

THANK YOU!

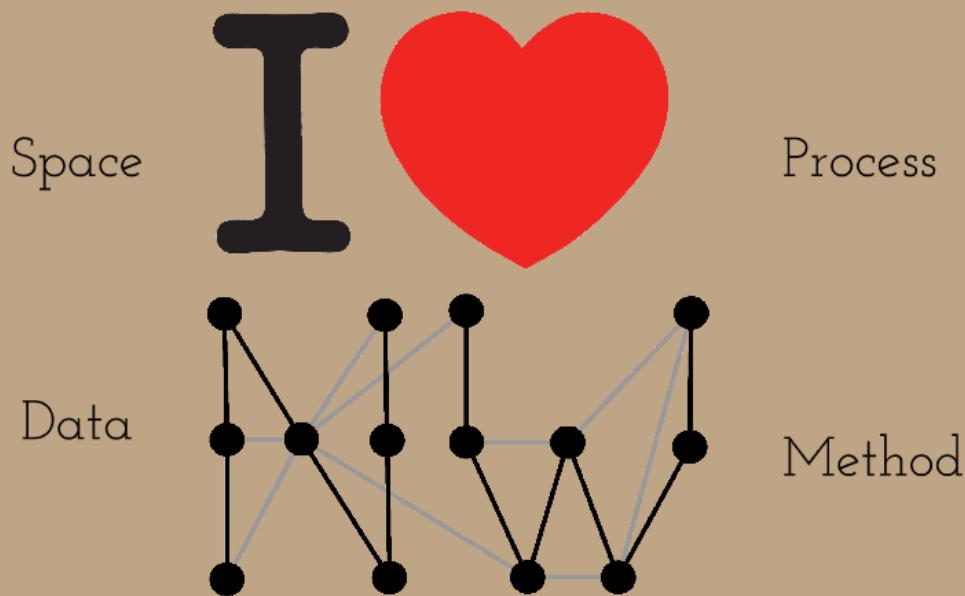
<http://connectedpast.soton.ac.uk/>
<http://archaeologicalnetworks.wordpress.com/>

Acknowledgements

Prof. Simon Keay - Dr. Graeme Earl - Prof. Claire Lemerrier - the networks network - AHRC - Dr. David Wheatley - Cat Cooper - Dr. Leif Isaksen - 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 - Institución Andaluza de Patrimonio Histórico - Prof. Antonio Cobos Rufino - Dr. Víctor Hurtado Pérez - Professor Francesca Chaves Tristán - Sr. José Manuel Rodríguez Hidalgo - Dr. José Beltrán Farías - Dr. Fernando Amates Corredor - Iza Romanczuk - 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.

Space

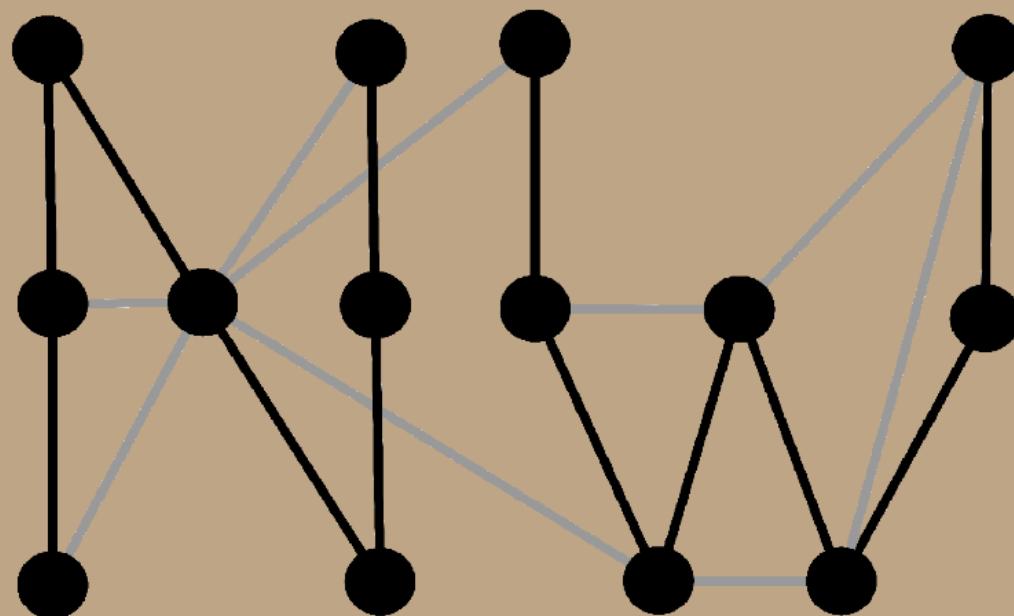
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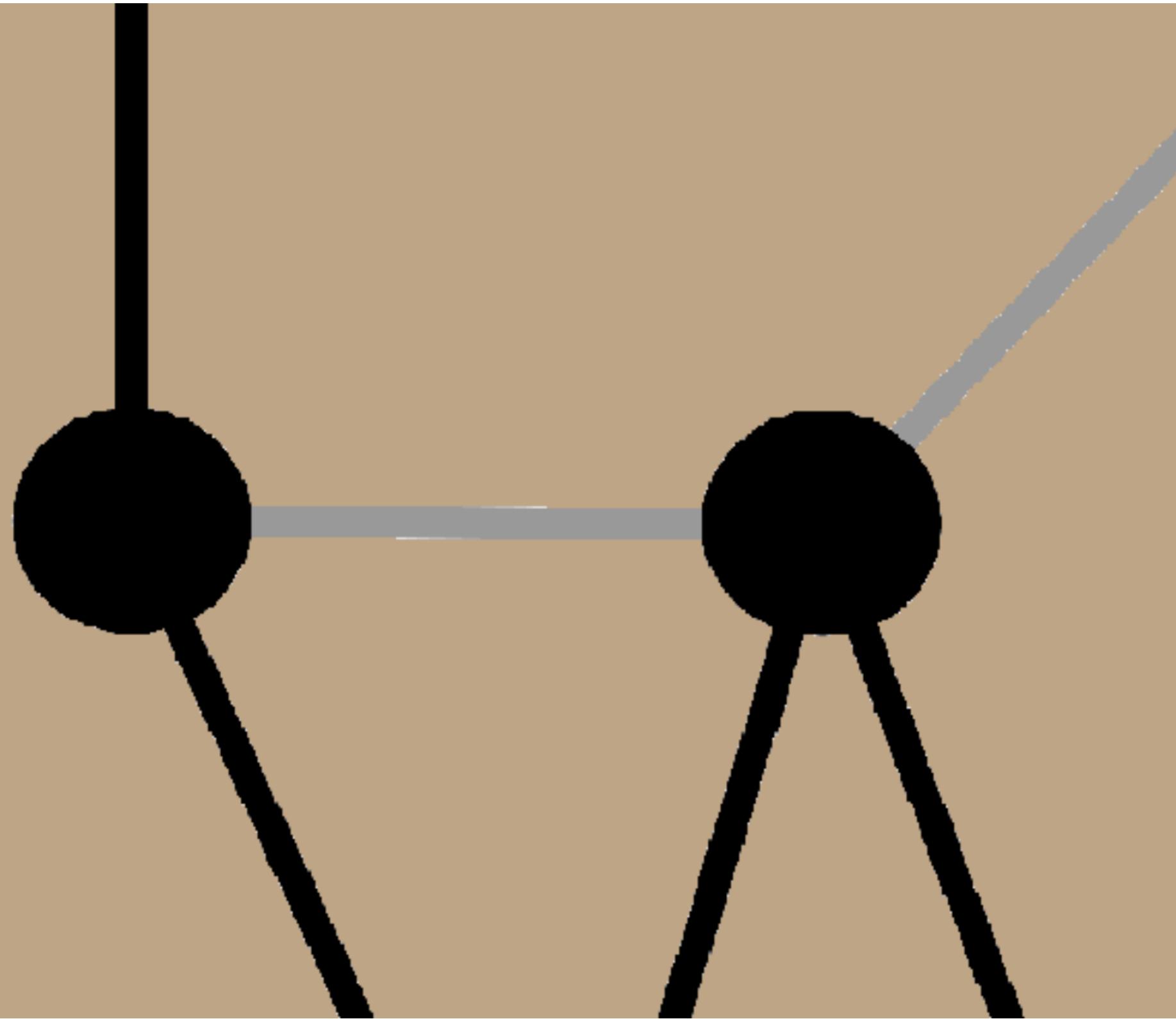
Data

