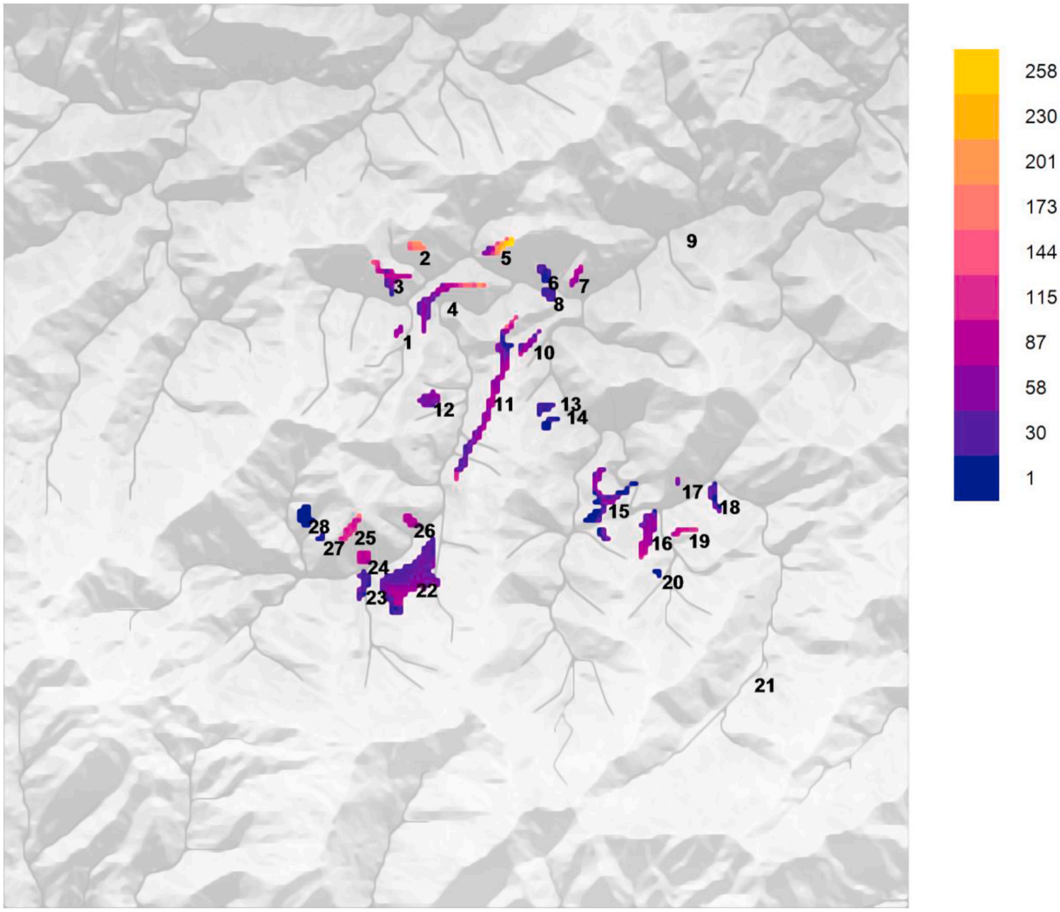

Fig. 8. Map of inter-visibility scores for the actual settlement.

4. Results

4.1. Inter-visibility

The hypothesis for inter-visibility indicates that if settlements were located to provide visual connectivity, then the expected score for the actual settlement would be better than most of the randomly generated settlements. Inter-visibility score for the actual settlement is in the top one percent of random scores outperforming 995 of the random settlements (Fig. 7 top), indicating the null hypothesis should be rejected, and that inter-visibility was an important consideration for settlements in SNSM.

4.2. Terrain visibility

The hypothesis for terrain visibility indicates that if settlements were located to provide terrain visibility, the expected score for the actual settlement would be better than most of the randomly generated settlements. The actual settlement has a score within the top one percent of the random scores outperforming 993 of the random settlements (Fig. 7 bottom). The score indicates the null hypothesis should be rejected, and that terrain visibility was a key consideration for the people of pre-Hispanic SNSM.

4.3. Comparison of sites in the existing settlement

Comparison of sites within the existing settlement allows us to consider our tertiary hypothesis that social hierarchy and visibility scores should correlate.

