

THANK YOU!

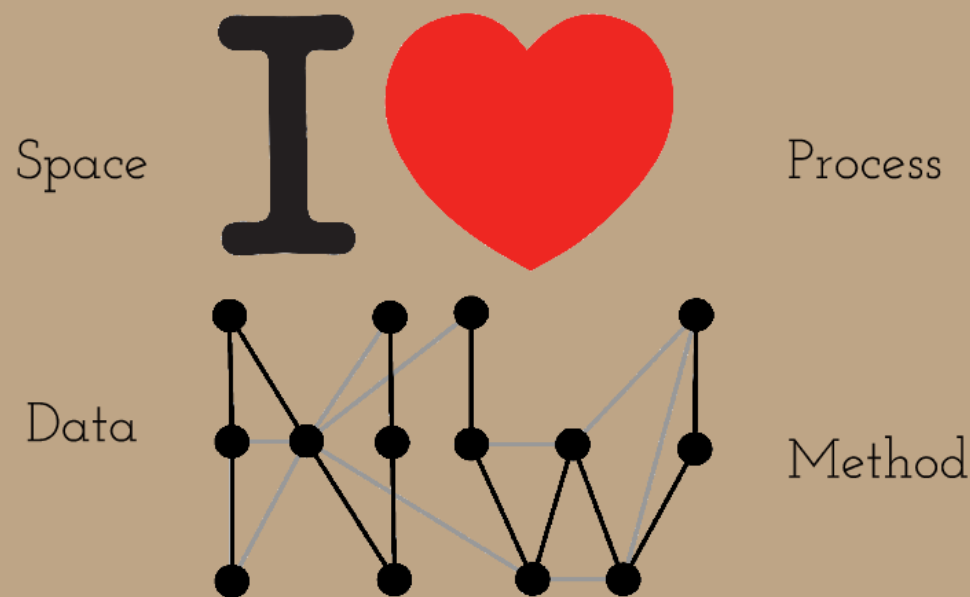
<http://connectedpast.soton.ac.uk/>
<http://archaeologicalnetworks.wordpress.com/>

Acknowledgements

Prof. Simon Keay - Dr. Graeme Earl - Prof. Claire Lemesurier - the networks network - AHRC - Dr. David Wheatley - Cat Cooper - Dr. Leif Isachsen - University of Southampton - Departamento de Prehistoria y Arqueología de la Universidad de Sevilla - Delegación Provincial de Sevilla de la Consejería de Cultura de la Junta de Andalucía - Intención Andalus de Patrimonio Histórico - Prof. Antonio Coballos Rufino - Dr. Víctor Hualado Peña - Profesora Fátima Chaves Tristán - Sr. José Manuel Rodríguez Hidalgo - Dr. José Beltrán Fortes - Dr. Fernando Anantes Carredano - Iza Romanovska - The Connected Past - Mathematics of Networks

Exploring visibility networks in Iron Age and Roman Southern Spain with Exponential Random Graph Models (ERGM)

Tom Brughmans, Simon Keay, Graeme Earl
Archaeological Computing Research Group
University of Southampton



Knappett, C. 2011. An archaeology of interaction: network perspectives on material culture and society. Oxford: Oxford University Press.
Brughmans, T. 2013. Thinking through networks: A Review of Formal Network Methods in Archaeology. Journal of Archaeological Method and Theory.

Mathematics of Networks, Southampton, 7 June 2013

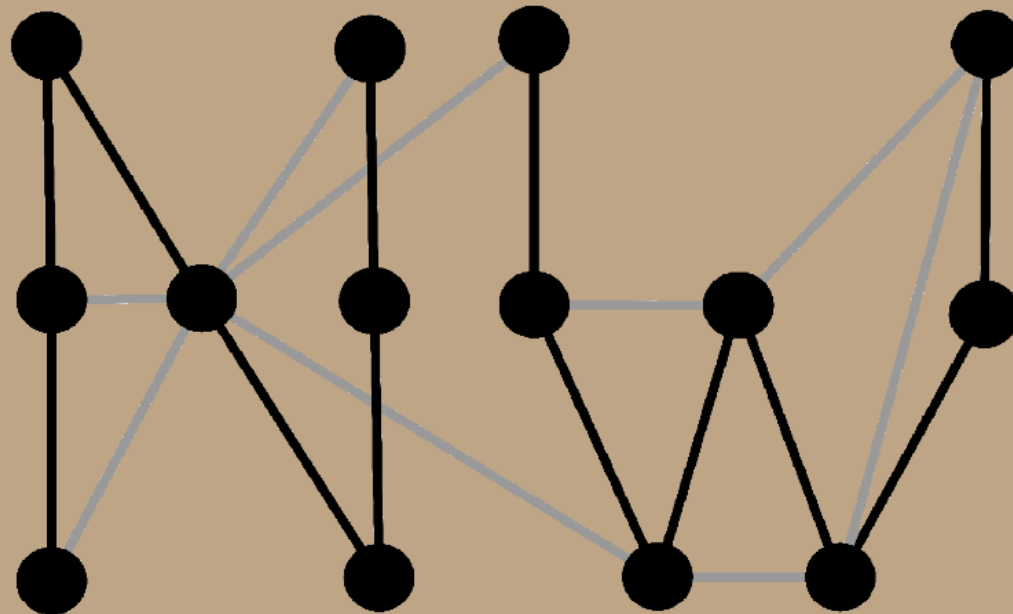
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Space



Process

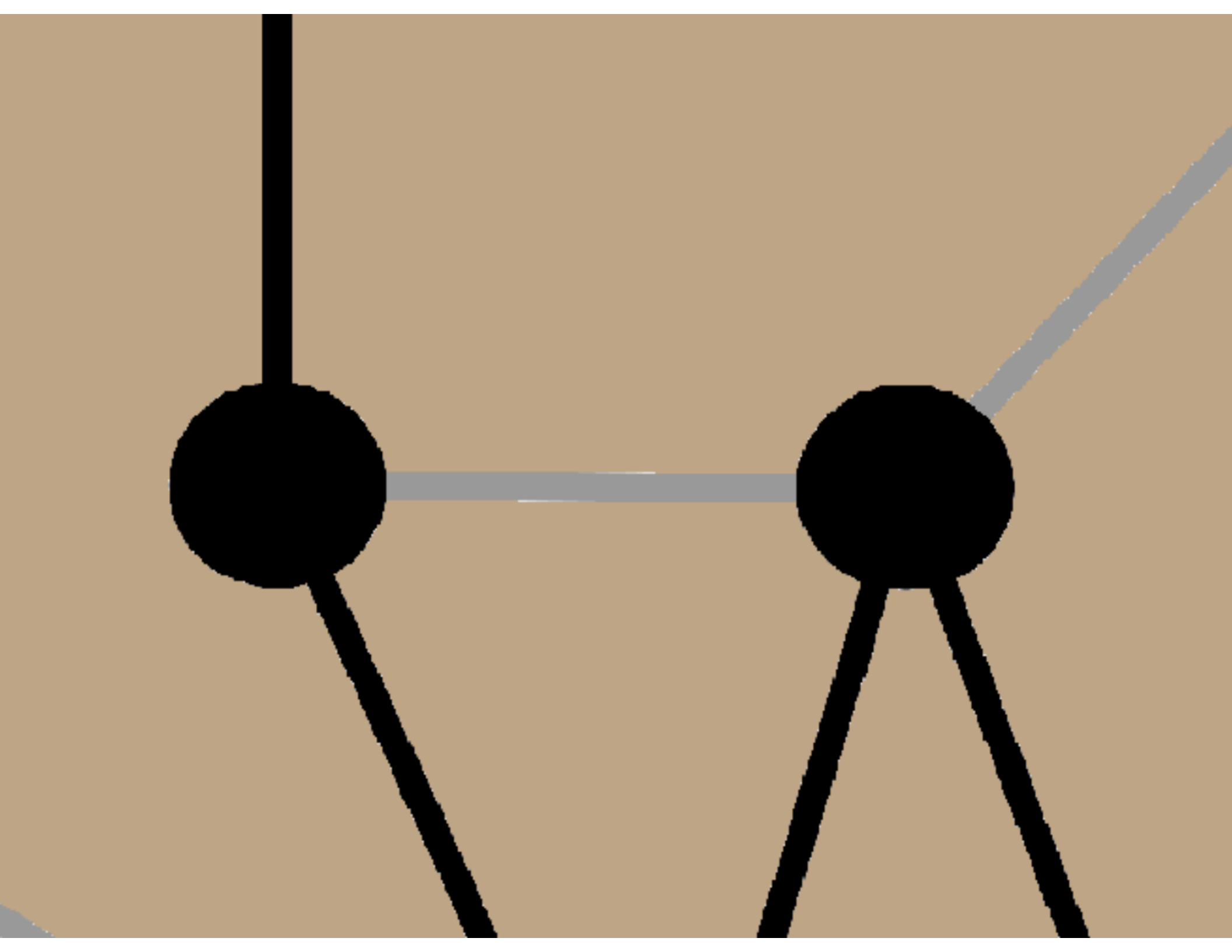
Data



Method

Knappett, C. 2011. An archaeology of interaction: network perspectives on material culture and society. Oxford: Oxford University Press.

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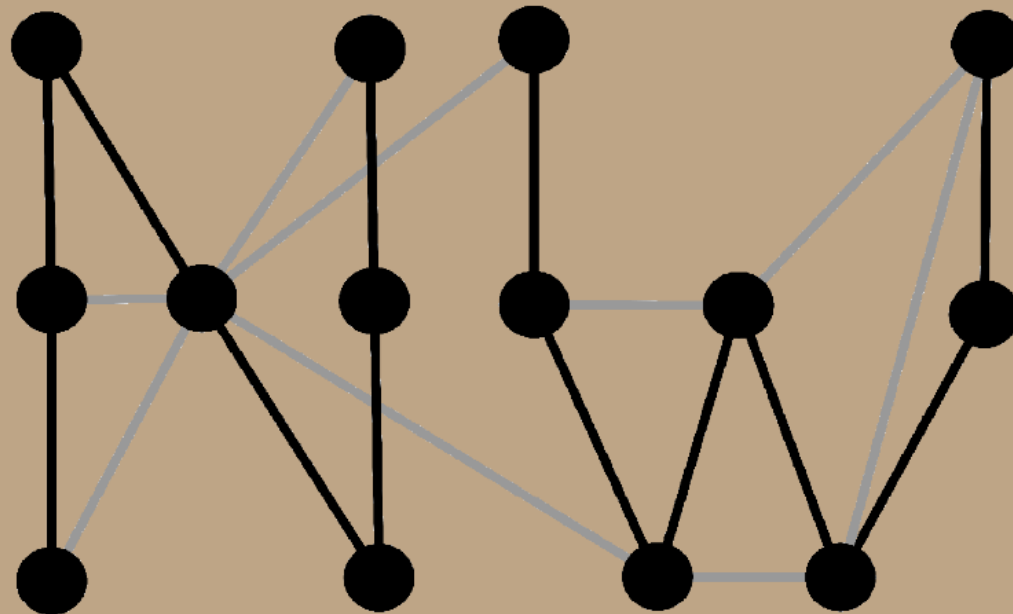


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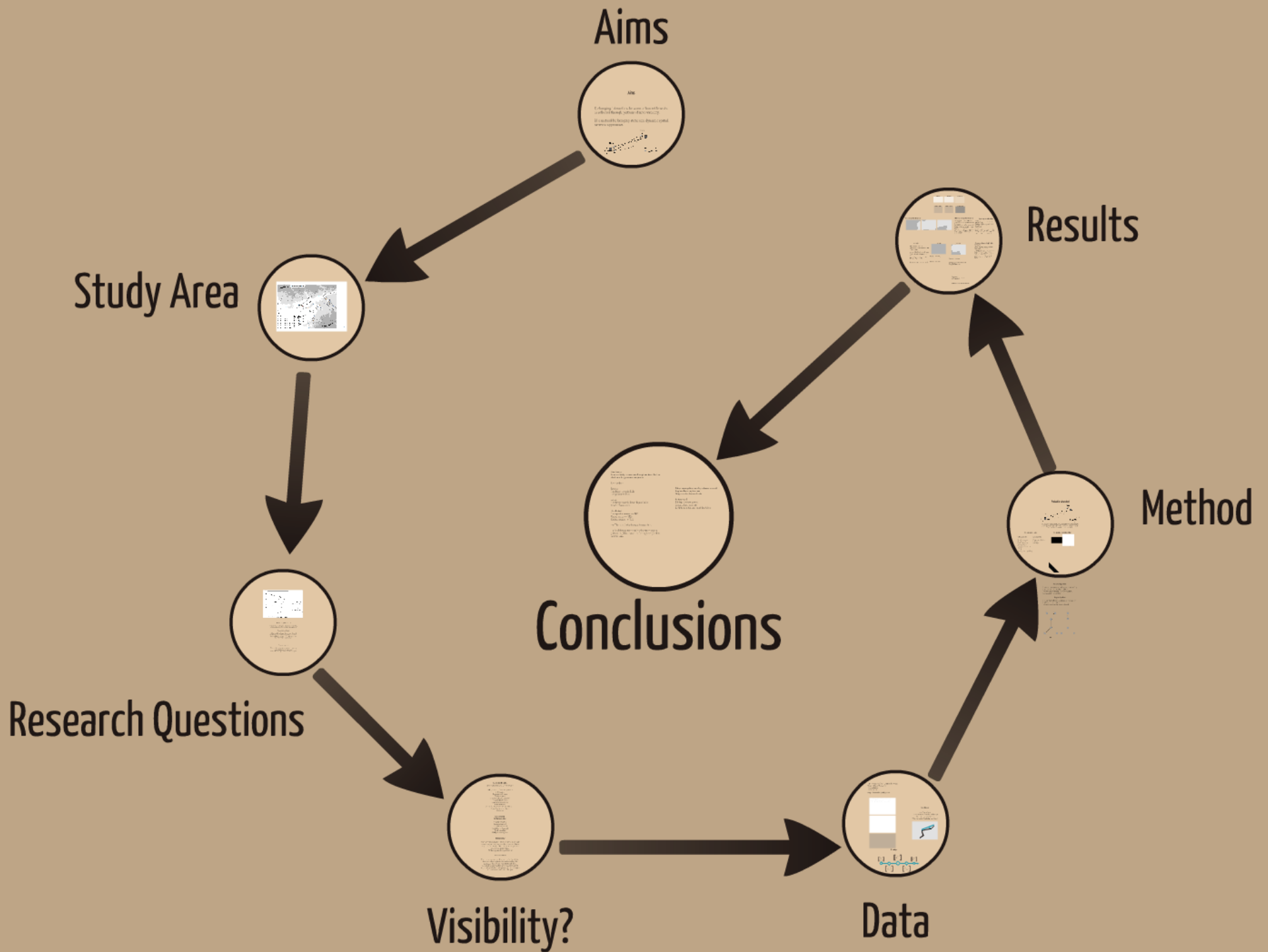
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Aims

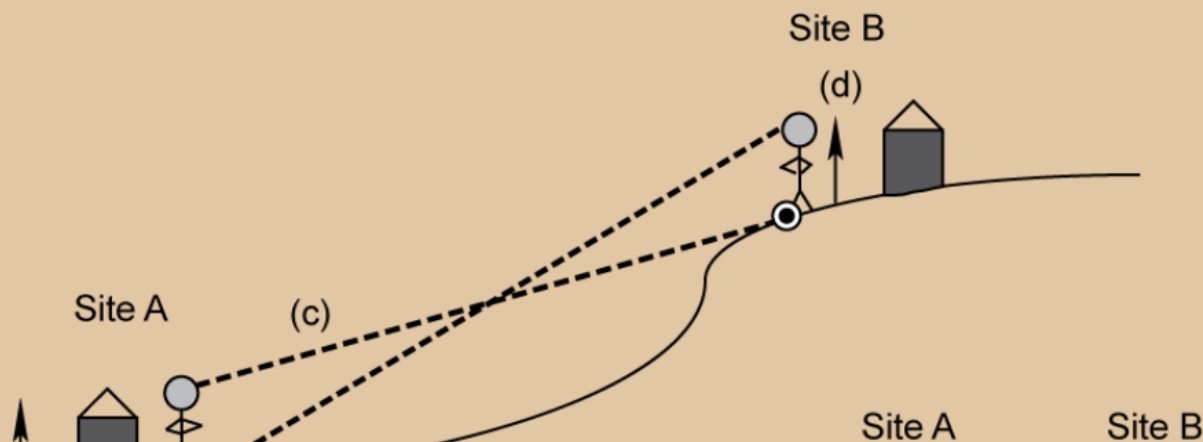
Aims

- 1) changing interactions between urban settlements, as reflected through patterns of inter-visibility.
- 2) a method for bridging static and dynamic spatial network approaches.