Method



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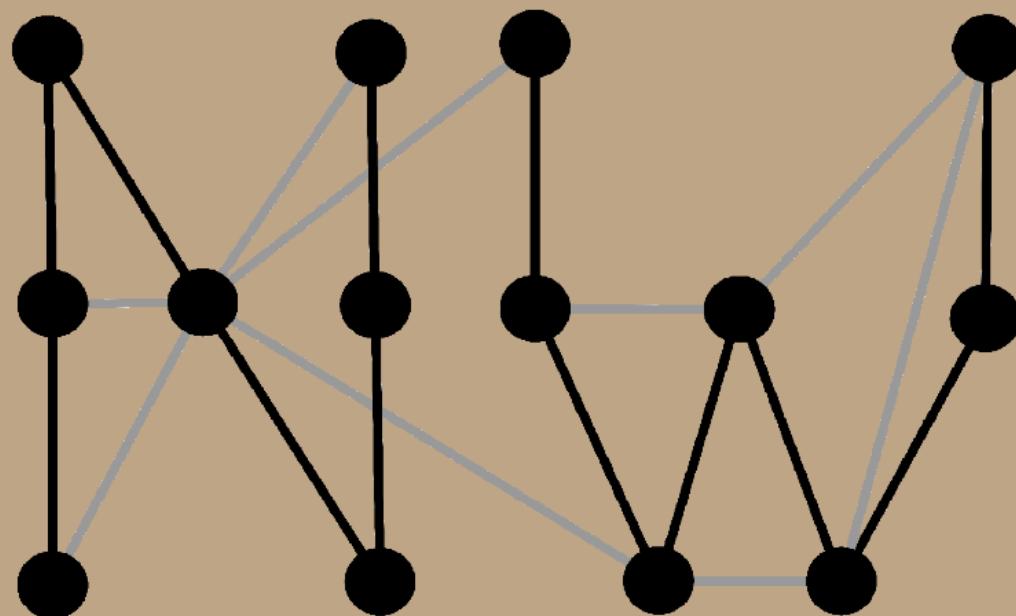
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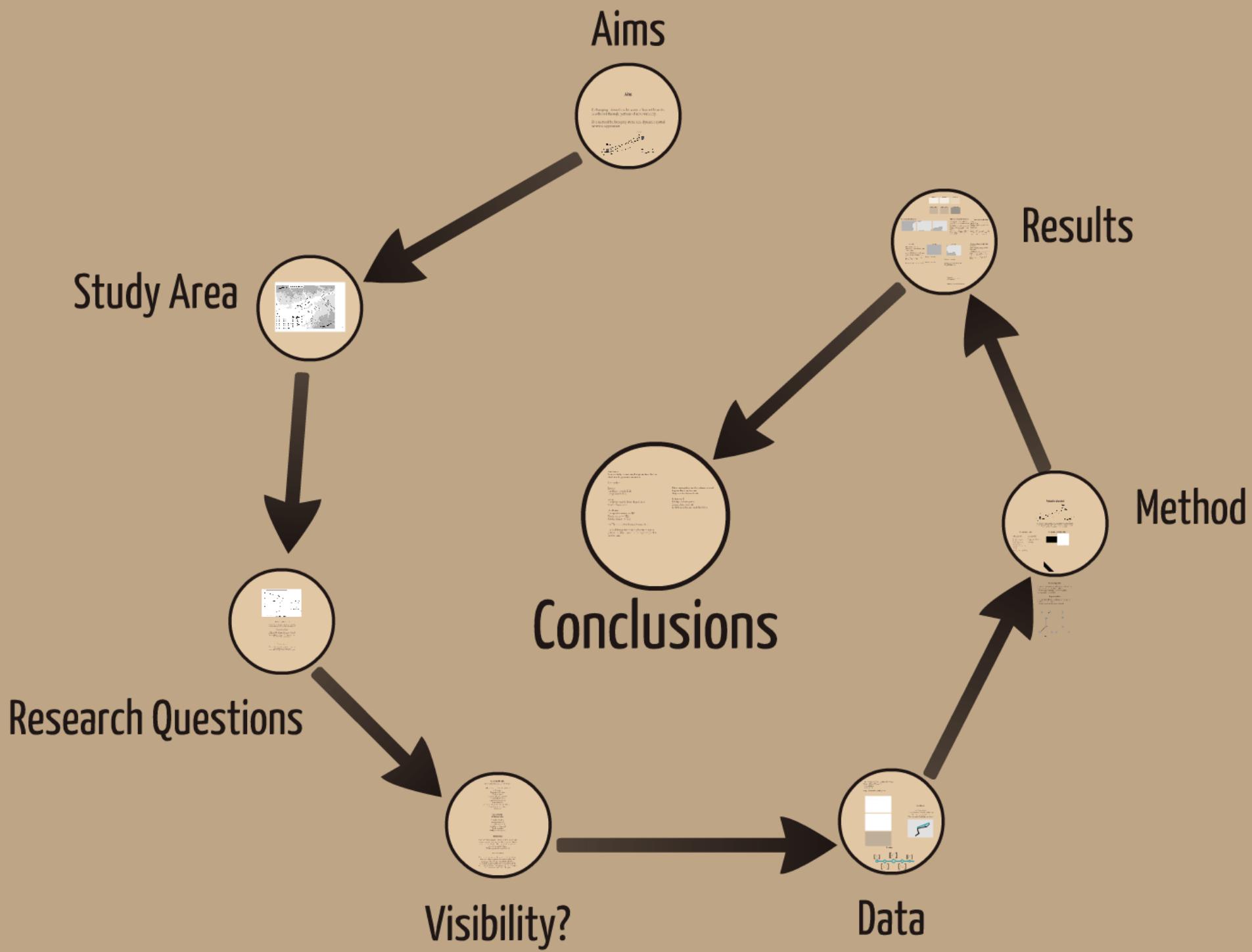
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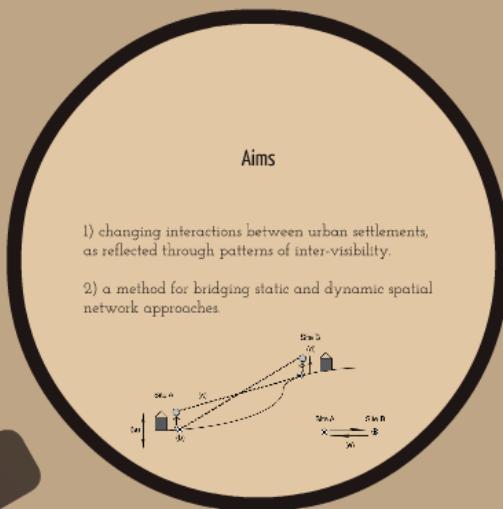