Table 1 shows the full set of scores per site ranked by population (Soto, 2006). Both inter-visibility and terrain visibility can be seen to generally correlate with population. This simple observation provides some indication that social hierarchy and visibility scores appear positively related. Topographic advantage and disadvantage explain exceptions to the general observed pattern. *Nulicuandecue* and *Gorgona* are located at the bottom of valleys isolated from the other sites giving zero intervisibility and lower terrain scores. Sites located at higher elevations with smaller populations *Piscina (2), Paramo (25), Zanudo (5) and Helipuerto II (24)* have better overview of their neighbours boosting visibility scores.

Geospatial mapping of the inter-visibility scores of individual points within each site of the actual settlement enables further insight into the relative differences in scores for individual sites (Fig. 8). Sites located in the north of the region, in particular *Piscina (2)* and *Zancudo (5)*, parts of *Piramide (4)*, the northern end of *Koskunguena* (11) and the southern end of *Ciudad Perdida* (22) and *Paramo* (25) have high inter-visibility scores due to higher elevations and good overview of neighbours. Geospatial mapping of the terrain scores (Fig. 9) indicates the settlements with high inter-visibility scores also perform well for terrain visibility.

In contrast to Fig. 9 where the score is assigned to the observer locations, Fig. 10 shows an alternative mapping of terrain visibility quantification where scores are assigned to the observed locations in the landscape. This representation captures the entire settlement viewshed, the limits of which are a non-physical spatial boundary. Mapping the scores of the observed locations also shows a roughly south-north axis of higher terrain visibility corresponding with the locations of *Ciudad Perdida* (22), *Koskunguena* (11), *Frontera* (8), *Lozano* (7) and *Purgatorio* (6). Two of these sites (*Ciudad Perdida* and *Koskunguena*) have the highest social rank with the largest population and built area.