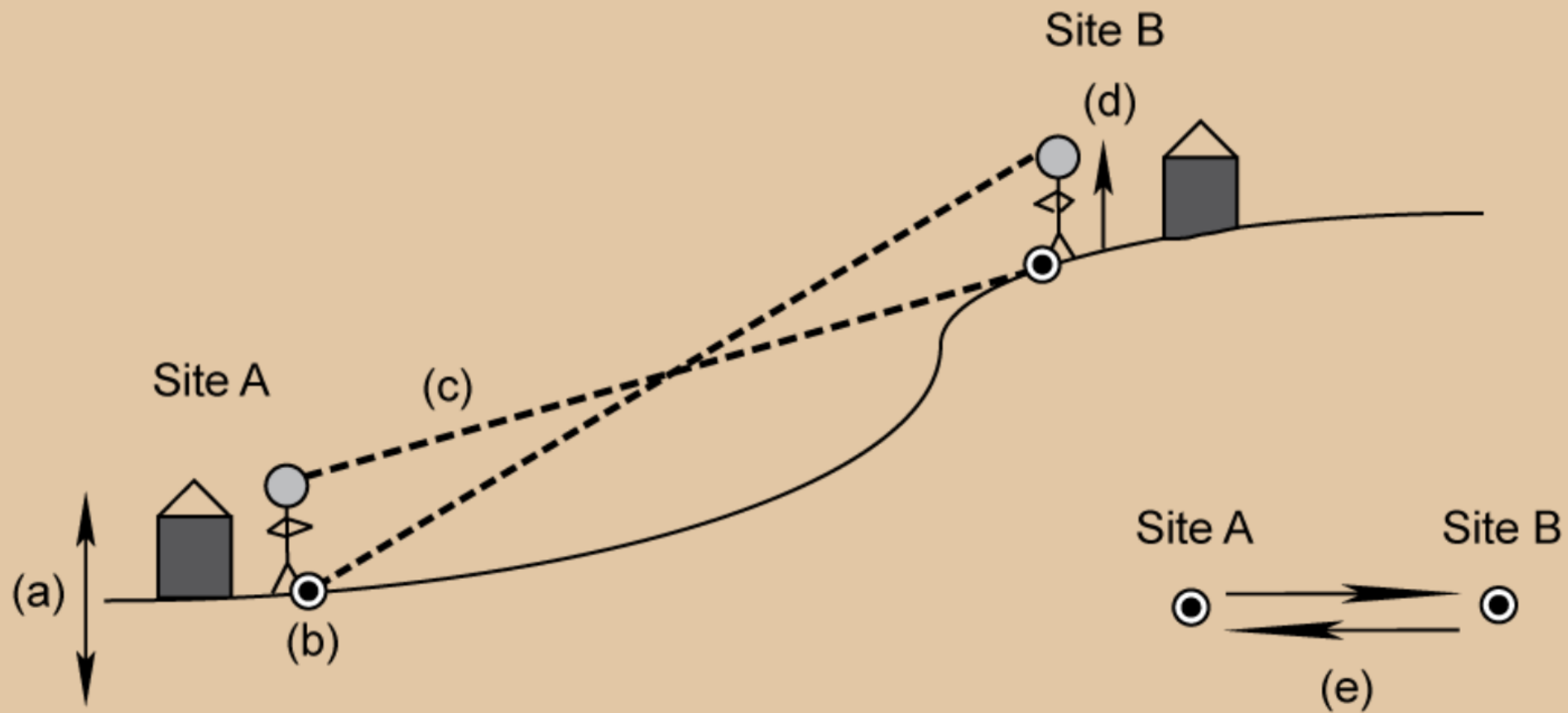


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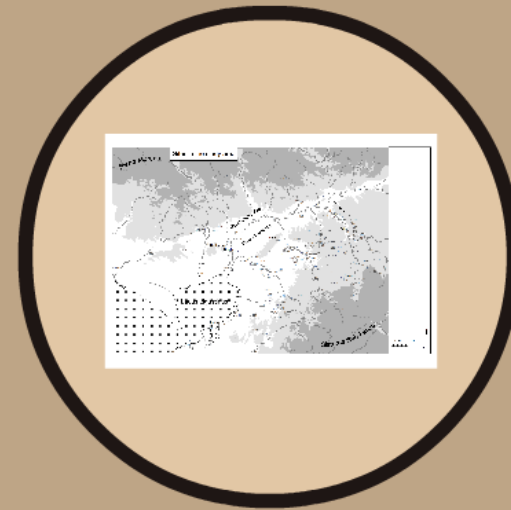
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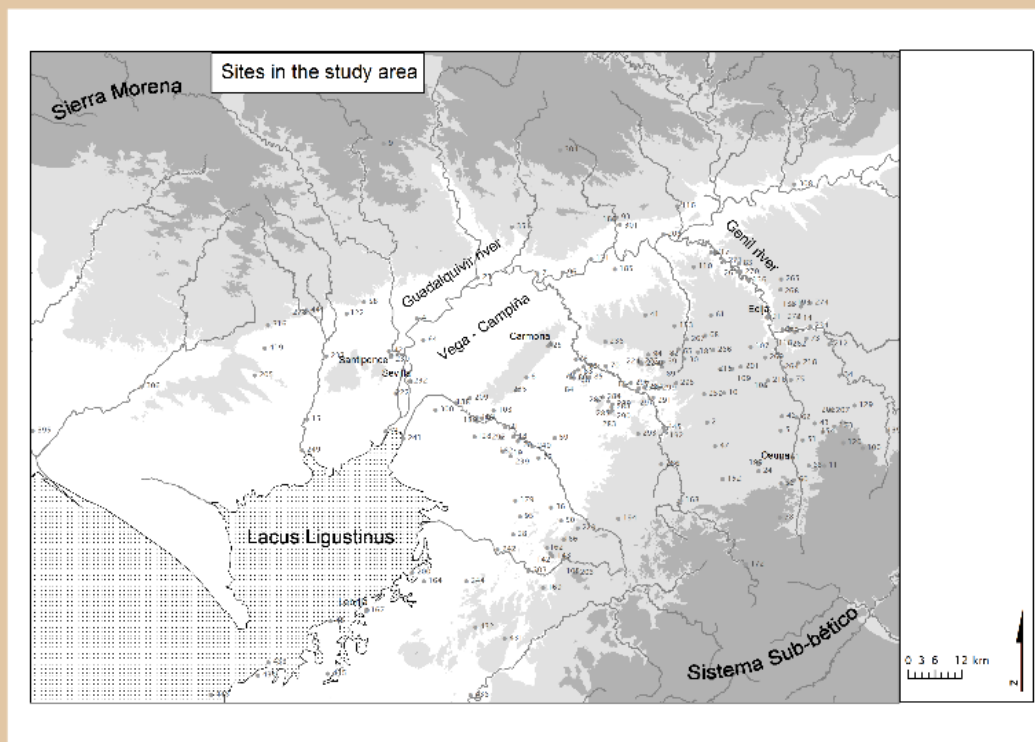
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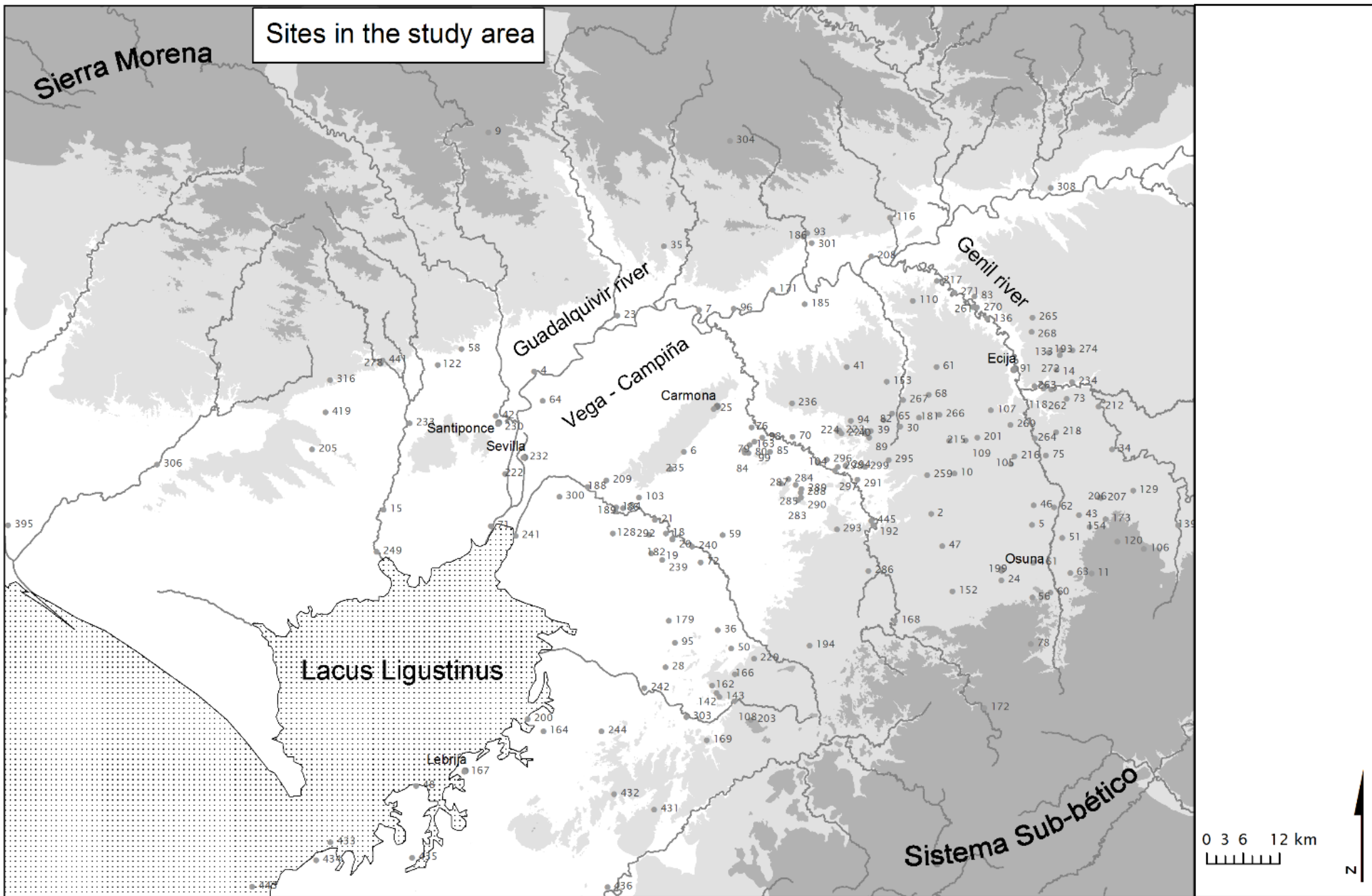
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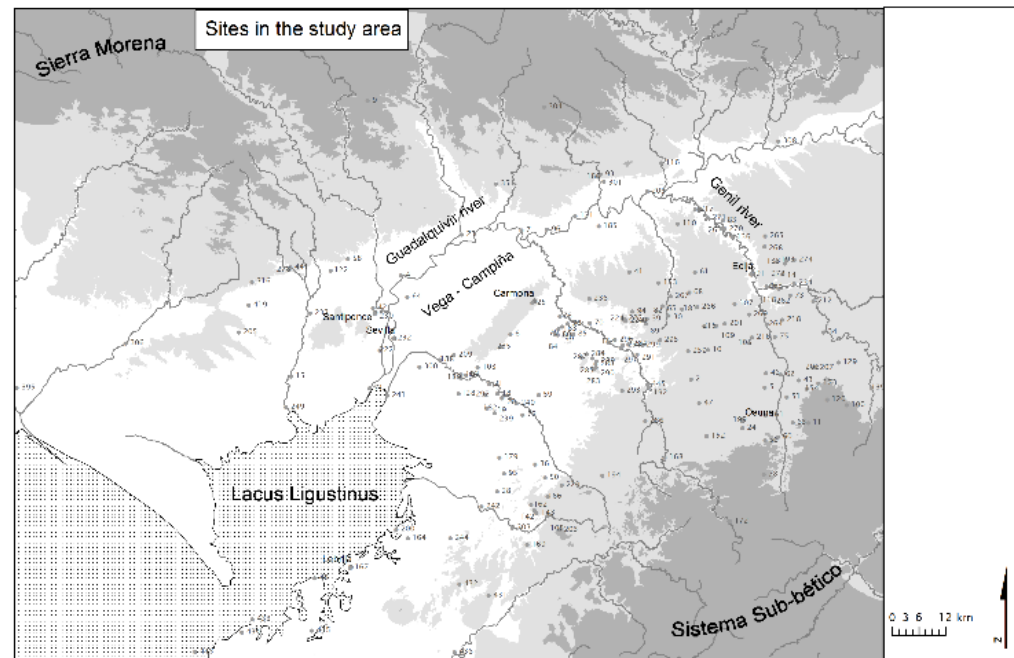