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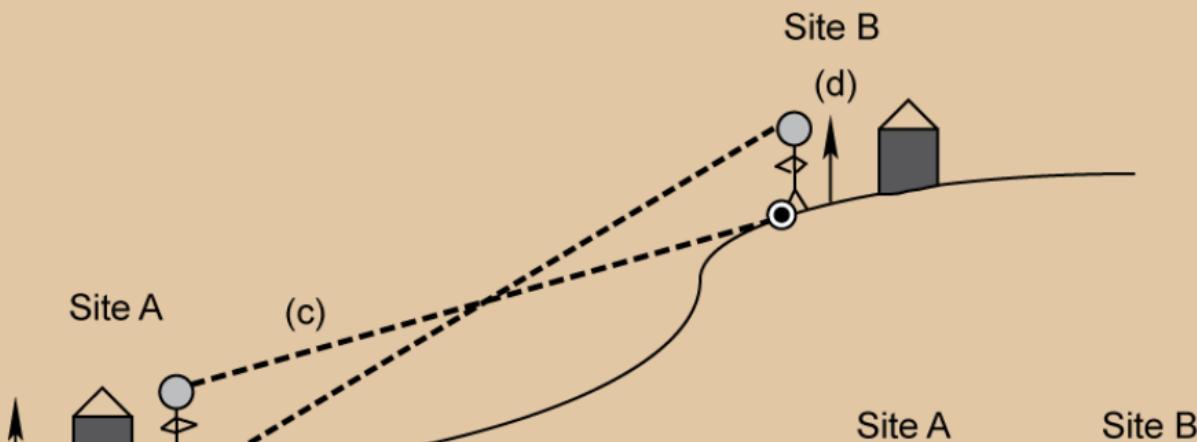


Aims

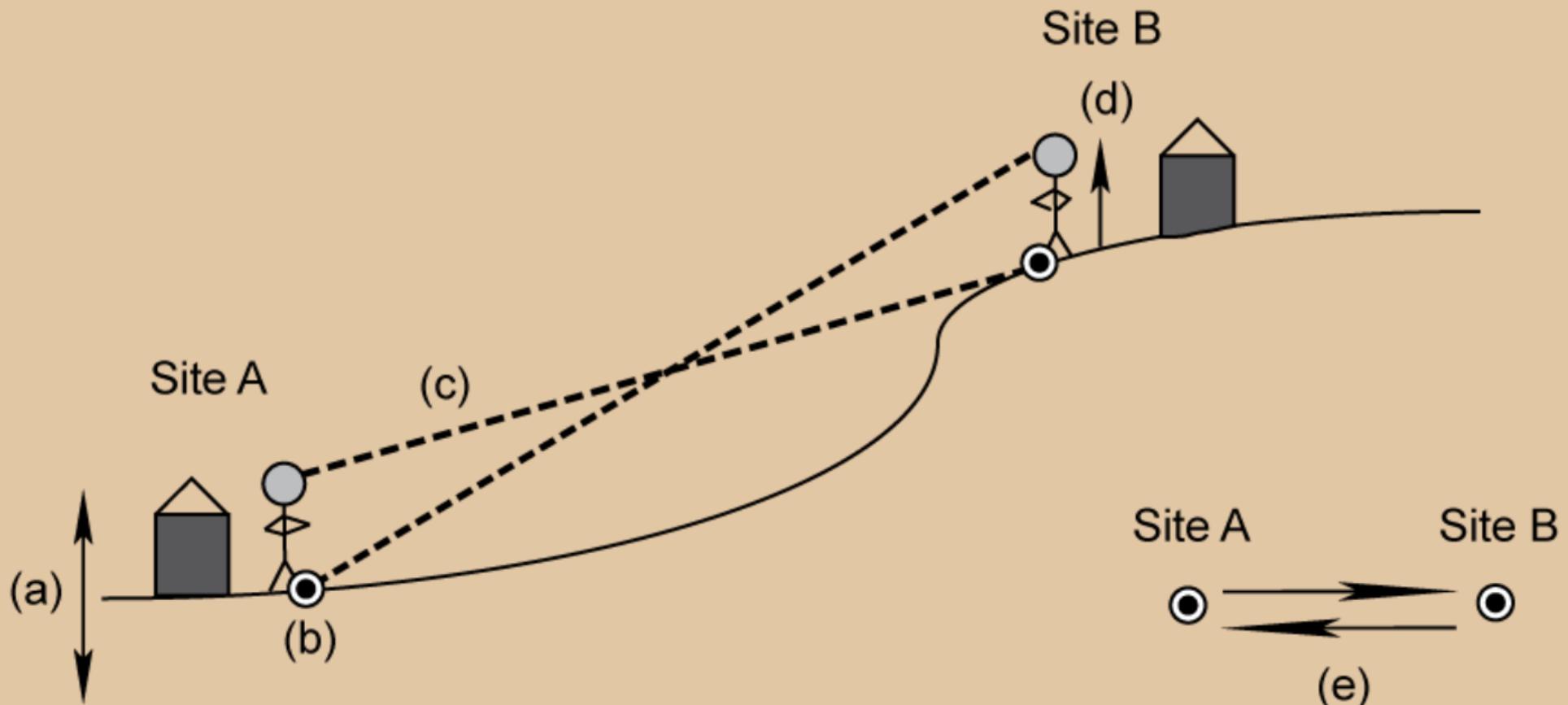


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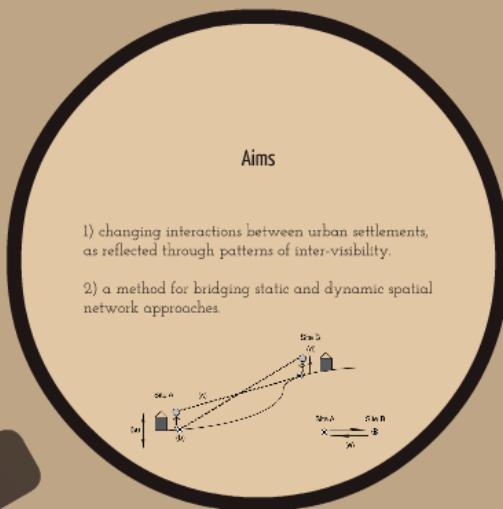
- 1) changing interactions between urban settlements, as reflected through patterns of inter-visibility.
- 2) a method for bridging static and dynamic spatial network approaches.