Fig. 11 plots inter-visibility against terrain visibility and the area of

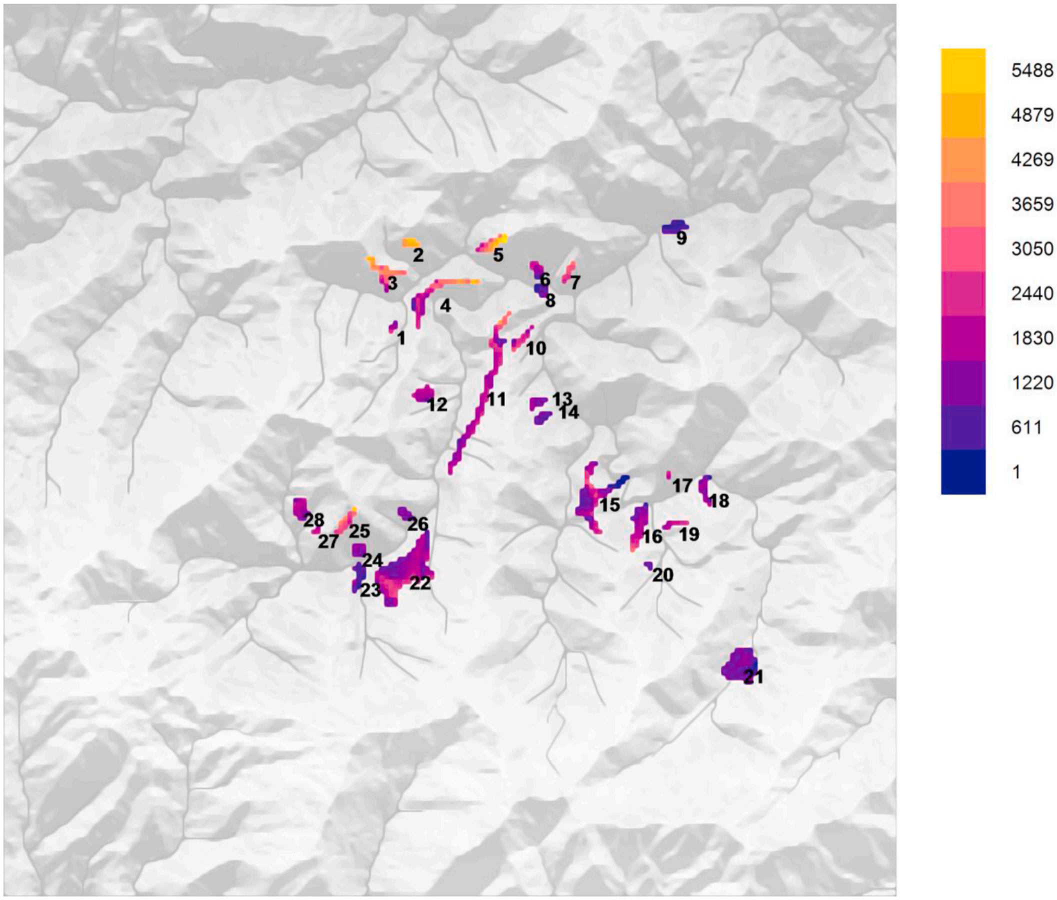

Fig. 9. Map of terrain-visibility scores for the actual settlement.

each site proportionally as the radius of each dot. A correlation between inter-visibility and terrain visibility is clear. The observed relationship shows a trend where sites that score well in both visibility scores generally have greater areas. The top-ranking (*Ciudad Perdida* and *Koskunguena*) have the largest size, highest social importance and are located centrally in the area studied for this research.

To eliminate the effect of the site area, scores were normalised (score per unit area) and dot radius representing the relative size of the ancient settlement (Fig. 12). Like Fig. 11, the correlation of inter-visibility and terrain-visibility is clear. This shows a different pattern to the one in Fig. 12. Sites with larger areas and architectural features that indicate high social importance (*Ciudad Perdida* and *Koskunguena*) rank in the middle of the hierarchy and the dominant sites (*Piscina*, *Paramo*, *Zancudo*, *Alto de Mira* and *Seis Planadas*) are located on higher ground and towards the periphery of the set of sites studied here. Although relatively small, some of these settlements are in a strategic position where terrain visibility extends beyond the *Buritaca* River basin. Specifically, the sites of *Alto de Mira*, *Piscina* and *Zancudo* may have had a surveillance function over the territory towards the north, invisible to the rest of the settlements in the studied area. Visual control over the neighbouring *Guachaca* River basin would alert the system of settlements in case of an anomaly. As mentioned in the Introduction, commercial and political alliances were common between these groups, but rivalries sometimes also led to conflict and warfare.

5. Discussion

5.1. Findings in relation to area of study

Until recently, most archaeological research on the pre-Hispanic communities that lived on the SNSM has focused on a functionalist perspective to explain land occupation and settlement construction as an adaptation to the surrounding environment for economic exploitation (Herrera, 1985; Groot, 1990; Soto, 2006). These approaches leave out more complex appreciations of social and political organization that could have determined sites' location, the relation between them and their territory. Besides architecture and road infrastructure, agriculture played a predominant role in extensive landscape and ecological transformation, in response to local feeding requirements and commercial exchange with other regions (Giraldo, 2010, 2018). Such research has concentrated almost entirely on two ancient sites on the SNSM, *Ciudad Perdida* (included in this paper) and *Pueblito* (over 30 km away), without the establishment of direct connections between them. Here we address a broader scale in a continuous area, to permit the identification of relations between sites in the upper *Buritaca* River basin.

The results show strong indications that inter-visibility and terrain visibility were both considerations in the establishment of settlements of SNSM. Furthermore, the comparison of scores between existing sites through mapping and scatter plots provides insight into the social roles of specific sites. The largest terraces in the ancient *Tairona* settlements of the upper *Buritaca* River basin are in what appear to be the major ceremonial centres (*Ciudad Perdida* and *Koskunguena*). These locations coincide with the strategic positions of greater inter-visibility with other sites. These two larger towns also had privileged visuals over sizeable portions of the territory, where the indigenous' agriculture fields were most likely located (Fig. 13).