Study Area

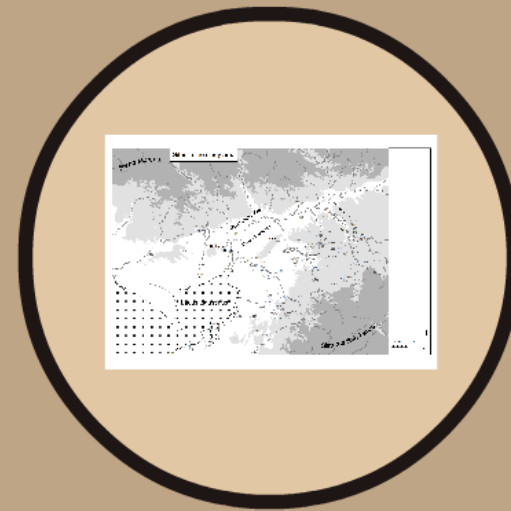


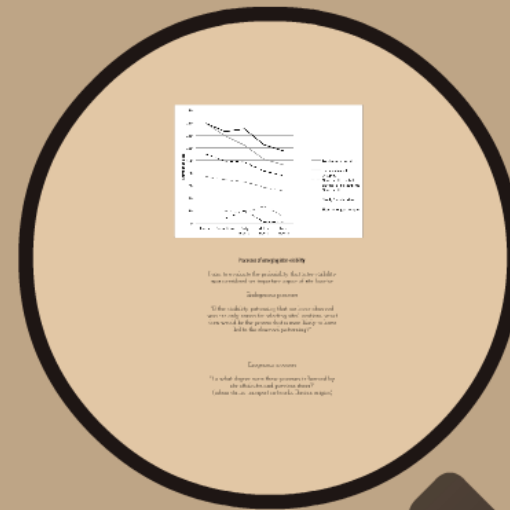




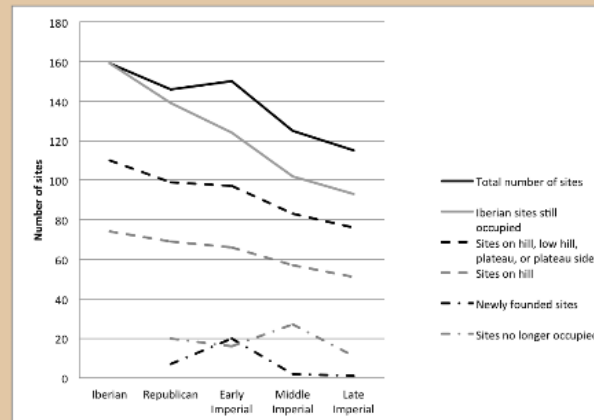


Study Area





Research Questions



Processes of emerging inter-visibility

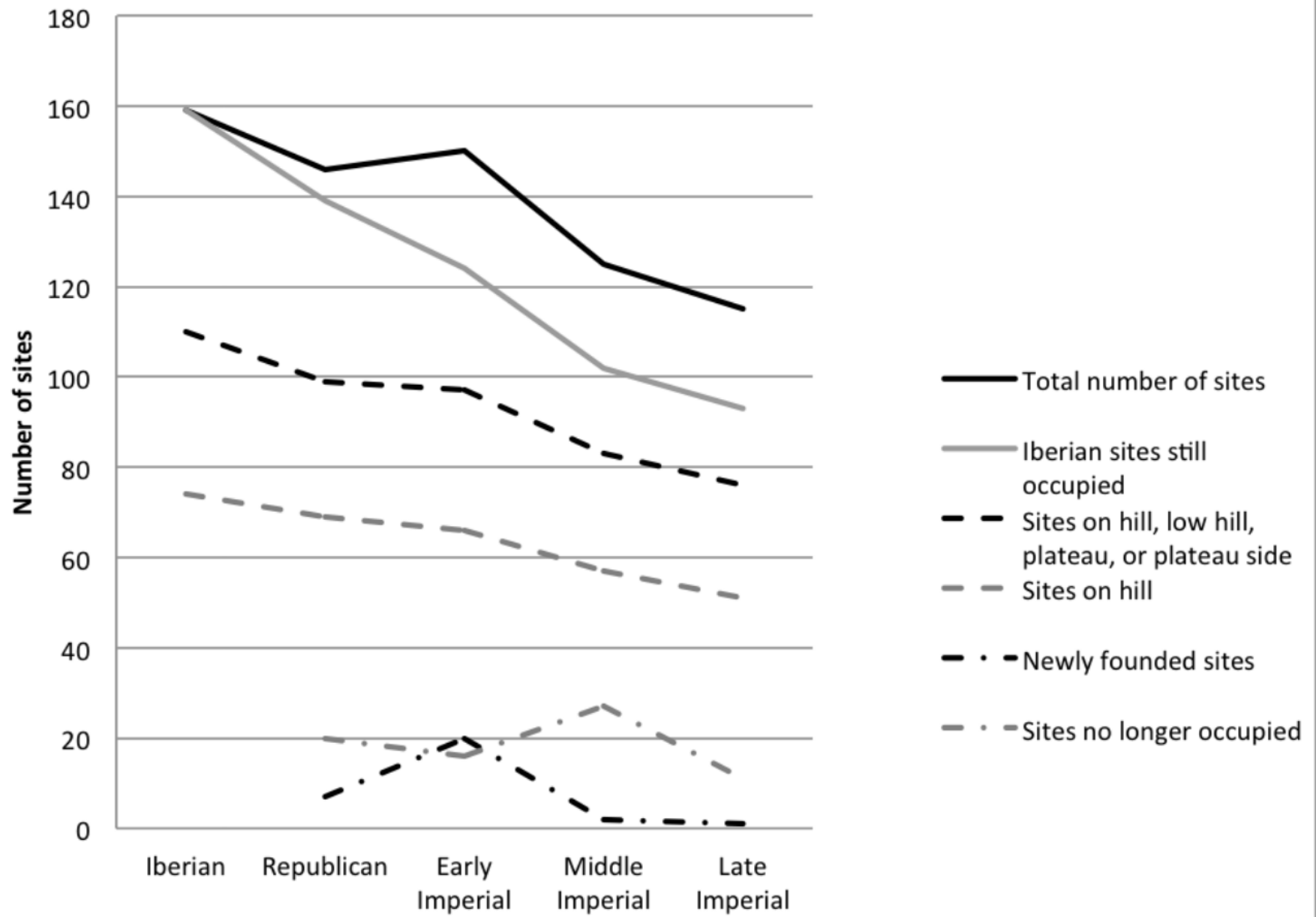
I aim to evaluate the probability that inter-visibility was considered an important aspect of site location

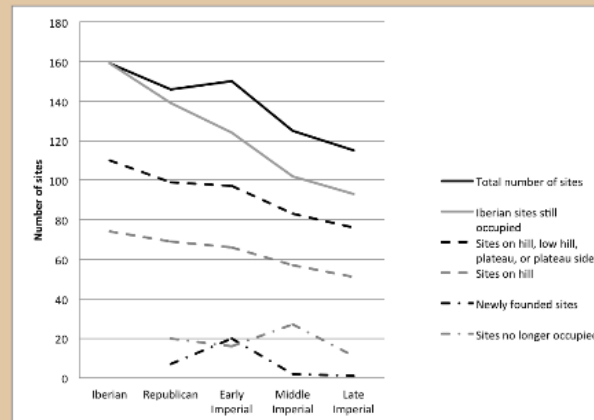
Endogenous processes

"If the visibility patterning that we have observed was the only reason for selecting sites' locations, what then would be the process that is most likely to have led to the observed patterning?"

Exogenous processes

"To what degree were these processes influenced by site attributes and previous states?"
(urban status, transport networks, Iberian origins)





Processes of emerging inter-visibility

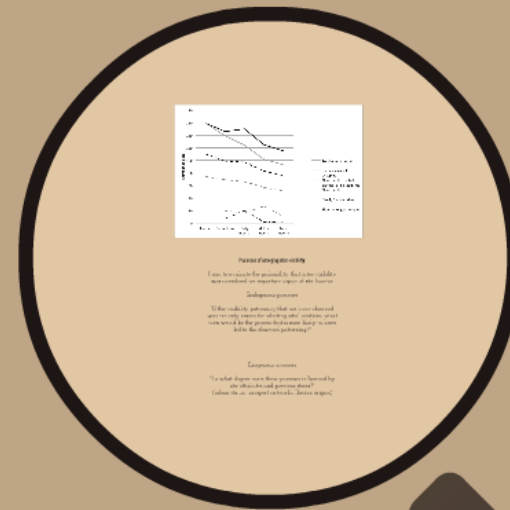
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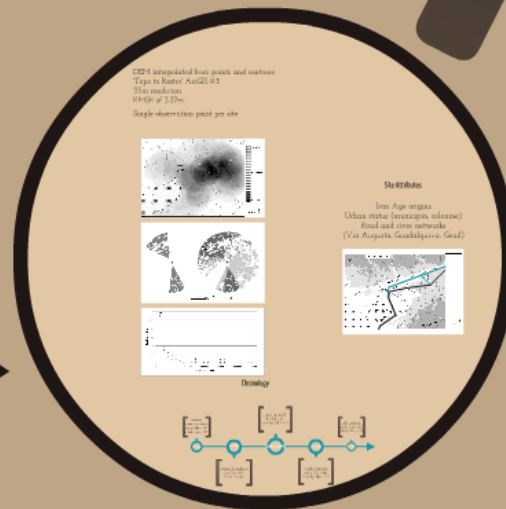


Research Questions

ns

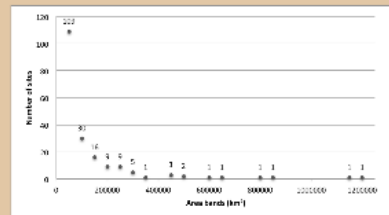
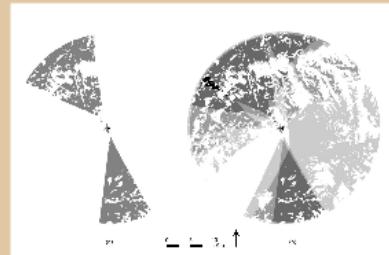
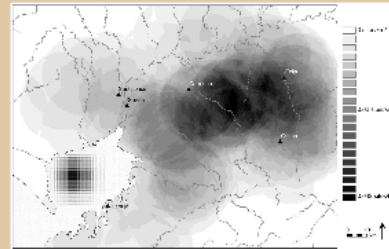


Visibility?



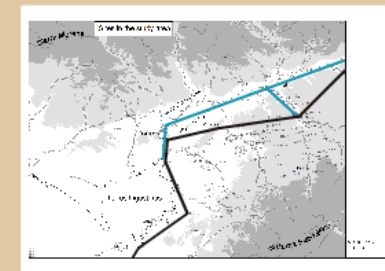
Data

DEM interpolated from points and contours
 'Topo to Raster' ArcGIS 9.3
 35m resolution
 RMSE of 3.37m
 Single observation point per site

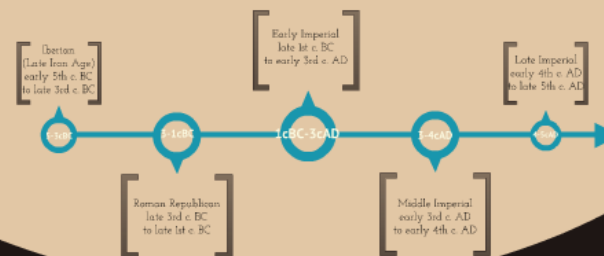


Site Attributes

Iron Age origins
 Urban status (municipia, coloniae)
 Road and river networks
 (Via Augusta, Guadalquivir, Genil)