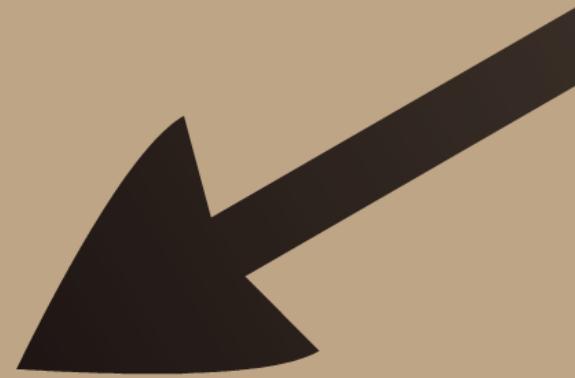
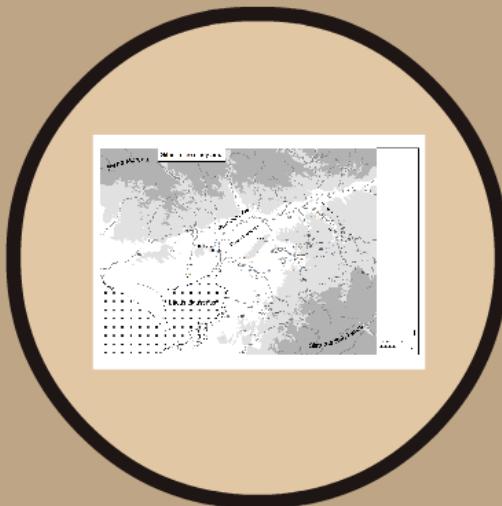
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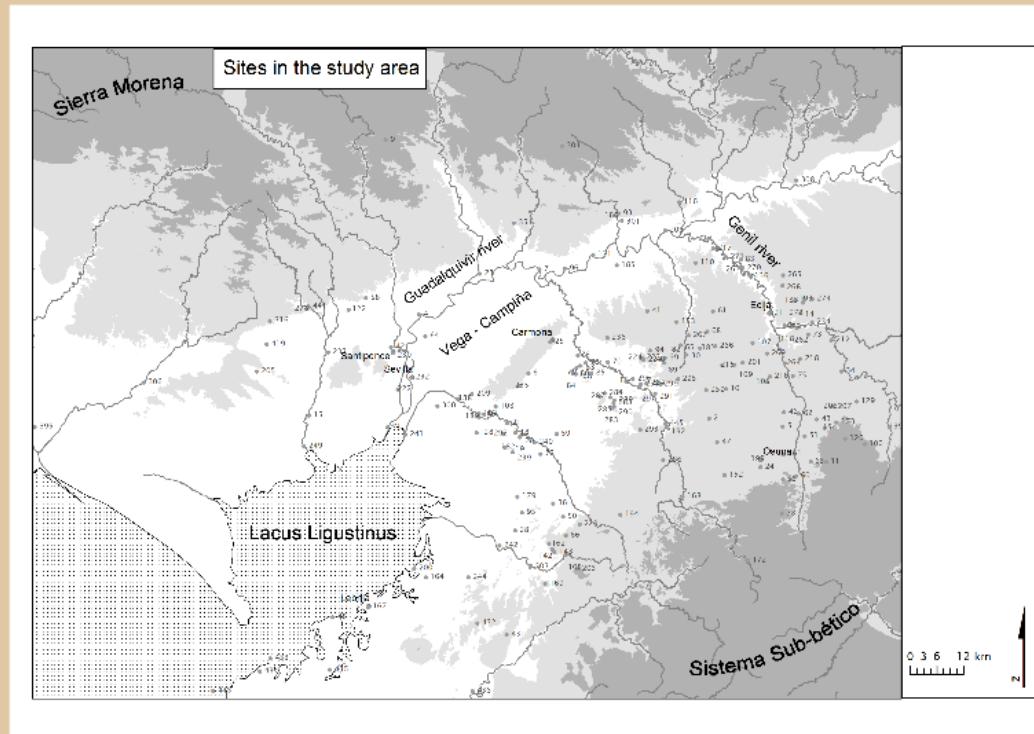


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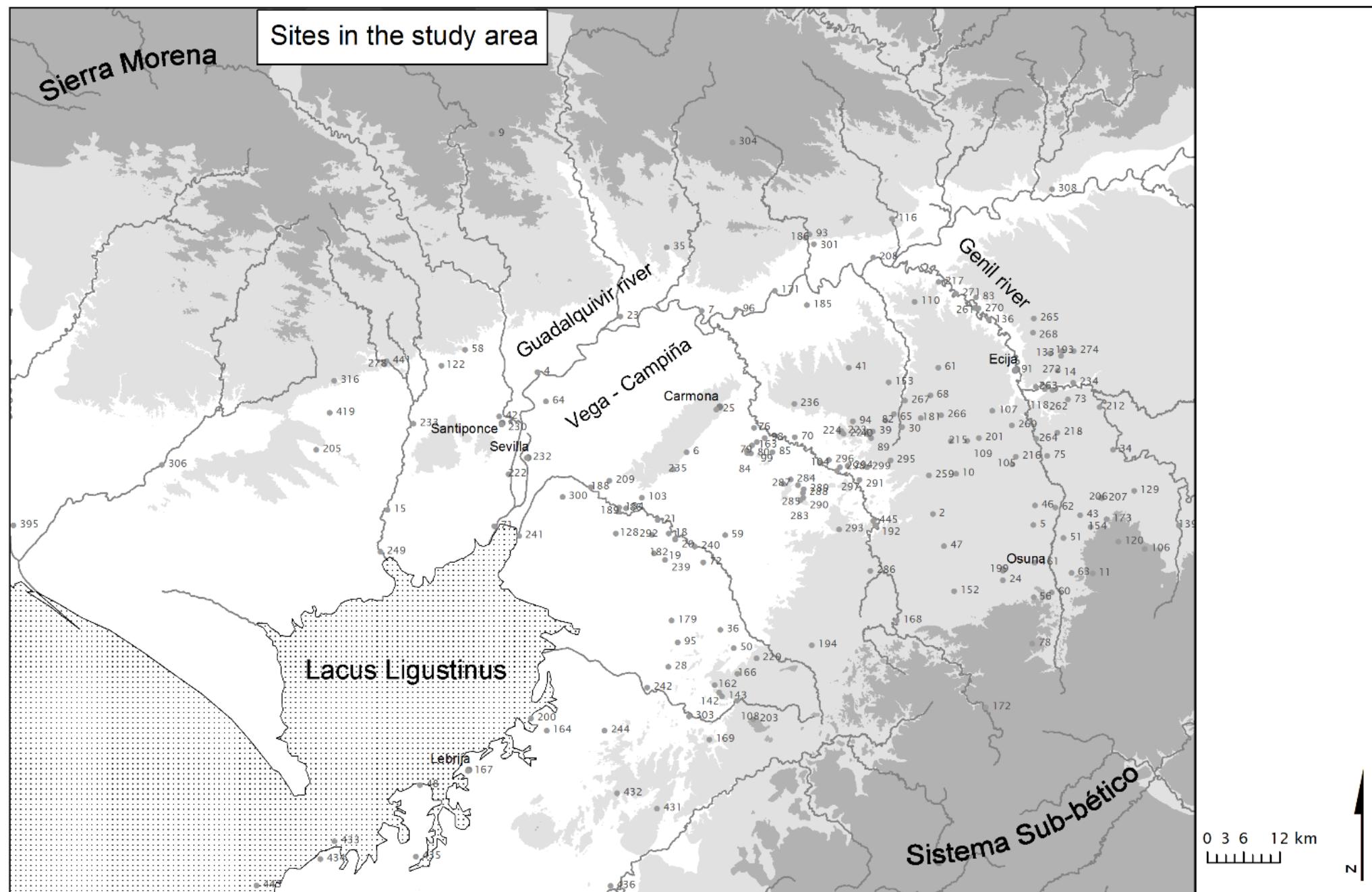