In the studied area, a set of at least 30 pre-Hispanic sites functioned as a system interconnected by visual relations and dominance over the surrounding territory. Agricultural products were harvested for the

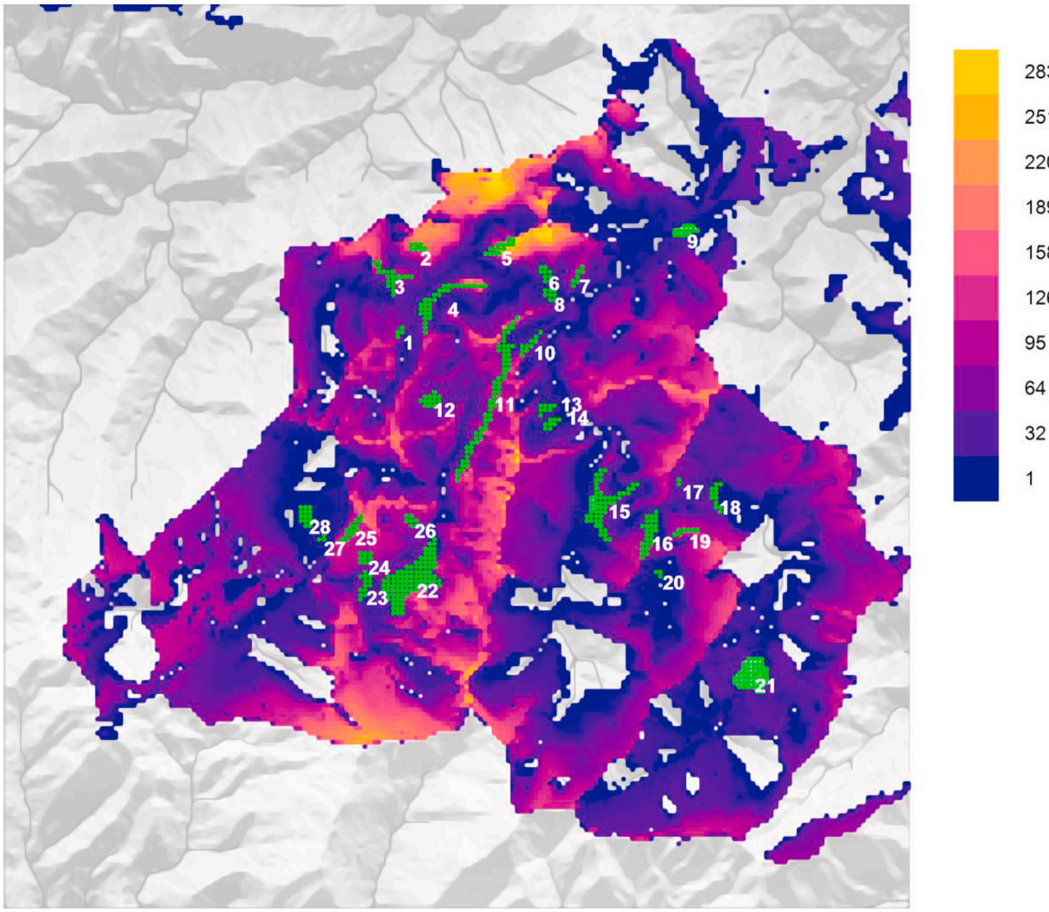

Fig. 10. Map of complete viewshed with visibility scores from the entire settlement (ancient settlements in green).