Chronology

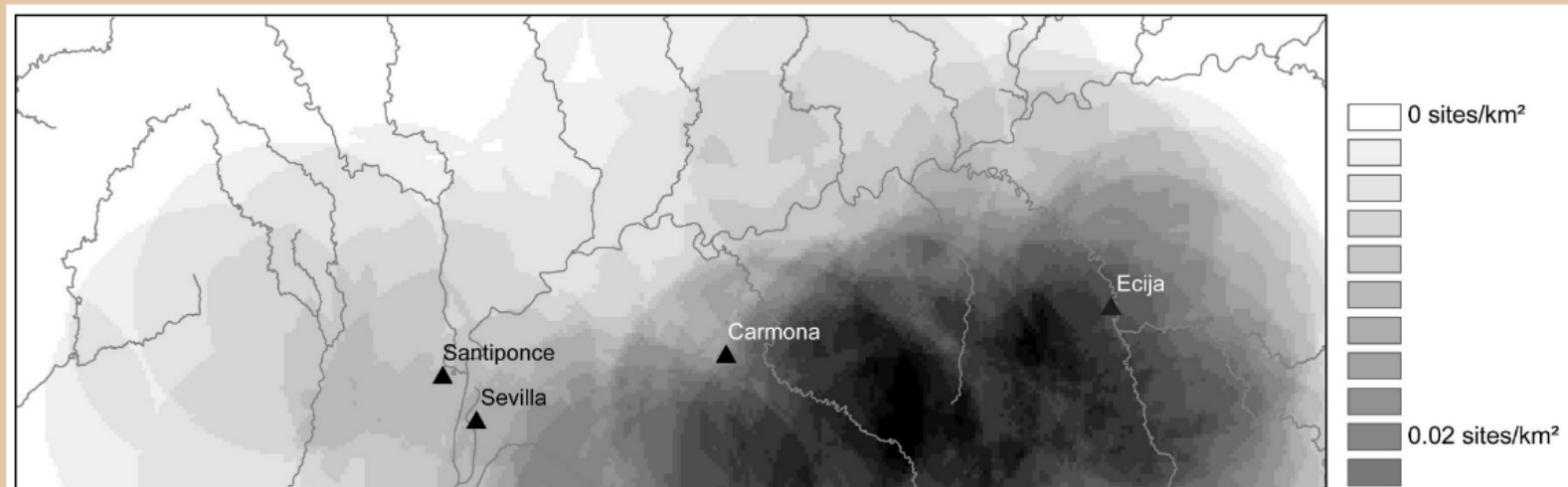


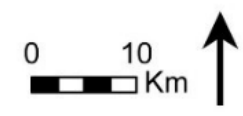
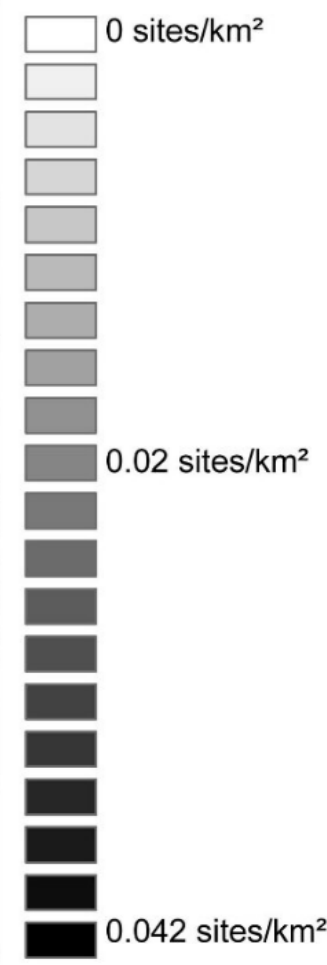
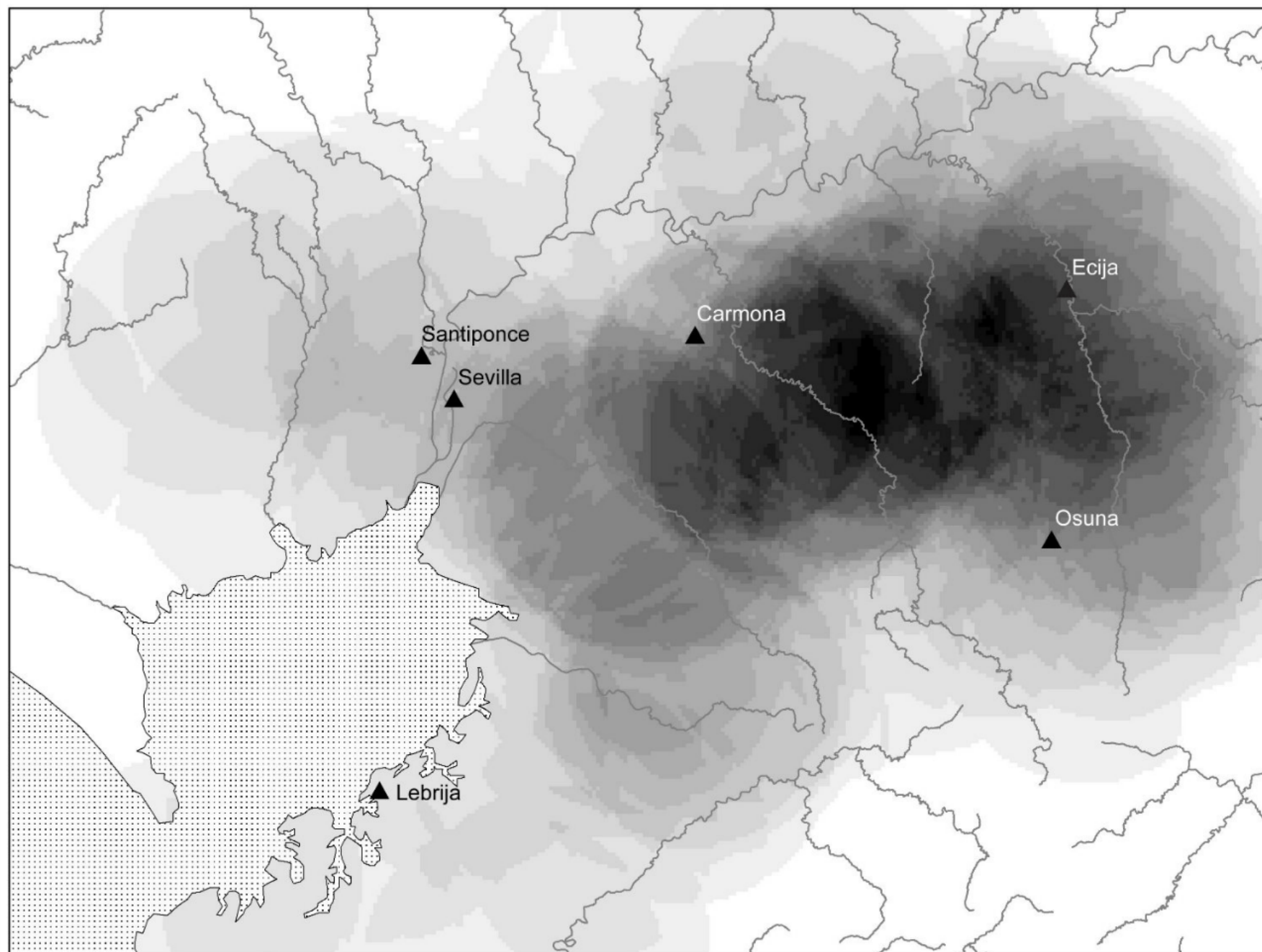
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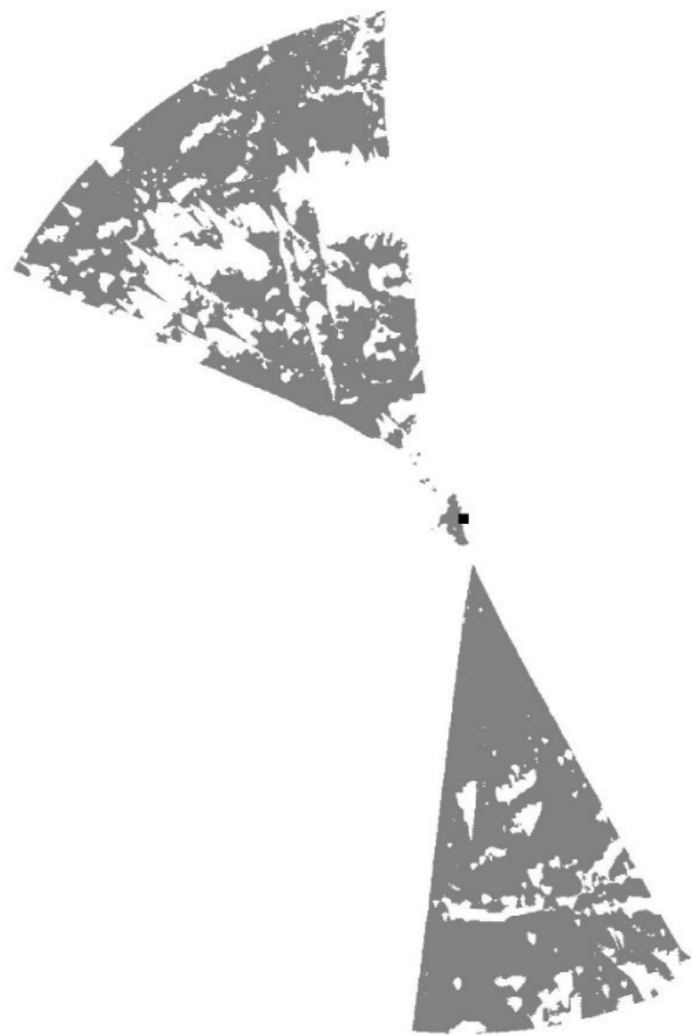
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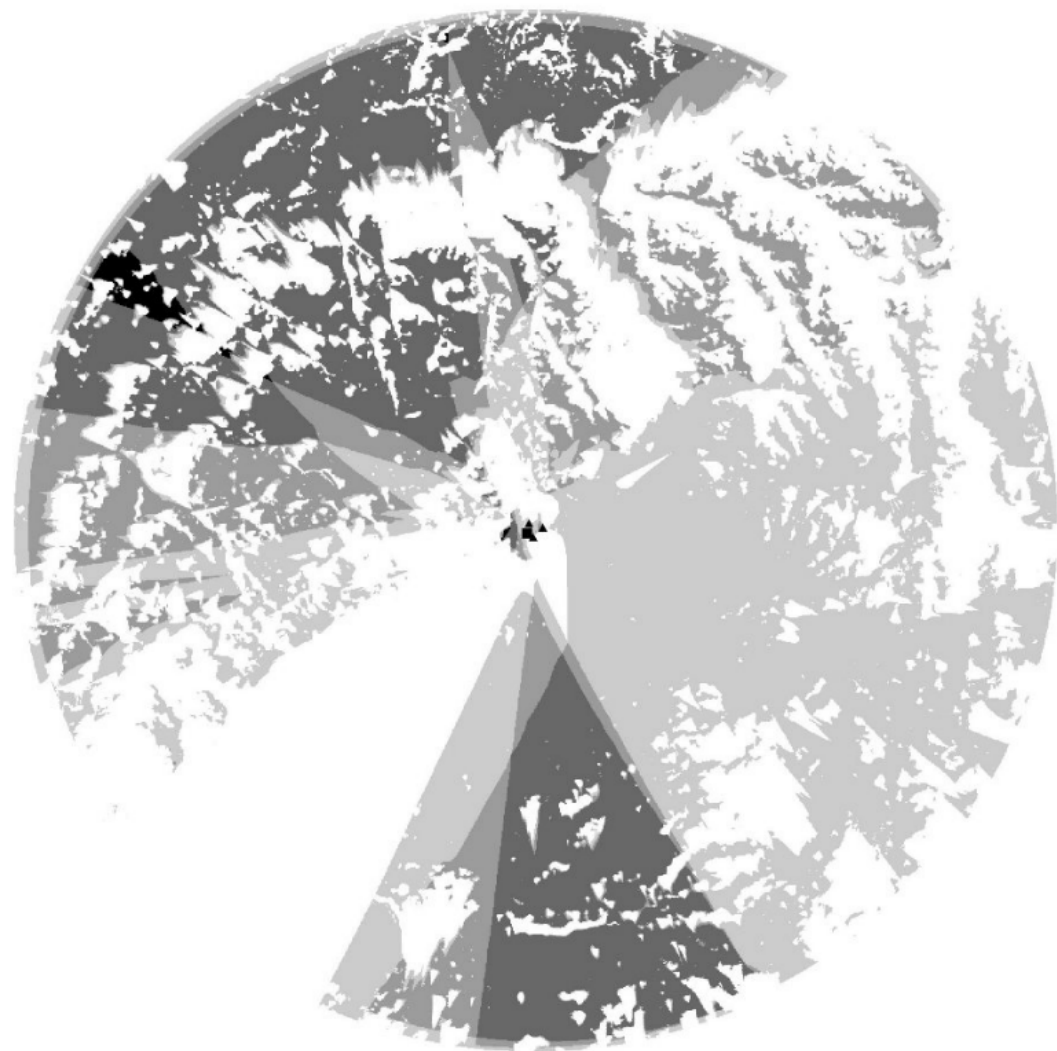






(a)

0 5 10 Km



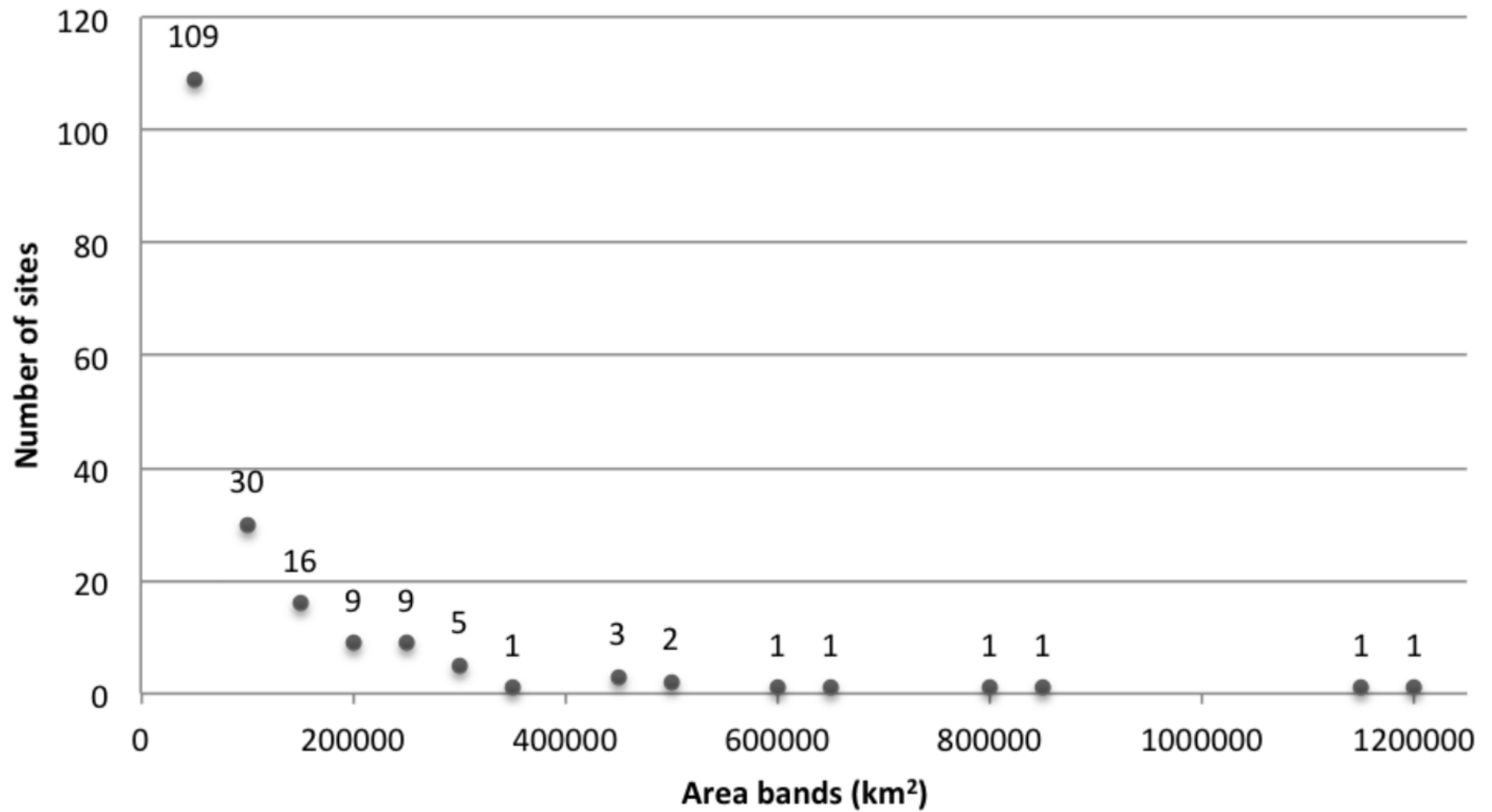
(b)

(a)

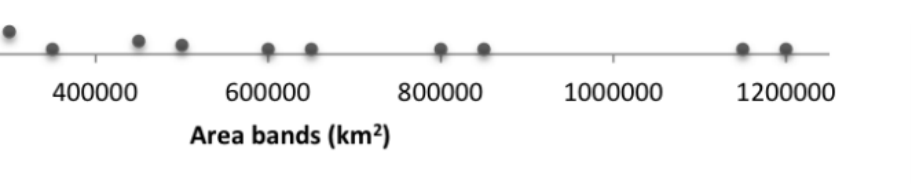
0 5 10 Km



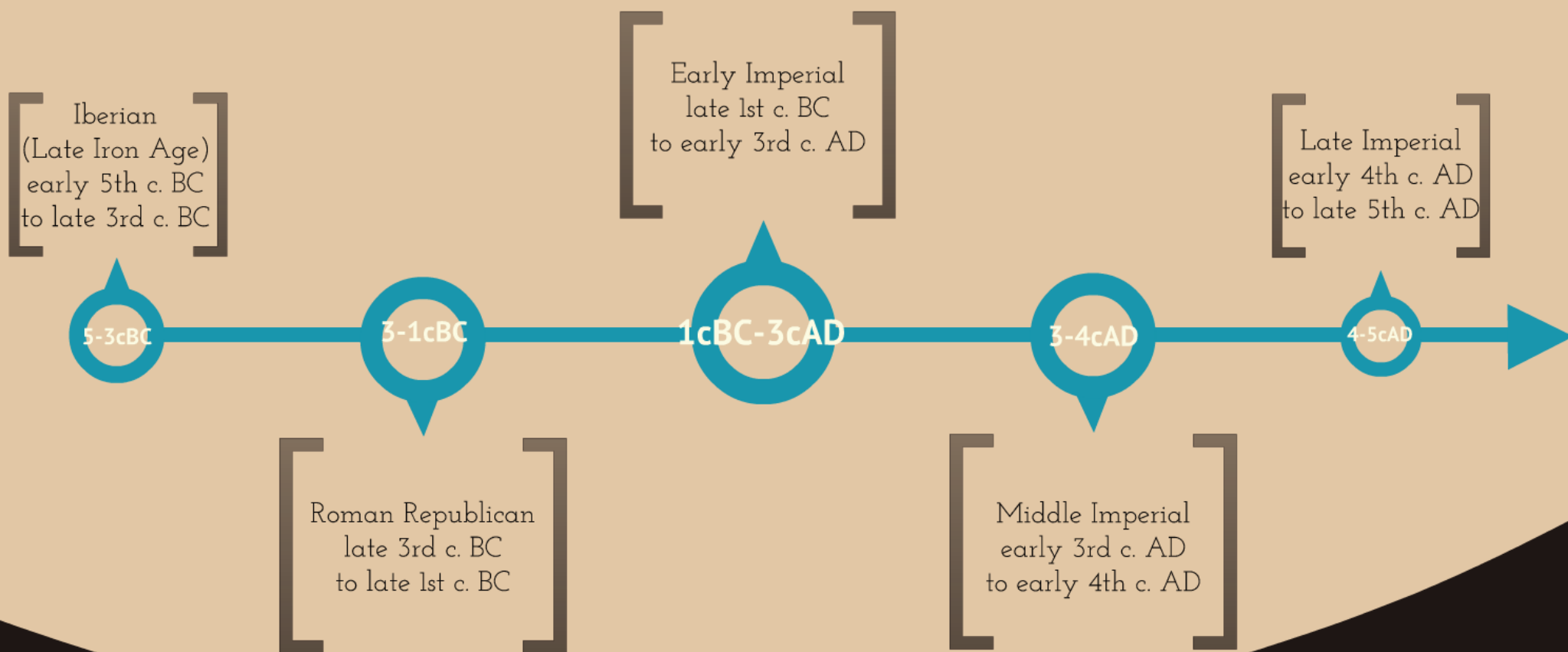
(b)