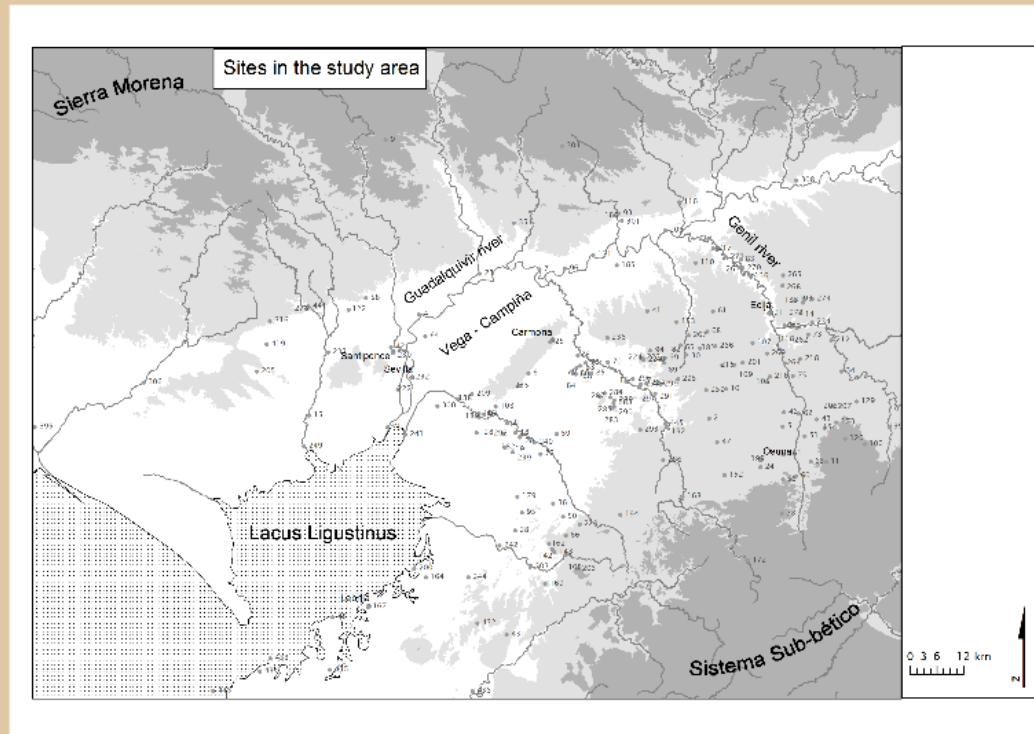
Study Area



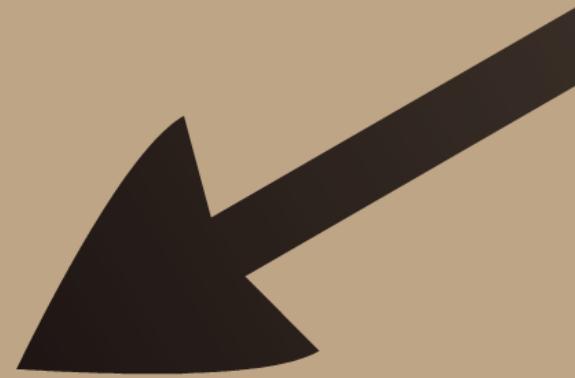
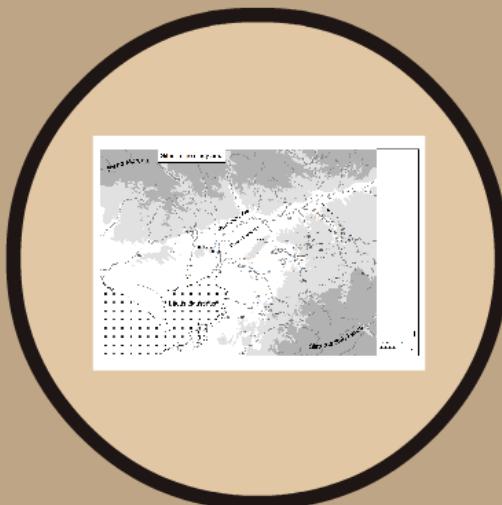


Sites in the study area

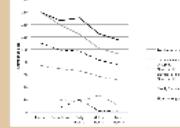
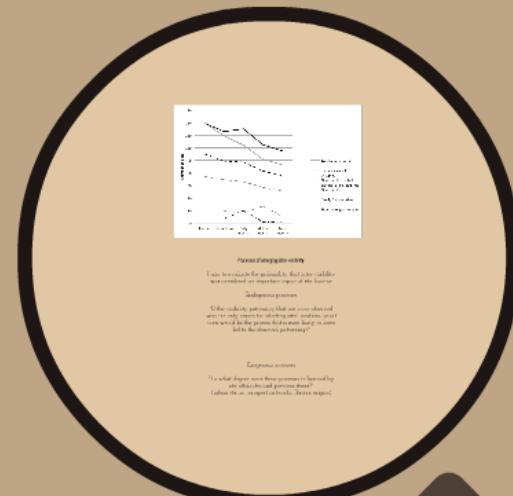




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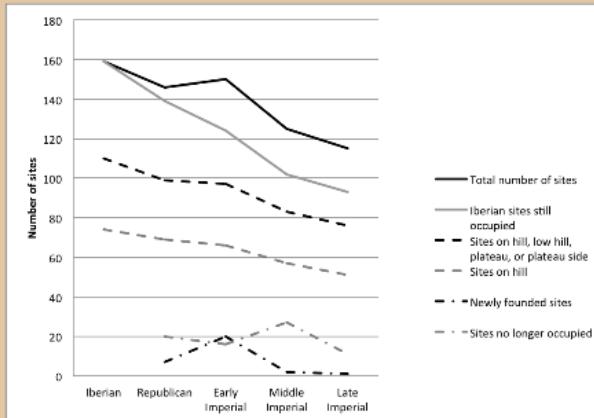
Research Questions



Background questions
Using knowledge for practical, but also valuable
information on important aspects of the disease

Objectives questions
What exactly patients think we can do and
what they expect from us? What interventions
they would like to receive to become less sensitive
to the disease/perturbation?

Measures questions
"To what degree are these processes altered by
the disease/perturbation?"
(above the ac., except in brachio-sympathetic region)