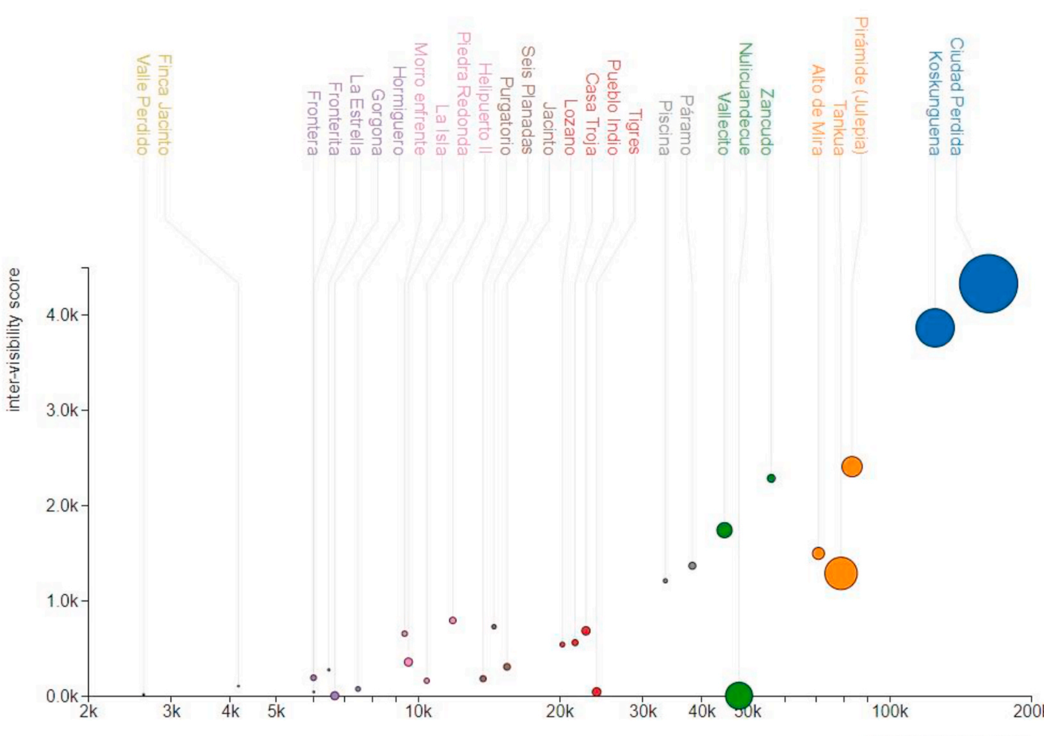

Fig. 11. Scatter graph plotting terrain visibility against inter-visibility of actual settlement.

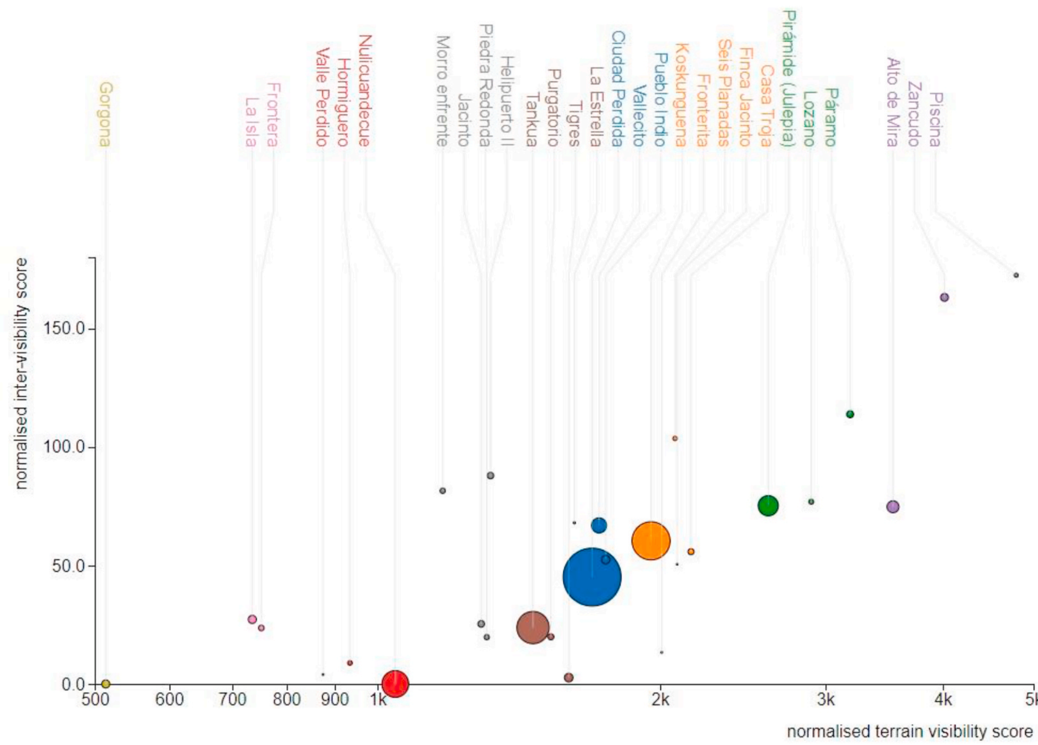

Fig. 12. Scatter graph plotting normalised terrain visibility against normalised inter-visibility of actual settlement.