Chronolog



Chronology



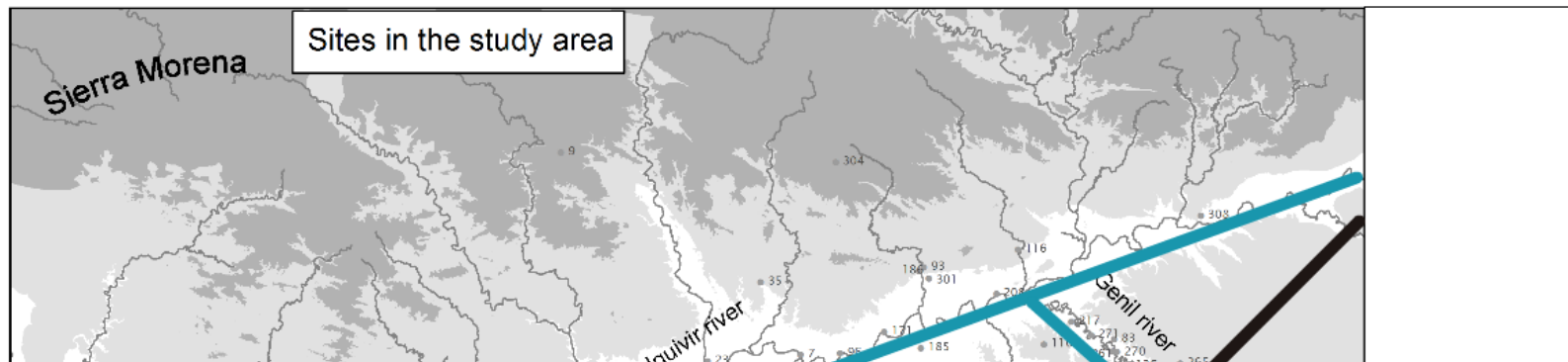
Site Attributes

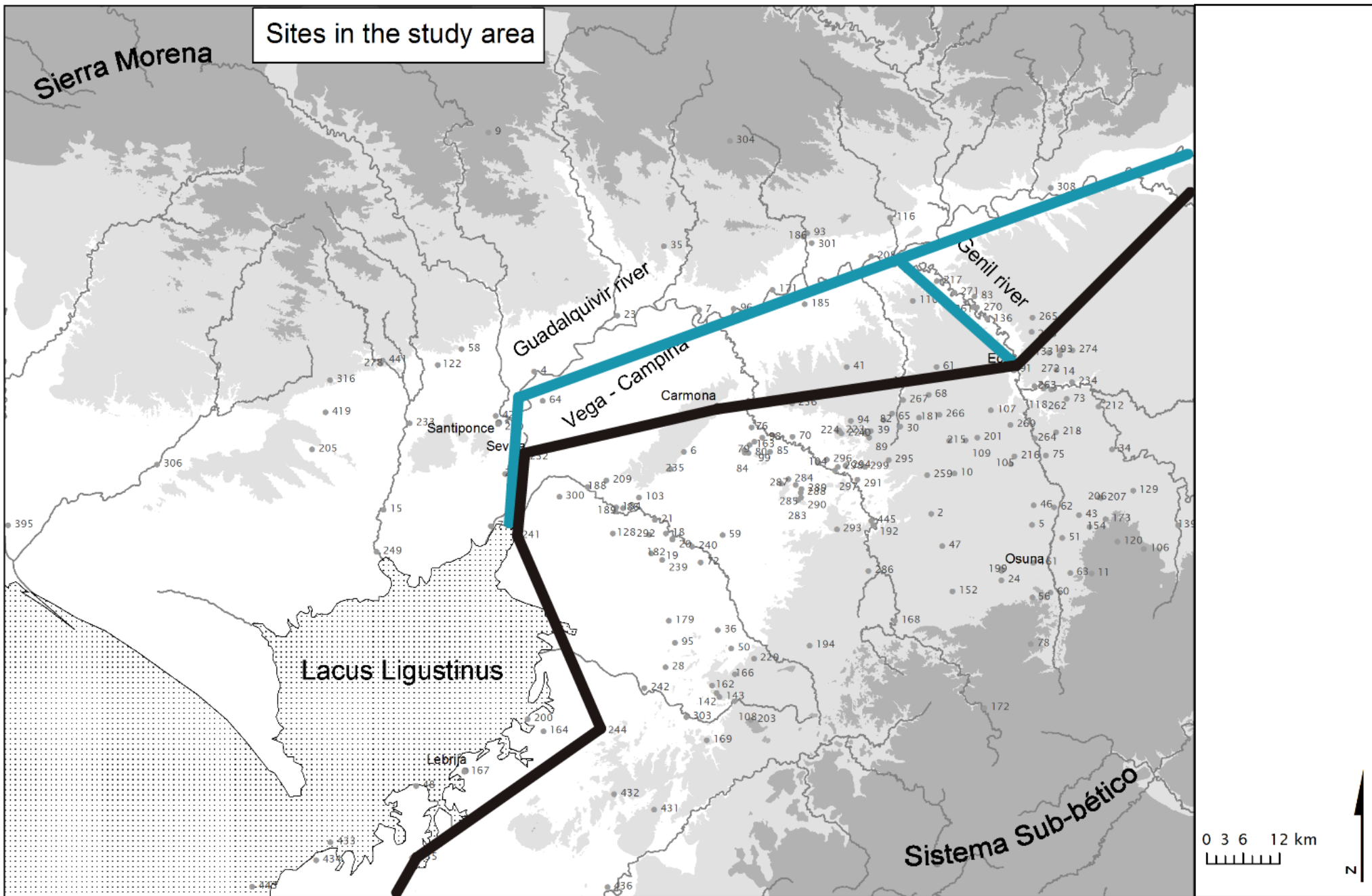
Iron Age origins

Urban status (municipia, coloniae)

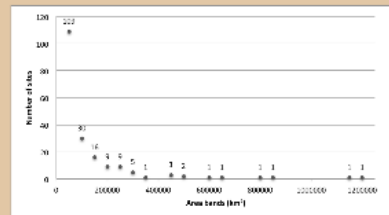
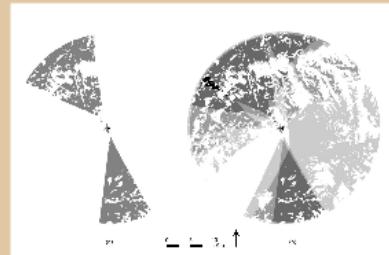
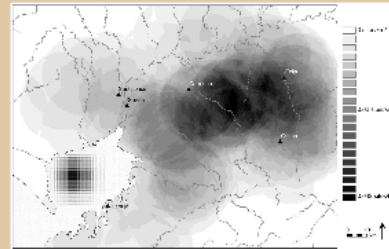
Road and river networks

(Via Augusta, Guadalquivir, Genil)



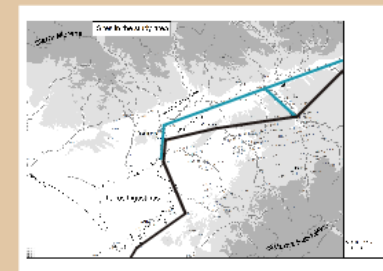


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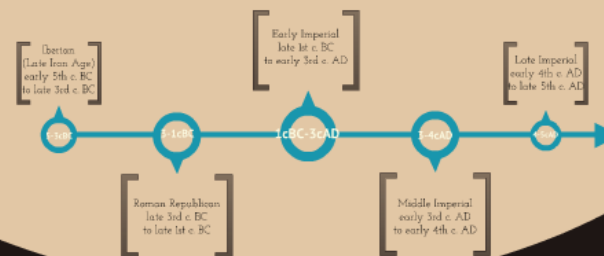


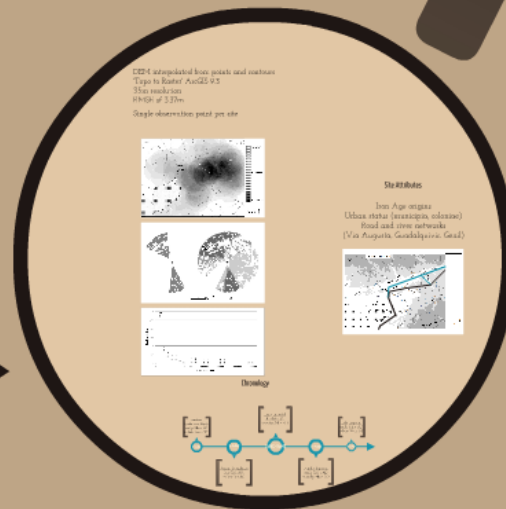
Site Attributes

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Chronology





Data

Method



Indigenous hypotheses

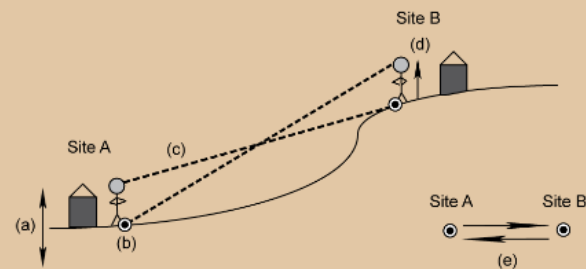
- (1) conceptually or methodologically → into validity
- (2) visual method → no going back
- (3) visually presented → increasing time
- (4) variable → not a rise

Indigenous hypotheses

- (1) time / age reflects mechanism in perception
- (2) time / age reflects
- (3) time / age reflects



Probable viewshed



(a) random error in probable viewshed = 5m; (b) observer point site A and target point for observer site B; (c) line-of-sight with probability p_a from observer A to target point site B; (d) observer height = 17m; (e) inter-visibility network where site A is connected to site B with probability p_a and site B is connected to site A with probability p_b .

Exploratory network analysis

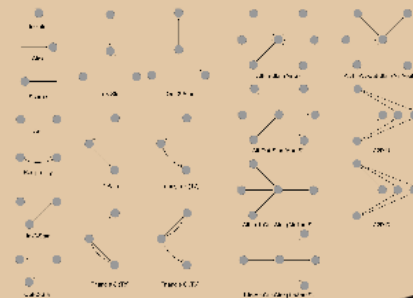
Global measures:

Number of nodes
Number of arcs
Clustering coefficient
Average degree
Connected components
Diameter
Density
Average shortest path length

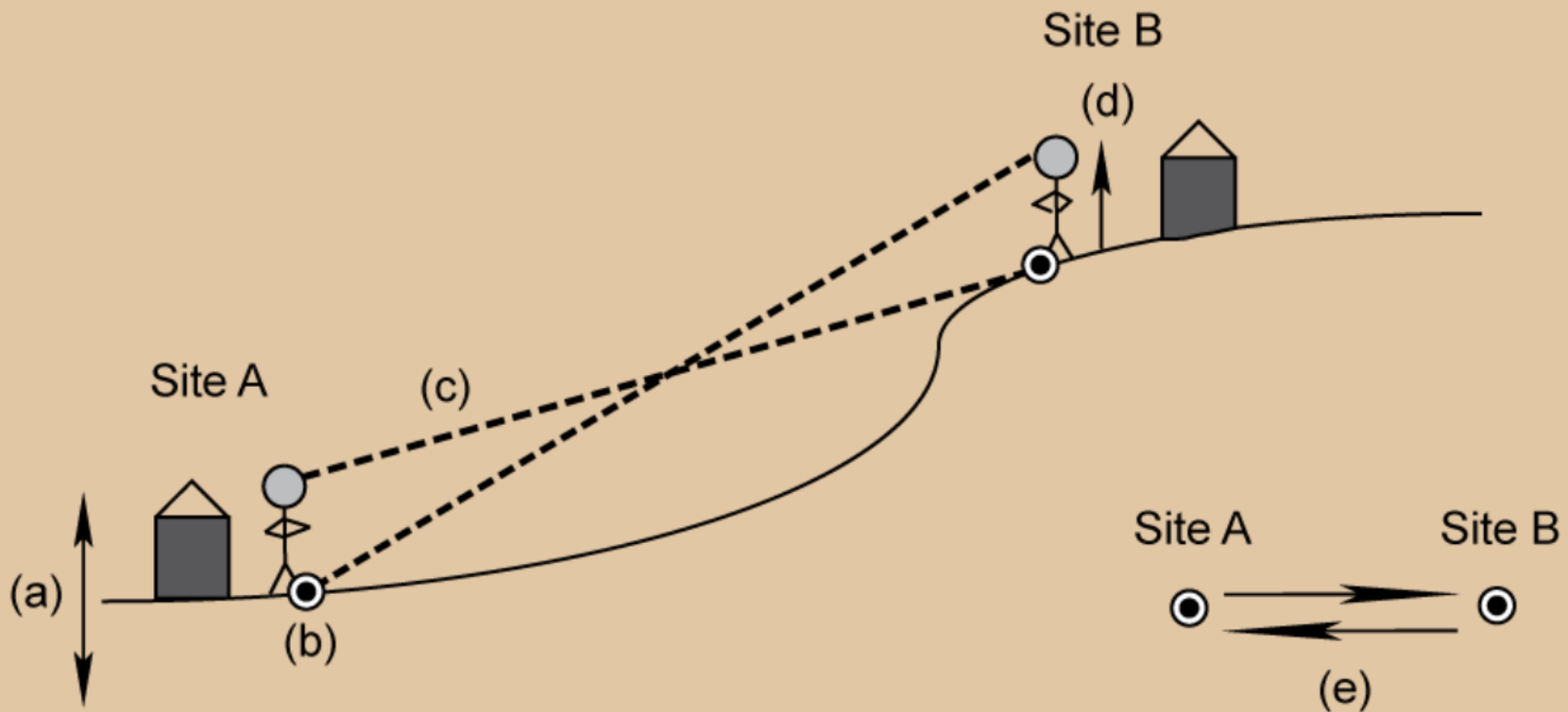
Local measures:

Clustering coefficient
Indegree
Outdegree

Exponential Random Graph Models (ERGMs)



Probable viewshed



(a) random error in probable viewshed = 5m; (b) observer point site A and target point for observer site B; (c) line-of-sight with probability p_a from observer A to target point site B; (d) observer height = 1.7m; (e) inter-visibility network where site A is connected to site B with probability p_a and site B is connected to site A with probability p_b .

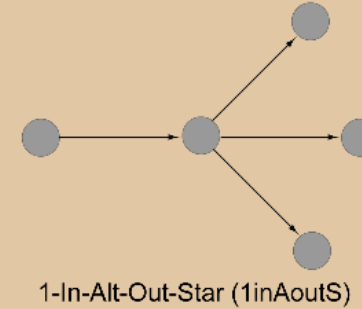
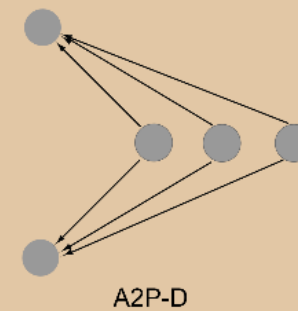
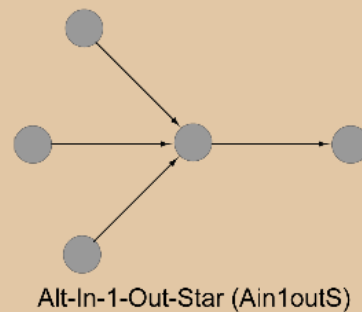
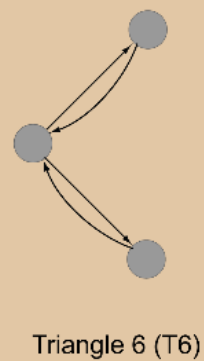
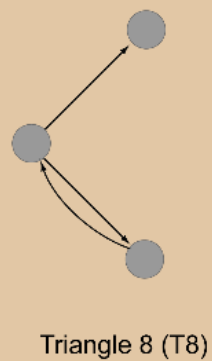
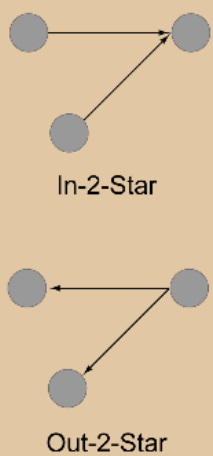
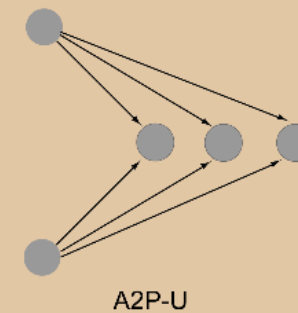
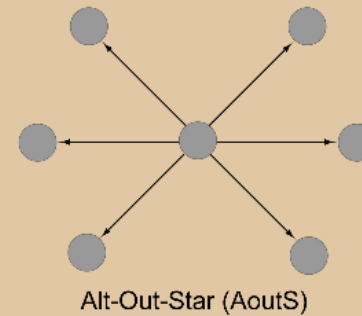
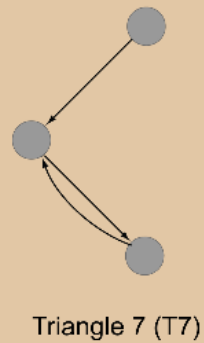
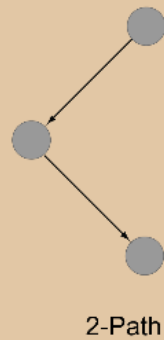
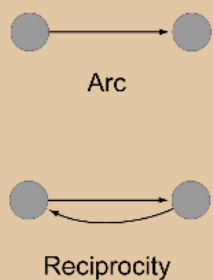
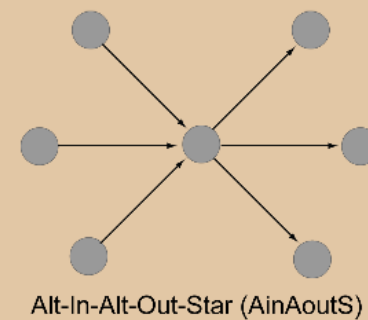
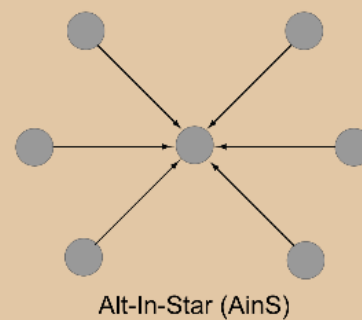
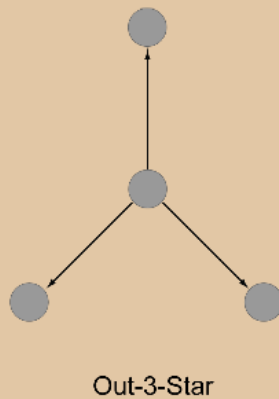
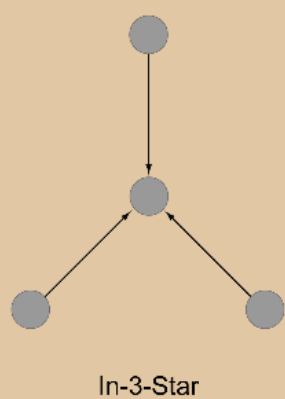
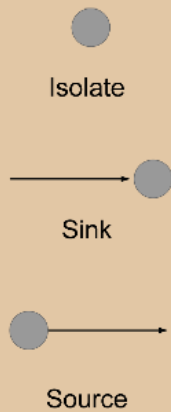
Exponential Random Graph Models (ERGMs)