Processes of emerging inter-visibility

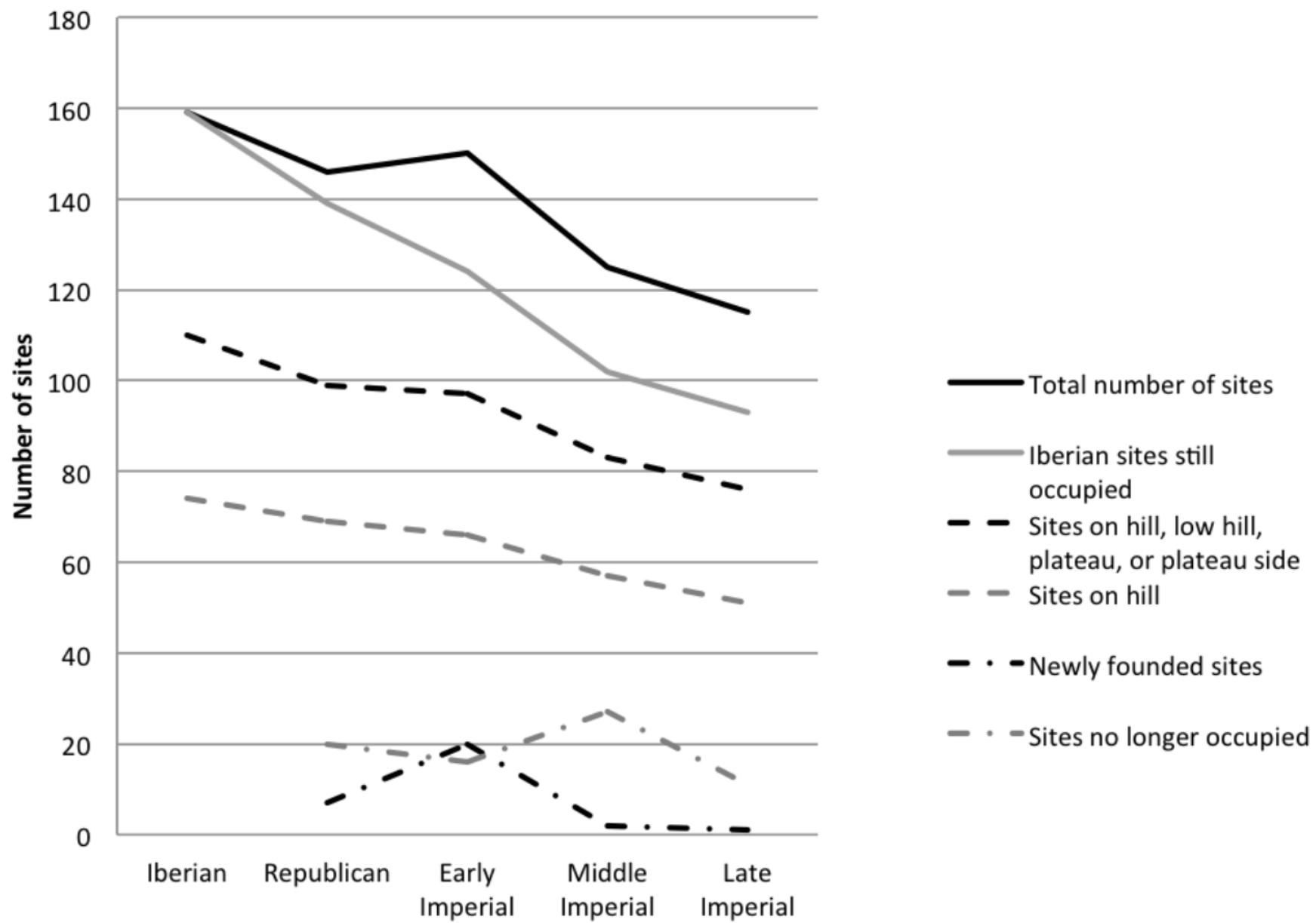
I aim to evaluate the probability that inter-visibility was considered an important aspect of site location

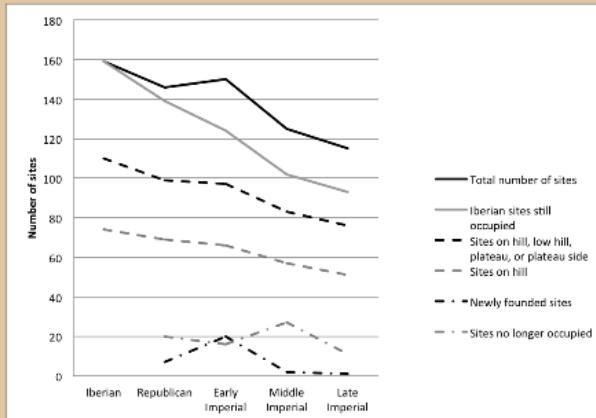
Endogenous processes

"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)





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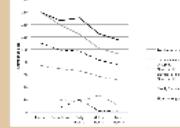
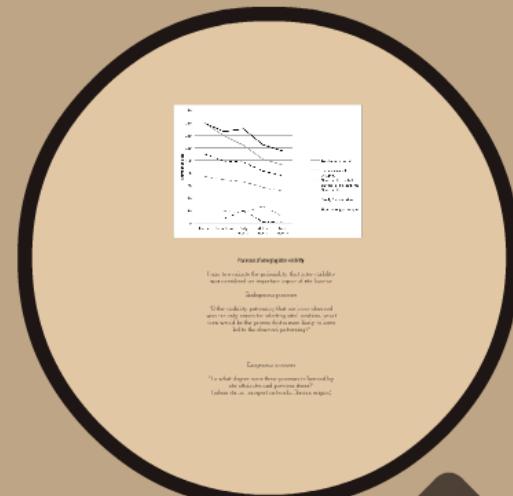
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Research Questions