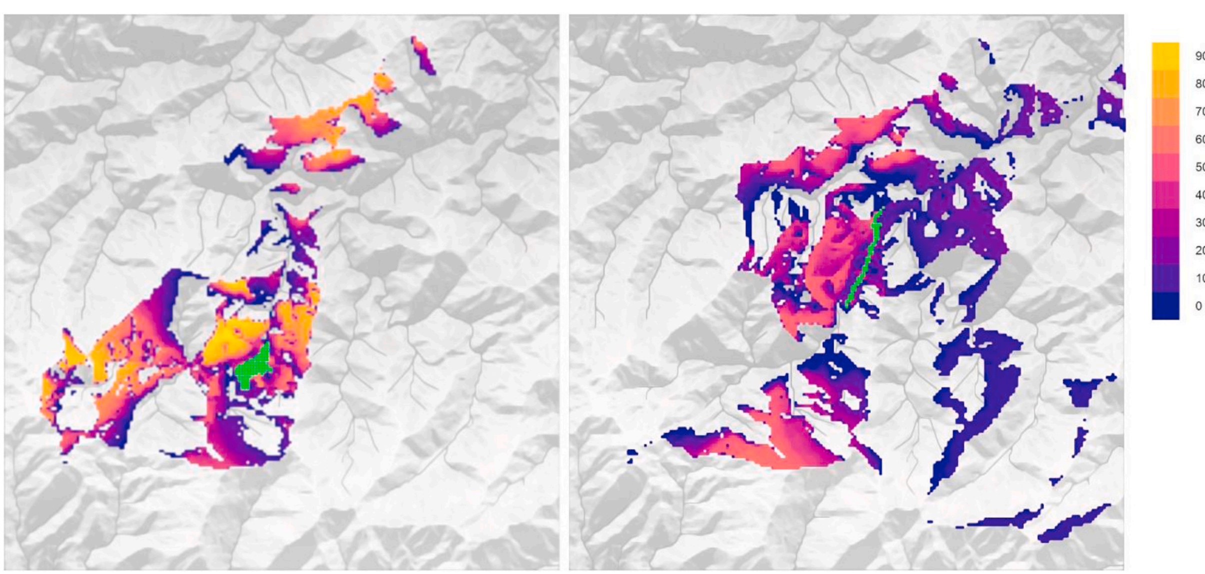

Fig. 13. Terrain visibility viewsheds for Ciudad Perdida (left) and Koskunguena (right).

ḿicro-verticaĺ commercial exchange between villages connected by roads, in diverse ecological zones at opposite ends of the height range (e.g., *Gorgona* at 387 MASL and *Paramo* at 1744 MASL). Besides an economic function, some roads might have had a political significance, when they were part of a network to connect more distant areas. In this case, small peripheral settlements with dominant visuals over neighbouring polities, would strengthen communications in the territory. The methodology described here allows not only the identification of hierarchical relations within a system of settlements, but also an interpretation of possible functions of each type of site and a better understanding of the *Taironaś* complex social organization.

5.2. Methodological advances

The present study makes several methodological advances in the field. The code used for the analysis was developed by the authors, designed specifically for this study and is opensource. Developing custom tools avoided constraints imposed by existing software and this enabled the implementation of novel approaches in the generation of thousands of settlements and the use of an area-based method for visibility analysis. Analysis of results in this study is not dependent on statistical analysis, instead graphical material is provided for visual interpretation.

Analysis in the present study did not depend on commercial or free

Fig. 14. Visual from the central terraces of Koskunguena towards the south. Ciudad Perdida (yellow arrow) is visible in the distance, at 4.8 km. Photograph by E. Mazuera.

software, instead we developed our own set of tools based on the requirements of the experiments. Proprietary software has embedded constraints that can determine methodology, custom software can avoid such limitations dictating how an experiment is undertaken. Our computational development competence freed us from the overhead of learning how to customise a small subset of functionality within complex software. Without the imposed limitations of existing software, we were able to develop new algorithms and tune their performance. Our code is opensource which makes our methodology transparent, inviting scrutiny. This is not the case for visibility studies that depend on proprietary software. Furthermore, an opensource approach is replicable and extendable by others. We would welcome and support the use of our tools in other archaeological locations where viewshed analysis is of interest.

We generated thousands of random settlement configurations that were analysed and compared to the existing settlement. The generation process uses a novel algorithm that combines a biologically inspired growth process with constraints of altitude range, slope and proximity to water source. Permitted values for the constraints were obtained by geospatial analysis of the existing settlement. Our opensource tools could be adapted for other studies with alternative observed geospatial constraints.