Image: http://www.bubblews.com/assets/images/news/1547424755_1359167060.jpg



Image: <http://www.frugallivingnw.com/wp-content/uploads/2010/11/amazon-lego-castle.jpg>



Endogenous hypotheses

- (i) communication or signalling --> inter-visibility
- (ii) visual control --> outgoing lines
- (iii) visually prominent --> incoming lines
- (iv) invisible --> isolation

Exogenous hypotheses

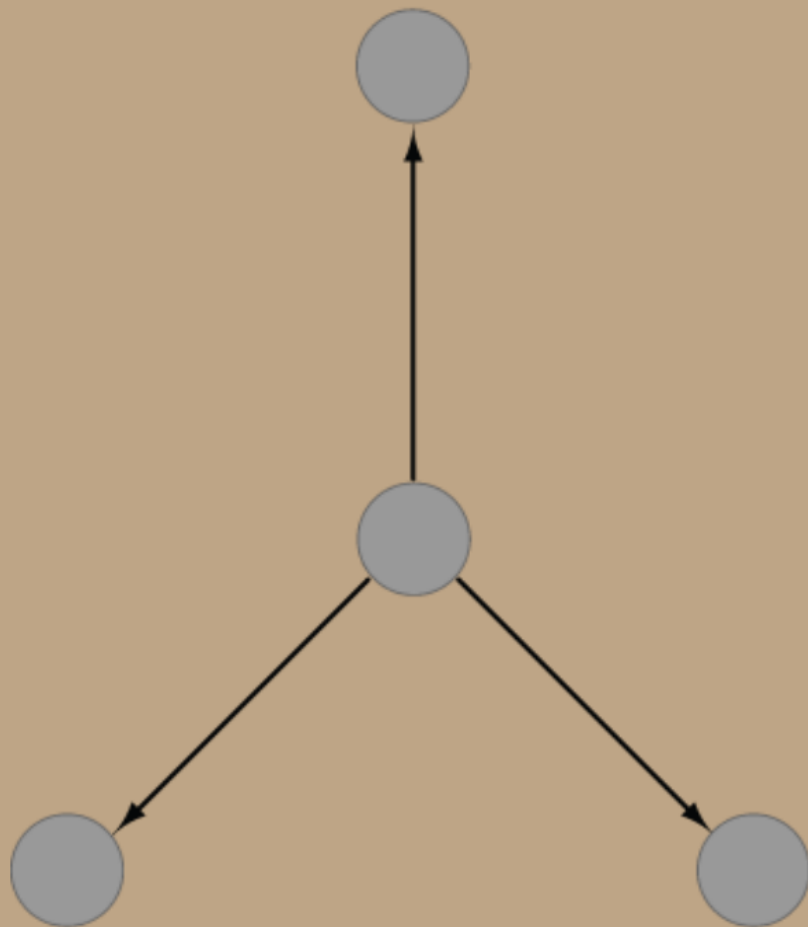
- (i) Iron Age settlements continuing in occupation
- (ii) Roman urban status
- (iii) river and road transport network



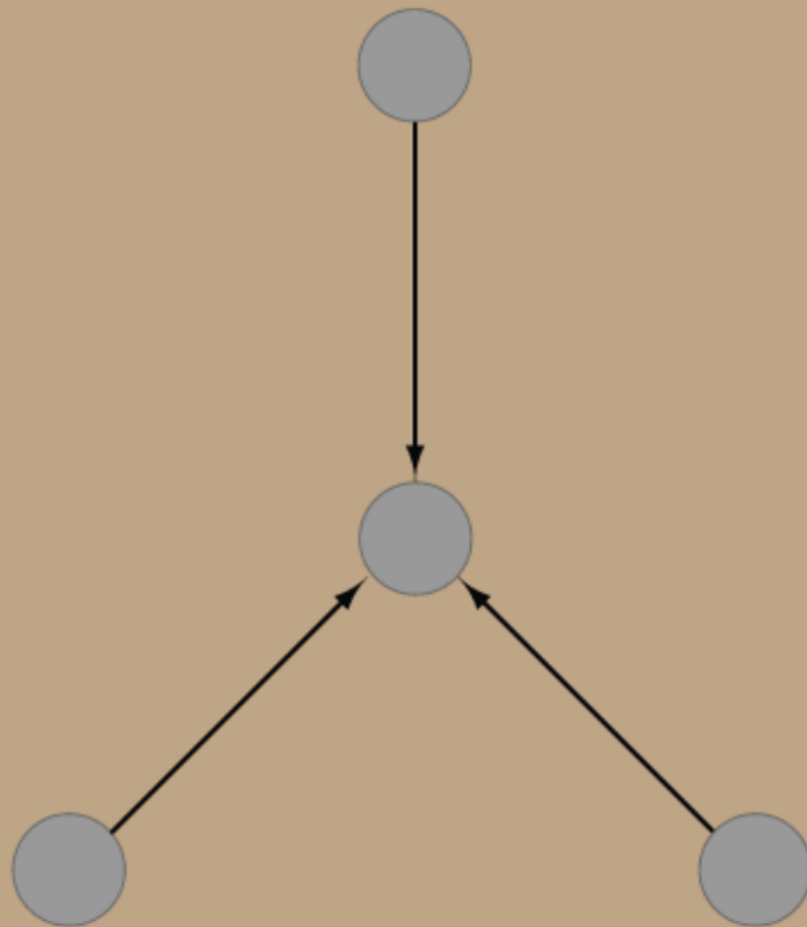
(a)



(d)

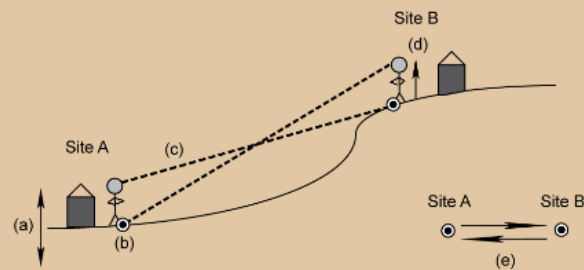


(b)



(c)

Probable viewshed



(a) random error in probable viewshed = 5m; (b) observer point site A and target point for observer site B; (c) line-of-sight with probability p_a from observer A to target point site B; (d) observer height = 17m; (e) inter-visibility network where site A is connected to site B with probability p_a and site B is connected to site A with probability p_b .

Exploratory network analysis

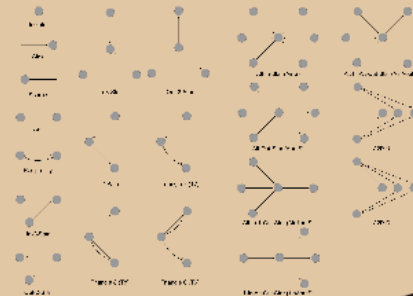
Global measures:

Number of nodes
Number of arcs
Clustering coefficient
Average degree
Connected components
Diameter
Density
Average shortest path length

Local measures:

Clustering coefficient
Indegree
Outdegree

Exponential Random Graph Models (ERGMs)



Probable viewshed

The number of probable viewsheds at each location depends on its position relative to the horizon and the height of the observer. The number of viewsheds at each location can be calculated by counting the number of locations that are visible from that location.

Topological network analysis

- Global measurements
 - Number of nodes
 - Number of links
 - Average connectivity
 - Average degree
 - Connected components
- Dynamic
 - Distance
 - Density
 - Average shortest path length

Spatial network analysis (GNSS)

- Local measurements
 - Centrality coefficients
 - Degree
 - Betweenness
 - Closeness



Equatorial Undercurrent Reversal 115

)

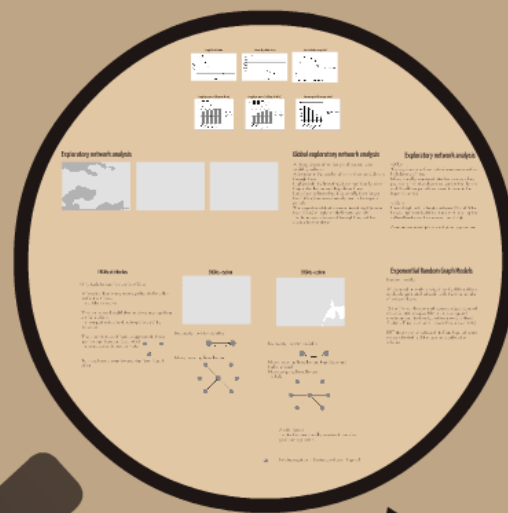
Indigenous hypotheses:

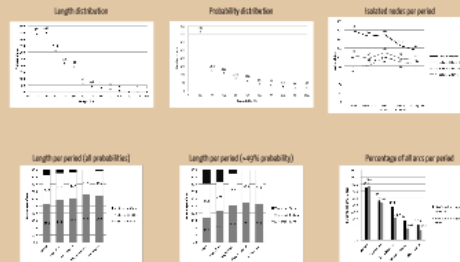
- ### Expansive hypotheses

- (i) Iron Age settlement increasing in competition
(ii) Roman urban status
(iii) river and sea transport network

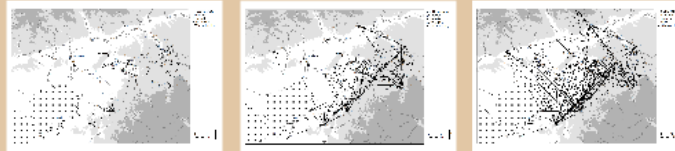


Results





Exploratory network analysis



Global exploratory network analysis

A strong degree of similarity and continuity in visibility patterns.
A decrease in the number of arcs and network density through time.
High probability lines of sight are significantly more frequent in Iberian and Republican times.
Long distance lines of sight (especially those longer than 50km) become extremely rare in the imperial periods.
The proportion of short distance lines of sight (shorter than 20km) is higher in the Imperial periods.
→ the networks fragment through time, but local clusters become denser.

Exploratory network analysis

<20km
The key clusters in these networks are areas with a high density of sites.
Many visually prominent sites that occupy a key position in the networks are occupied in the Iberian and Republican periods but cease to be so in the Imperial periods.

<50km
Lines of sight with a length between 20 and 50km have a significantly different role in structuring the cultural landscape than shorter lines of sight.

Colonias and municipia are not visually prominent

ERGMs attributes

Only Early Imperial networks <20km

All models show many more significant effects than without attributes.
→ attributes matter

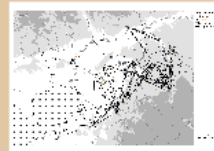
The river or road model does not show any significant attribute effects.
→ transport networks do not explain visibility networks

The urban status and Iberian origins model has a positive significant out-2-star effect.
→ visual control but not as hubs

Both also have a negative and significant 2-path effect.



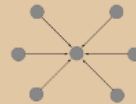
ERGMs <50km



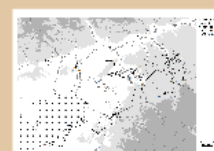
Reciprocity → inter-visibility



Many incoming lines Iberian



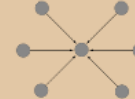
ERGMs <20km



Reciprocity → inter-visibility



Many incoming lines Iberian, Republican and Early Imperial
Many outgoing lines Iberian
→ hubs



2-path Iberian
→ sites that are visually prominent are also good vantage points



Isolates negative in Iberian, positive in Imperial

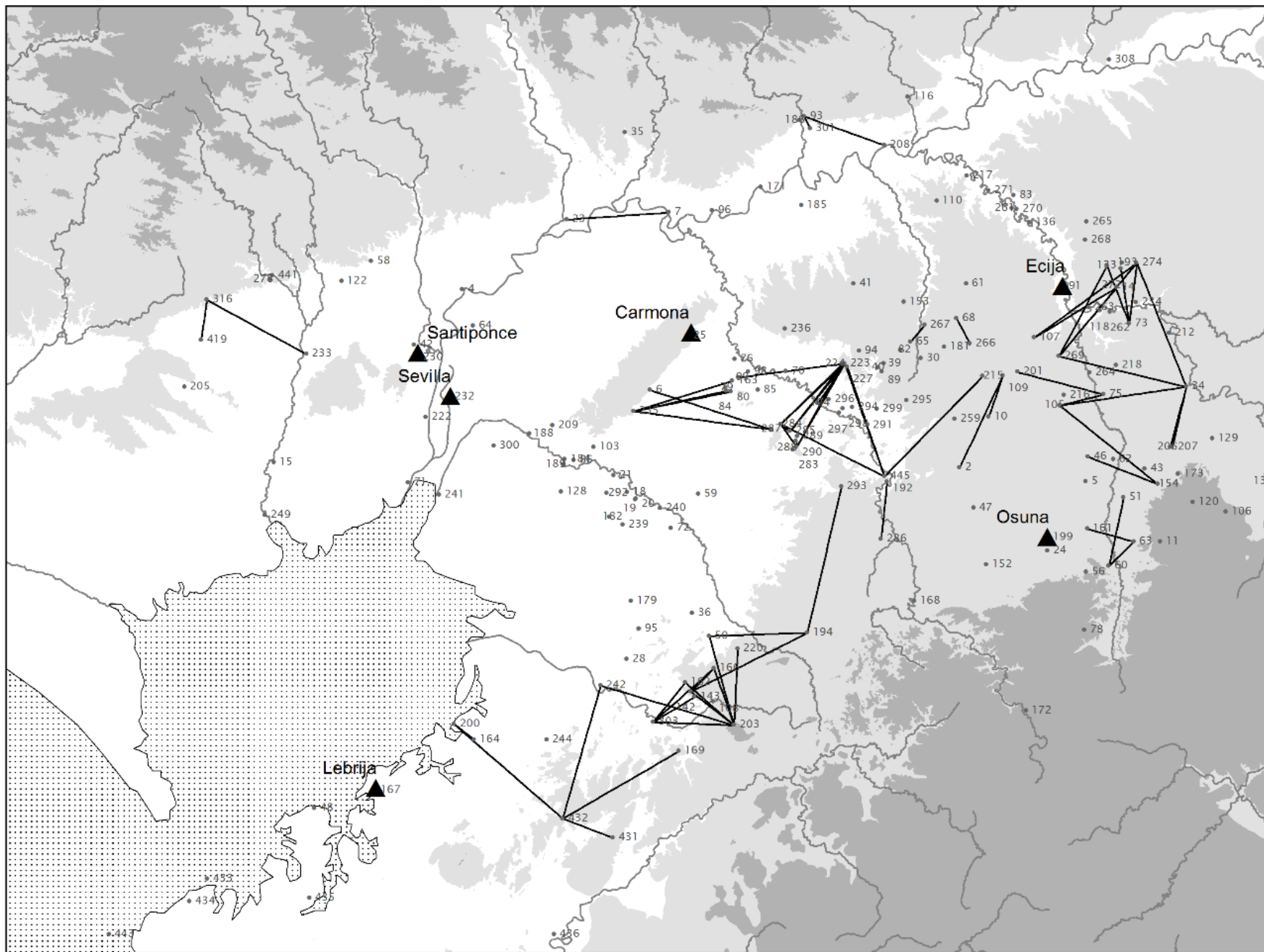
Exponential Random Graph Models

Random models

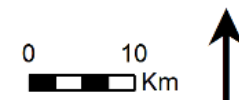
All observed networks are significantly different from randomly generated networks with the same number of nodes and arcs