Background

Objectives

Measures

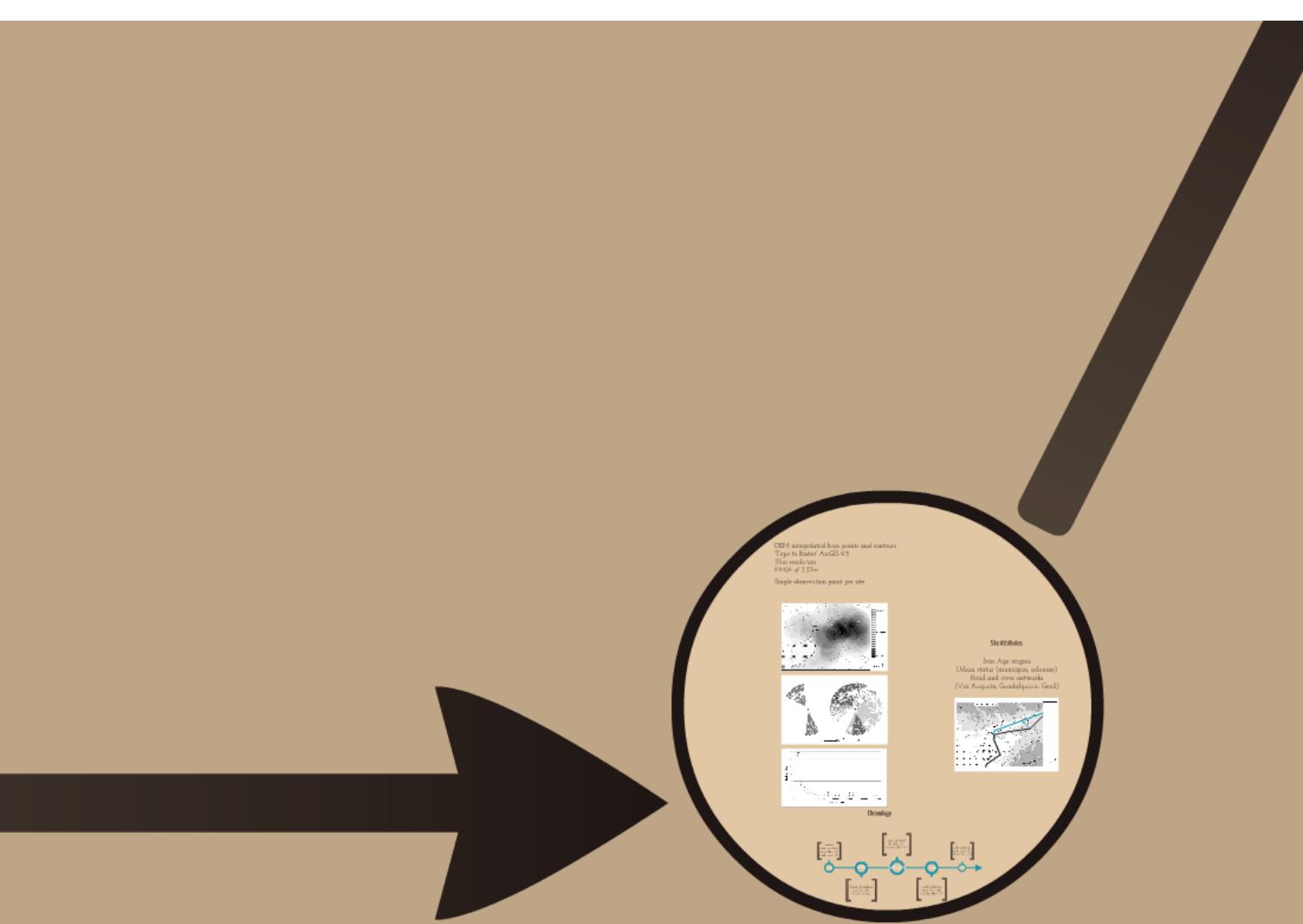
Interventions

Evaluation

ns

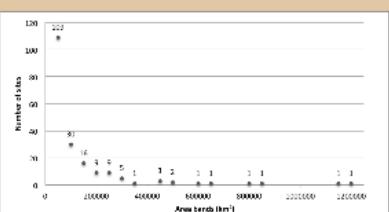
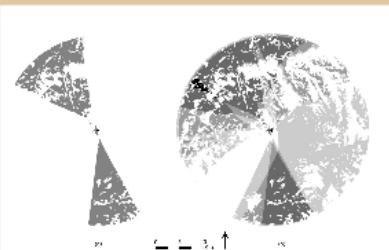
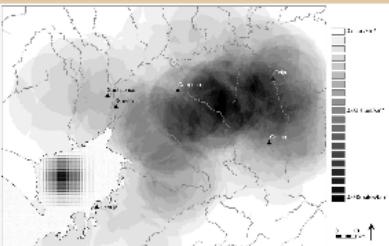


Visibility?

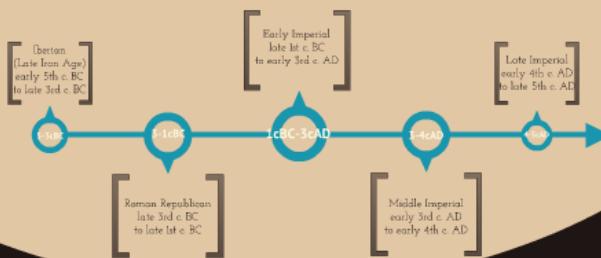


Data

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

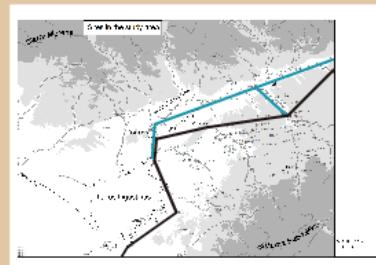


Chronology



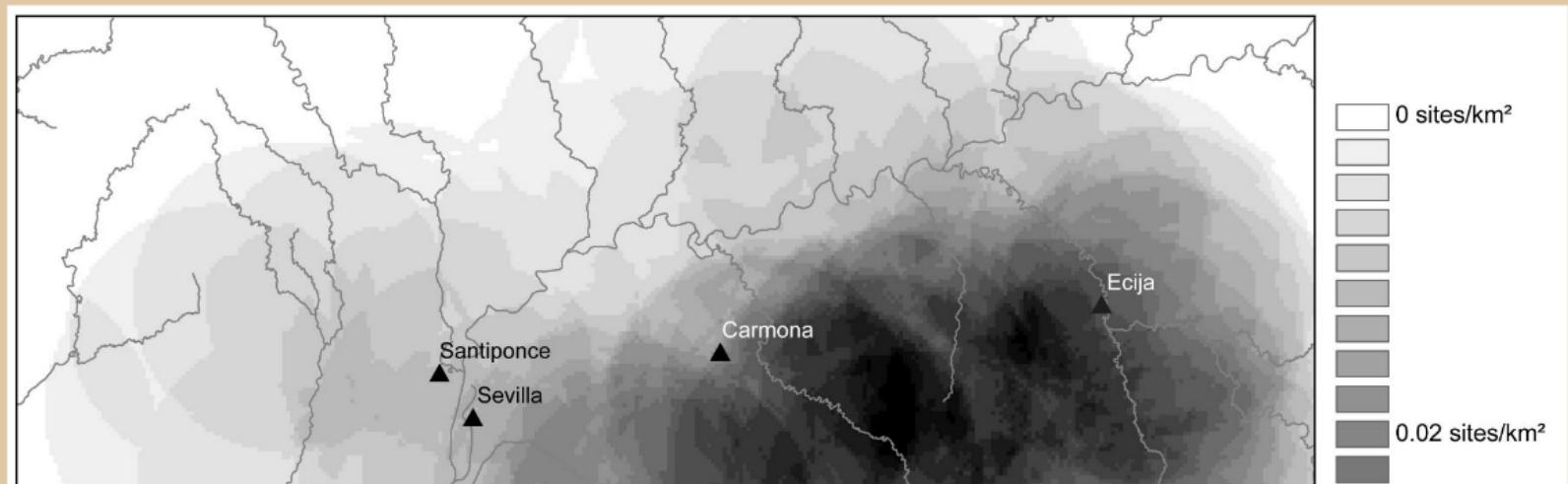
Site Attributes

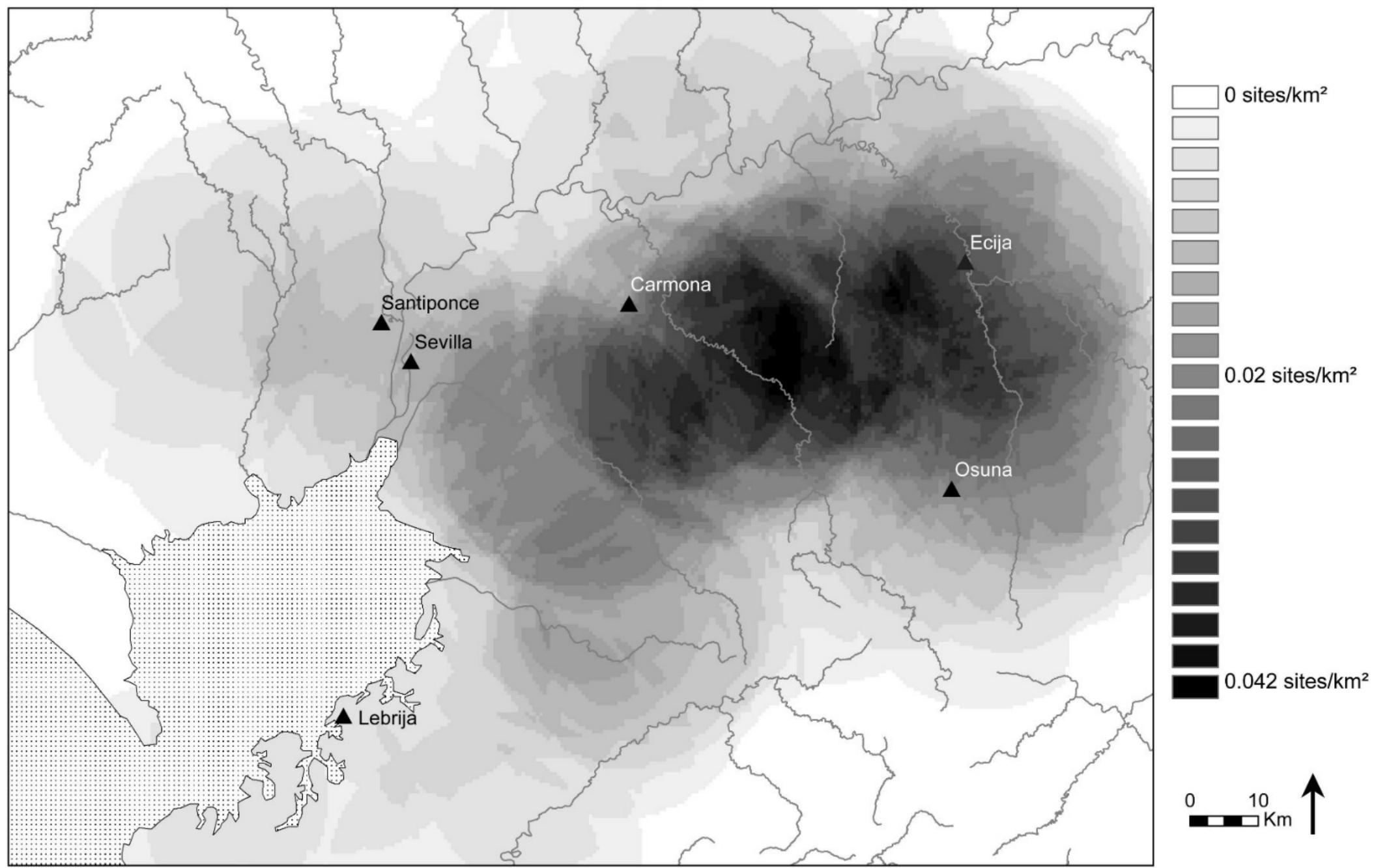
Iron Age origins
Urban status (municipia, coloniae)
Road and river networks
(Via Augusta, Guadalquivir, Genil)