Visibility scores for each site within the settlement were generated by representing a single site as a group of points. Each of the points is subjected to a viewshed analysis and each point score contributes to the score of the whole site. Typically, other studies have used a single point to capture a visibility score for a site. Single point analysis is appropriate for study of individual lookout locations but when used for visibility analysis of areas of human settlements may not capture visibility accurately. We believe an area-based approach captures visibility in a dynamic, natural manner. Rather than assume inhabitants of a site would stand in a single location to view their surroundings, our method captures the possibility that local observations are made while going about daily tasks and moving within a site. It is perhaps due to the constraints embedded in commercial software that single point analysis is common. We avoided these constraints by developing custom analytical tools.

In arriving at the findings in this study we chose not to use statistical analysis but instead generated geospatial maps of results and scatter plots. These graphical artefacts were visually examined to arrive at the conclusions. This approach is not dependent on statistical expertise to understand the significance of the results. Instead, this invites the interpretation of the results by any individual that can read a map and scatter plot. This approach provides transparency and accessibility for a wide range of readers in what we consider a multi-disciplinary experiment. Using a common graphical language to convey results enabled a software engineer and archaeologist to communicate and arrive at conclusions in this collaborative project.

5.3. Methodological advances applied to surrounding area

The methodology used in these experiments can be applied in other areas of SNSM for different purposes and to expand the existing knowledge about pre-Hispanic communities. Here, the upper *Buritaca* River basin was taken as an exploration scenario, due to the variety of quantitative data available from the archaeological sites and recent fieldwork carried out to observe this. However, other areas do not have as much information, and the location of the sites is barely known. In these cases, the applied methodology could identify those settlements that are most relevant in terms of visual dominance over other ancient villages and the surrounding territory.

This methodology could be used to identify places with the potential to host sites that are still undiscovered, even in areas where there is no record of archaeological sites. Identifying strategic locations within the territory, by computational means, could be the basis for the search criteria in field work and ground truthing explorations. The strong role of visibility in the location of sites (Fig. 14) suggests future studies should explore an analysis of the visibility graph and how it could represent the performance and relationships of a social network.

6. Conclusions

Recent archaeological research has centred its attention on how ancient societies transformed their environment, not only in an attempt to adapt for survival and economic reasons, but furthermore to build social organization and relationships with surrounding territory. Inter-visibility and cumulative viewshed analysis can serve as arguments for such explanations. In doing so, inhabited space can be characterized and differentiated to reveal the possible significance of settlements' locations (Kosiba and Bauer, 2013; Jones, 2006; Llobera, 2003).

This study demonstrates that inter-visibility and cumulative viewsheds can provide a deeper understanding of a culture that no longer exists. Viewshed analysis in the SNSM provides insight into the relationship between the Tairona people and their environment. Using simple examination of viewshed results our experiment shows that the ability to see the surrounding area and see neighbours by direct line of sight was important to the Tairona. This study shows that advantageous overview of the both the inhabited and uninhabited environment was an important part of the decision-making process when selecting sites for inhabitation. Furthermore, variations in visibility score characteristics offer a new way of examining current assumptions relating to the social hierarchy and roles of individual sites in a community.

The methodology used is independent of the constraints of software typically used to undertake viewshed analysis. Informed by the requirements of the study a new set of custom tools were developed. This unconstrained approach enabled the implementation of novel algorithms that efficiently generated aleatory sites with similar characteristics to those observed in the existing settlement. Settlements were scored for inter and terrain visibility using a variant of the standard cumulative viewshed analysis developed specifically for the task. Developing the software needed for the experiment gave us full control of input data, the processing of it and the choice of format for output. This transparent workflow provided the authors with greater confidence in the experiment that is unobtainable when using standard software that obscures the inner procedures.

The methods and the findings from this study contribute directly to a global archaeological interest in visual connectivity within ancient communities. The tools developed are opensource and extendible for others seeking to apply a similar viewshed based approach to gain deeper understanding of historic inhabitation in other geographical contexts. Results from this study provide an example of importance of line-of-sight to determine spatial relations and inform social order.

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Declaration of competing interest

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