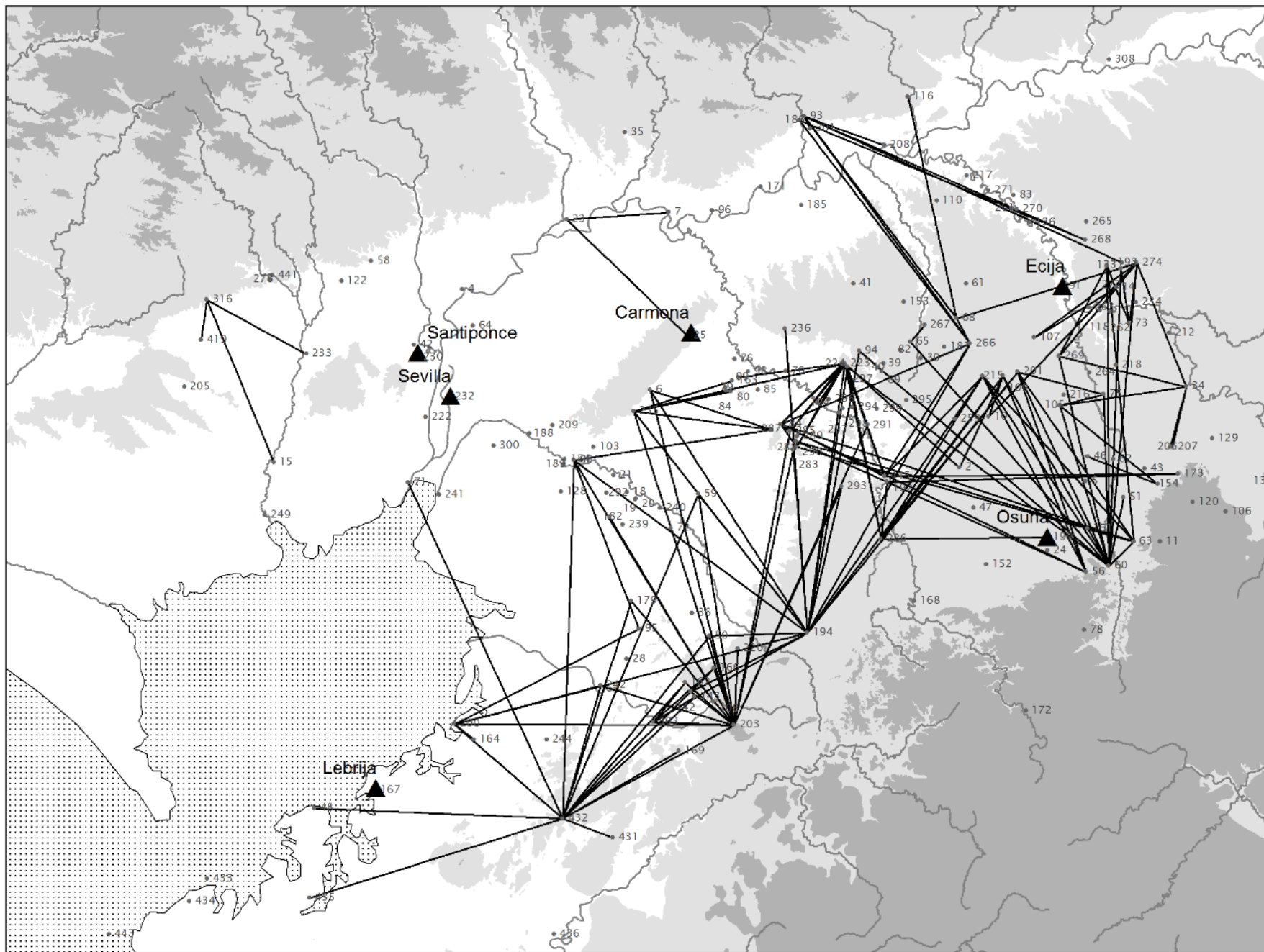
(50 million random networks generated per observed network, 1000 samples. Minimum, average and maximum counts of configurations were considered. Student's T-test p-values all lower than α -level 0.05)

BUT the maximum values of the Late Imperial period network limited to 20km was not significantly different

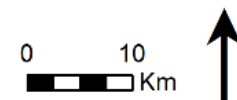


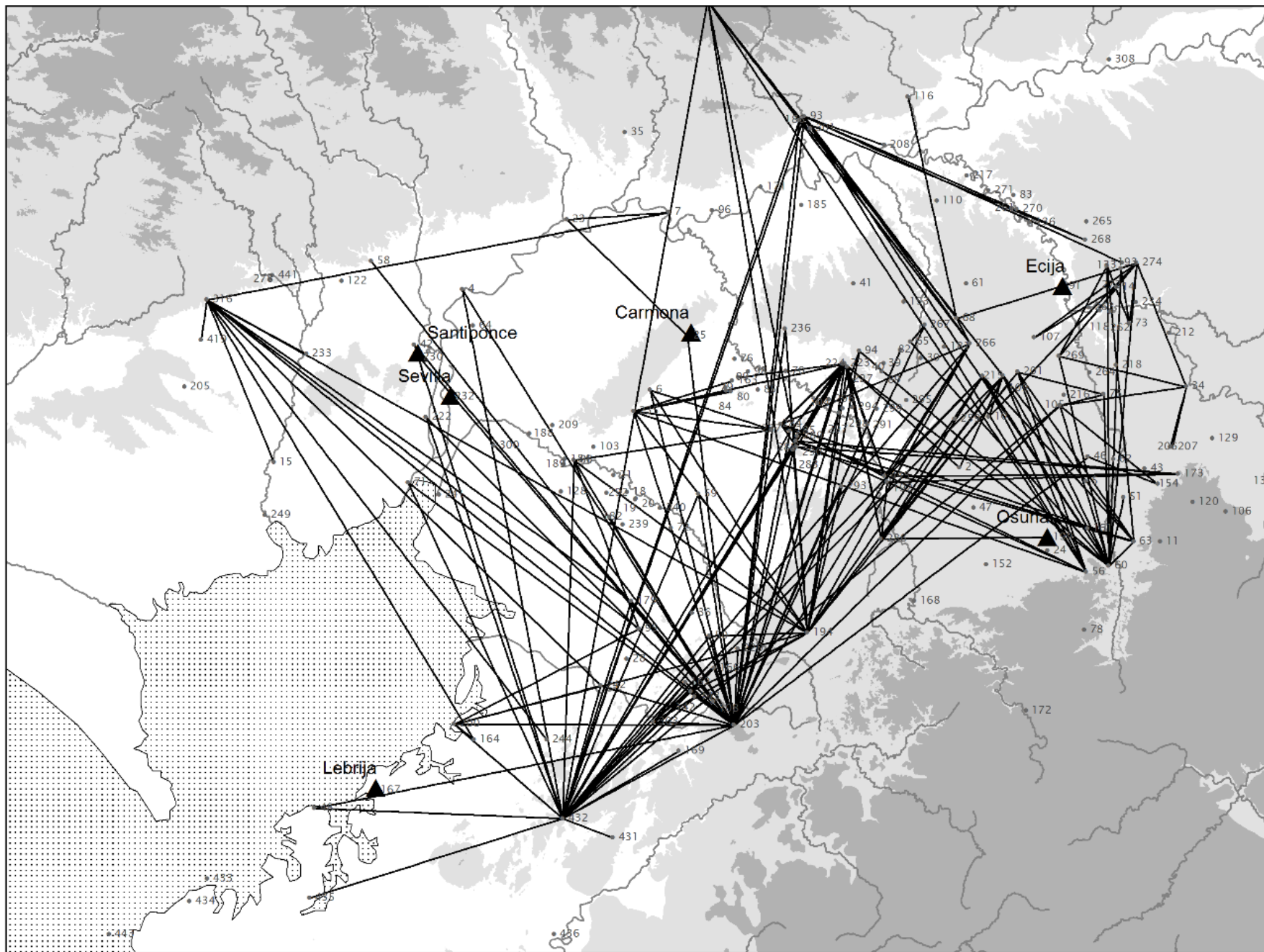
Visibility network
Undirected
All periods
20km radius
>50% probability



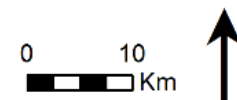


Visibility network
Undirected
All periods
50km radius
>50% probability





Visibility network
Undirected
All periods
Unlimited radius
>50% probability



Global exploratory network analysis

A strong degree of similarity and continuity in visibility patterns.

A decrease in the number of arcs and network density through time.

High probability lines of sight are significantly more frequent in Iberian and Republican times.

Long-distance lines of sight (especially those longer than 50km) become extremely rare in the imperial periods.

The proportion of short distance lines of sight (shorter than 20km) is higher in the Imperial periods.

--> the networks fragment through time, but local clusters become denser.

Exploratory network analysis

<20km

The key clusters in these networks are areas with a high density of sites.

Many visually prominent sites that occupy a key position in the networks are occupied in the Iberian and Republican periods but cease to be so in the Imperial periods.

<50km

Lines of sight with a length between 20 and 50km have a significantly different role in structuring the cultural landscape than shorter lines of sight.

Coloniae and municipia are not visually prominent.

Exponential Random Graph Models

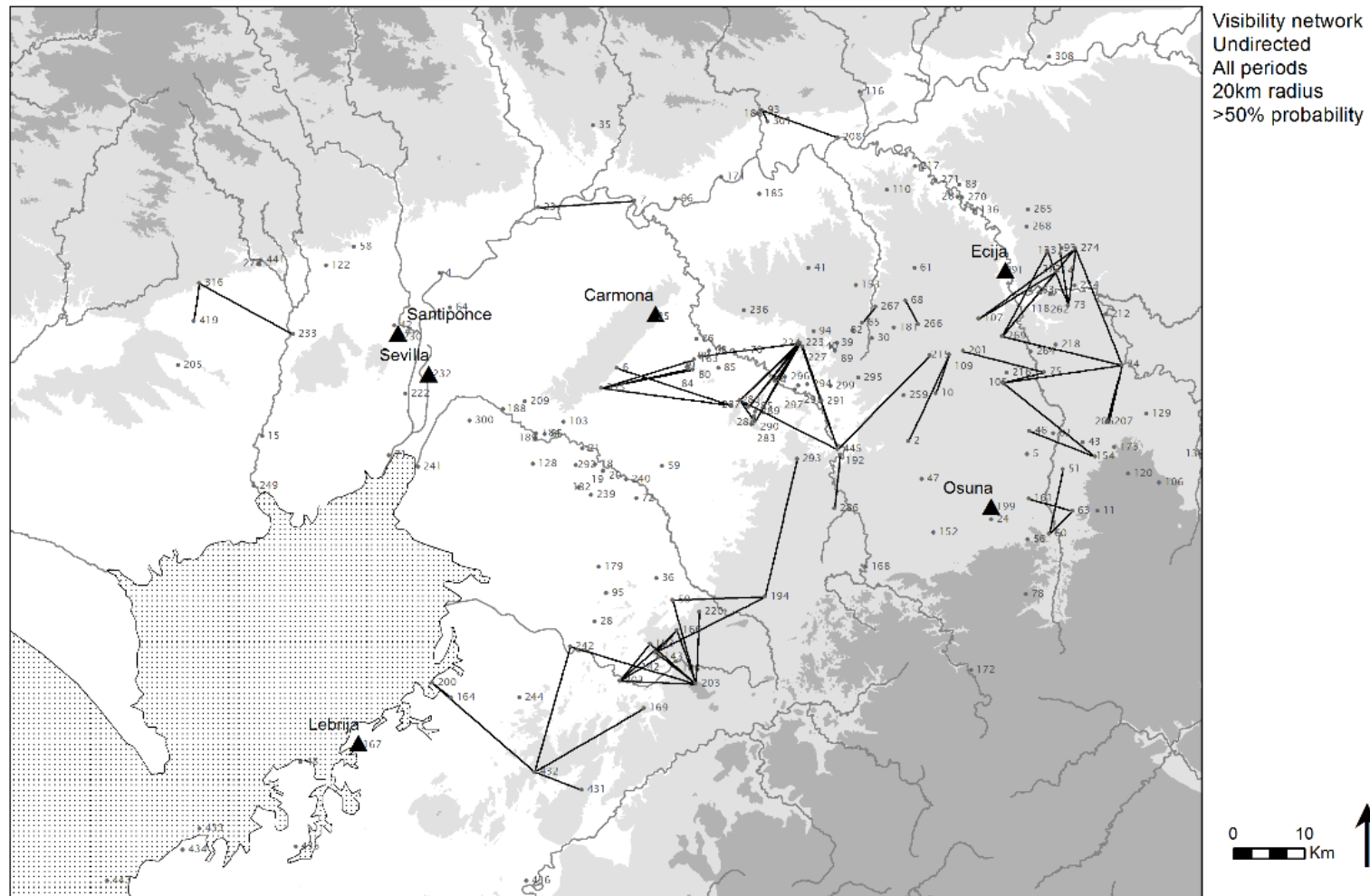
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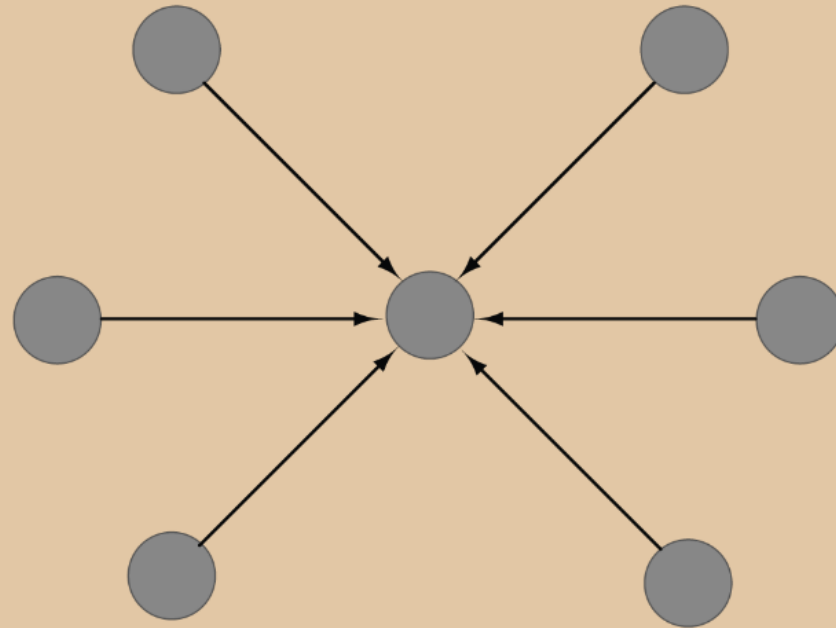


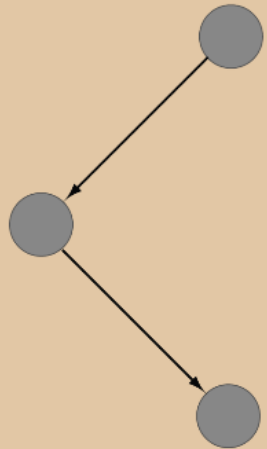
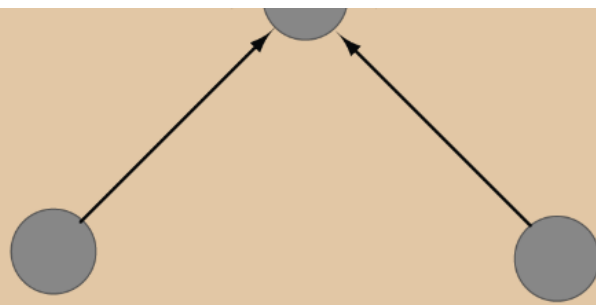
Reciprocity --> inter-visibility



Many incoming lines: Iberian, Republican and Early Imperial

Many outgoing lines: Iberian
--> hubs





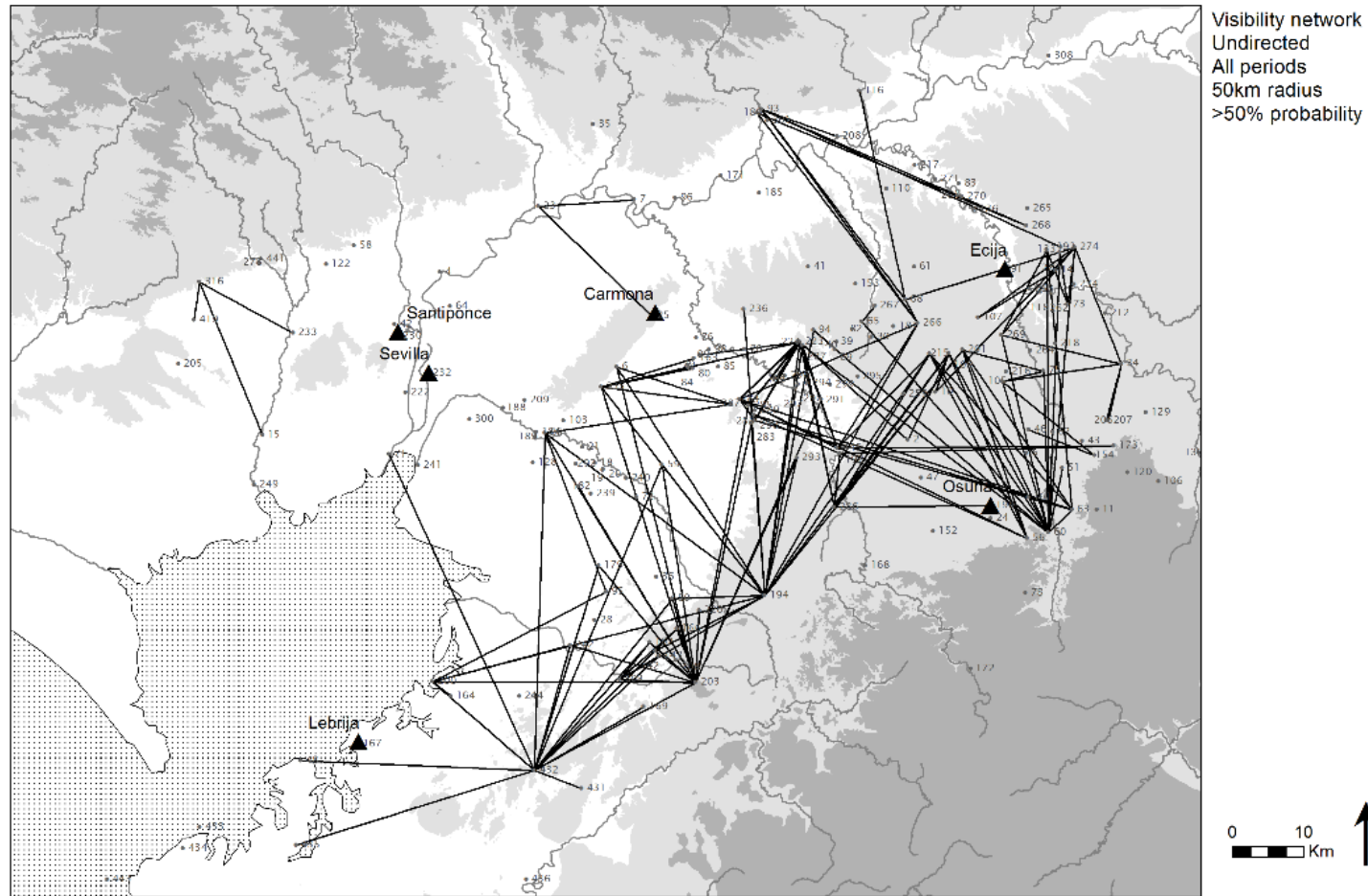
2-path: Iberian

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Isolates: negative in Iberian, positive in Imperial

ERGMs <50km



Reciprocity --> inter-visibility

ent



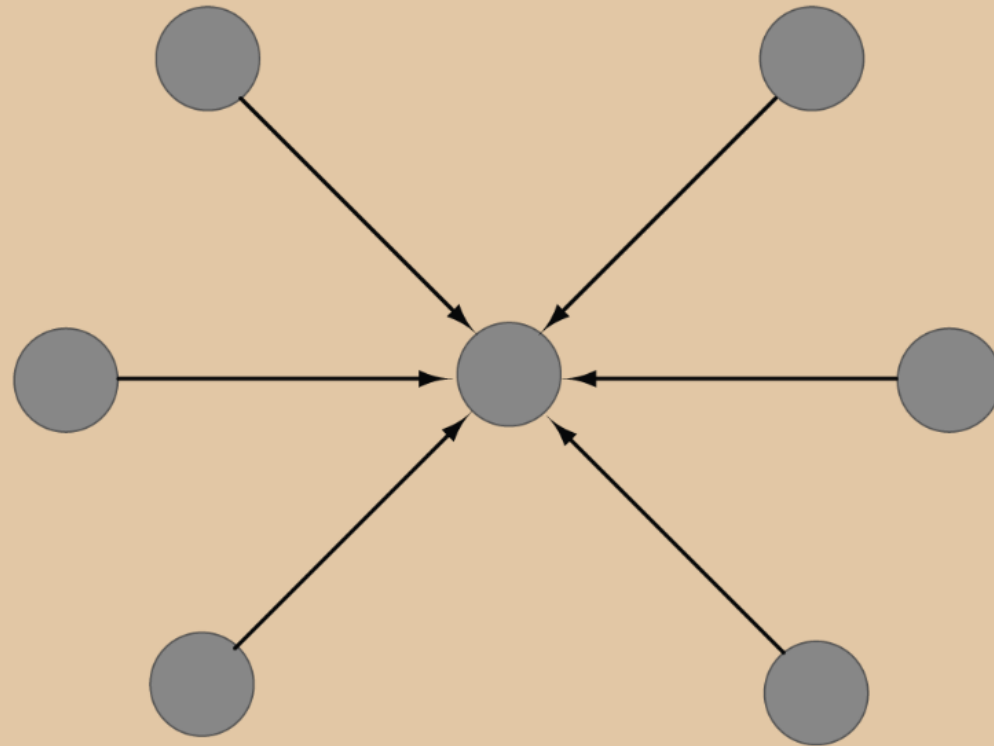
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Many incoming lines: Iberian



Many incoming lines: Iberian



ERGMs attributes

Only Early Imperial networks <20km

All models show many more significant effects than without attributes.

--> attributes matter

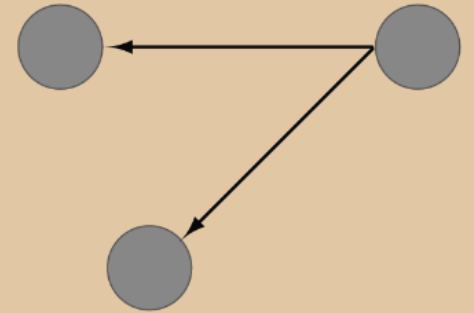
The river or road model does not show any significant attribute effects.

--> transport networks do not explain visibility networks

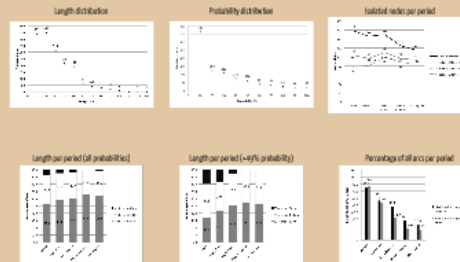
The urban status and Iberian origins model has a positive significant out-2-star effect.



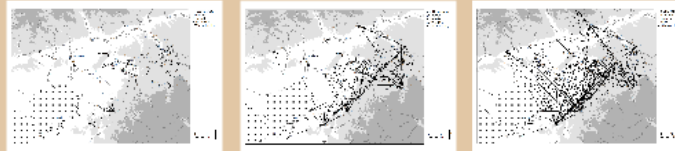
The urban status and Iberian origins model has a positive significant out-2-star effect.
--> visual control but not as hubs



Both also have a negative and significant 2-path effect.



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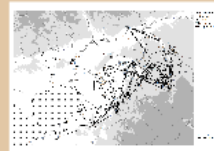
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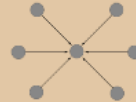
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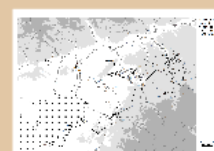
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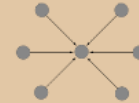
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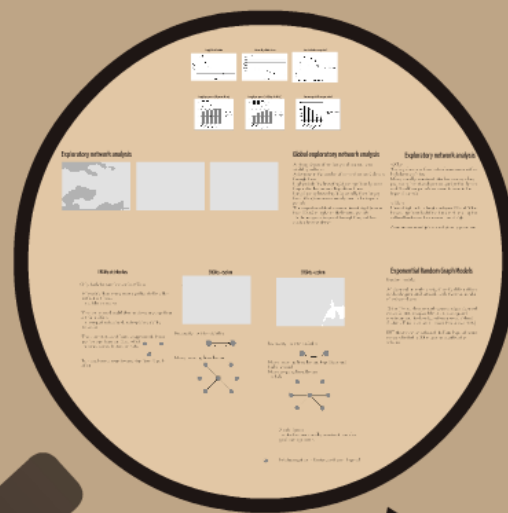
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Results





Conclusions

Continuity:

Inter-visibility is common throughout time, both in short and long distance networks.

Not random

Iberian:

Tendency towards hubs

Long distance lines

Later:

Tendency towards lower degree hubs

Short distance lines

Attributes?

Transport networks --> NO

Urban status --> YES

Iberian origins --> YES

--> The role of sites changes through time

--> Visibility patterns and site locations require different explanations in the Iron age compared to Roman times

Make assumptions and hypotheses explicit

Explore their implications

Stay close to observed data

Future work:

Multiple viewer points

Longitudinal analysis

ERGMs as a starting point for ABMs

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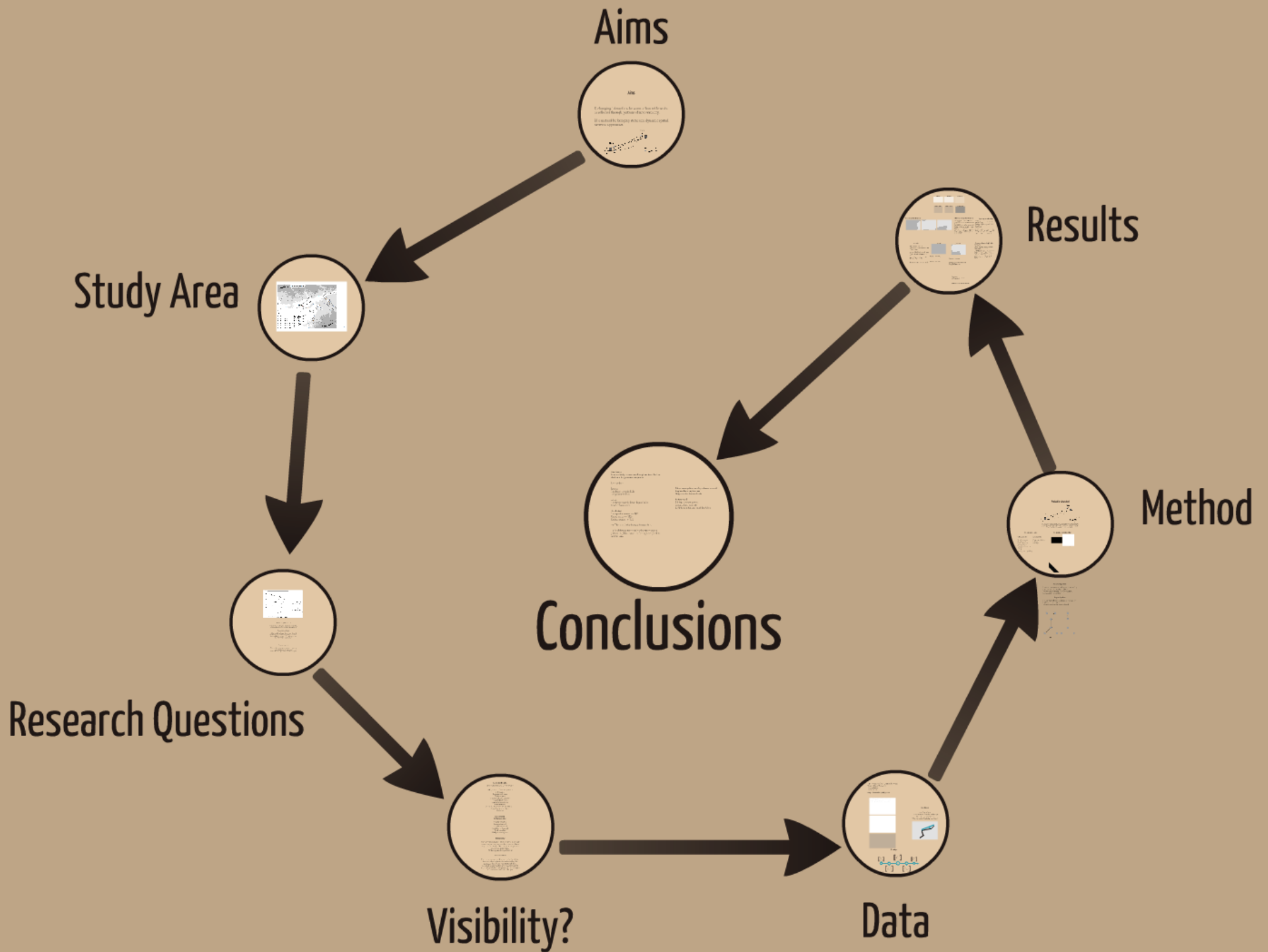
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Conclusions



THANK YOU!

<http://connectedpast.soton.ac.uk/>
<http://archaeologicalnetworks.wordpress.com/>

Acknowledgements

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