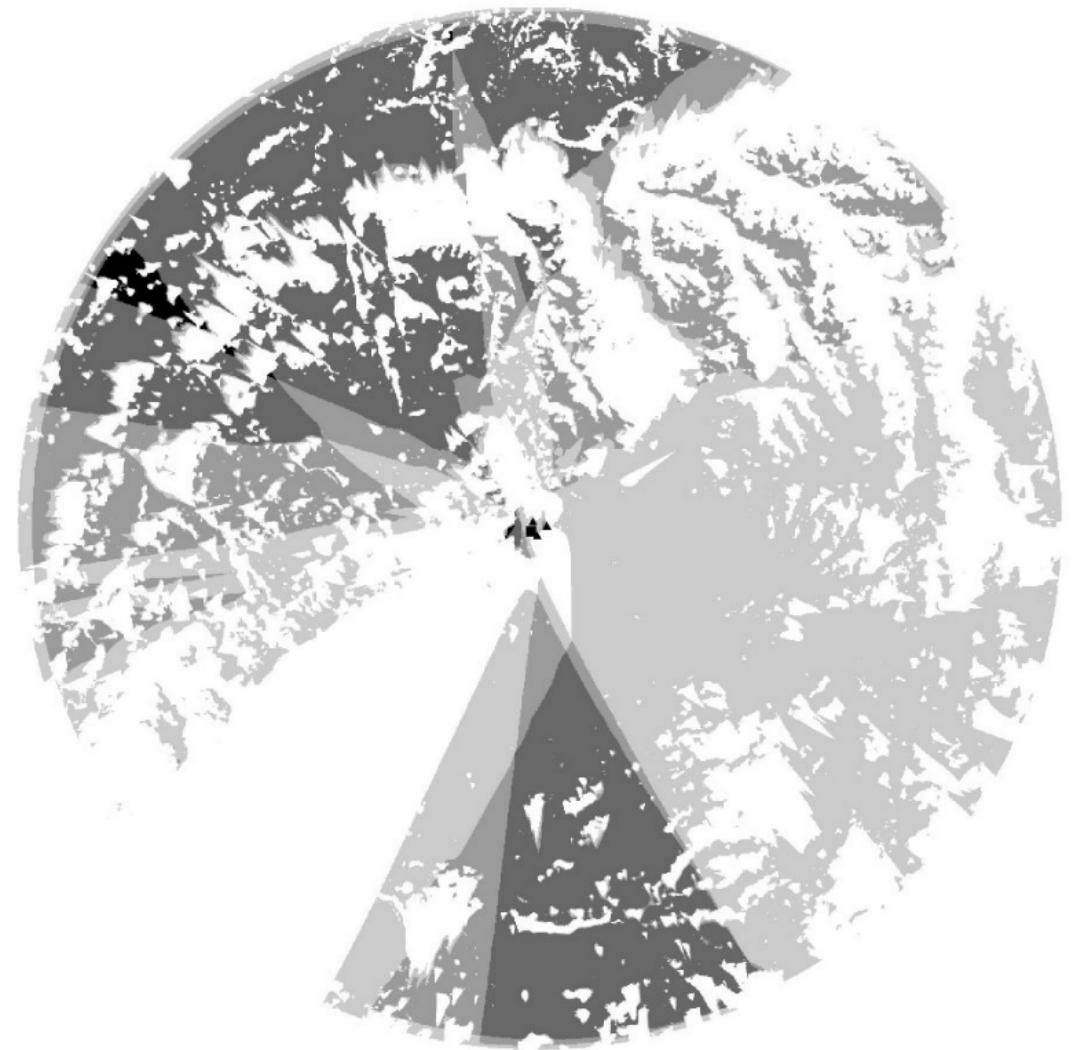
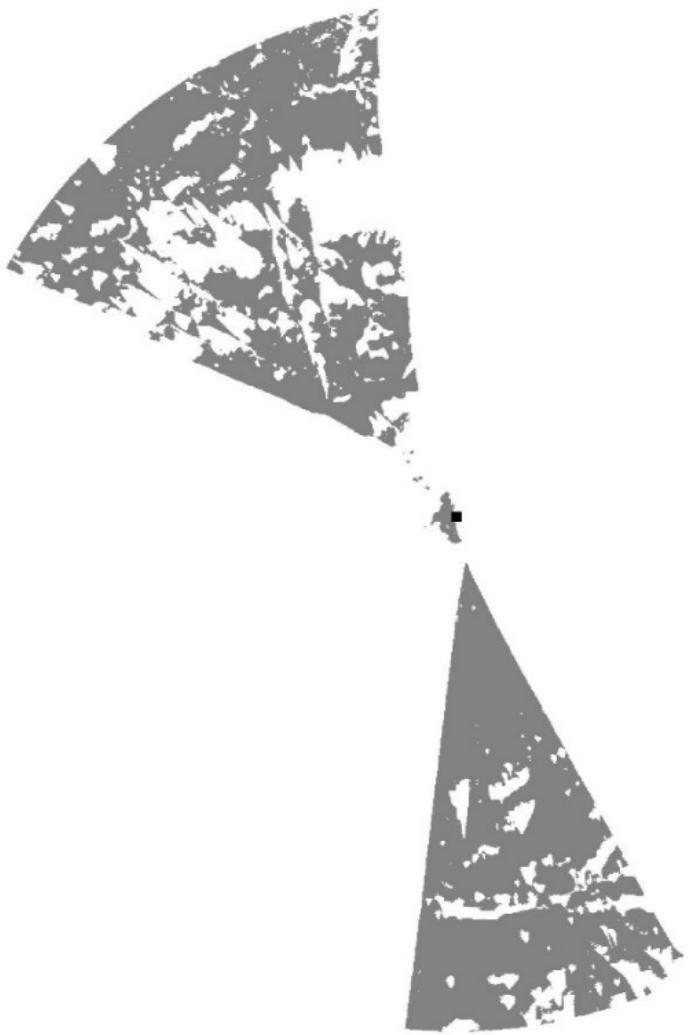


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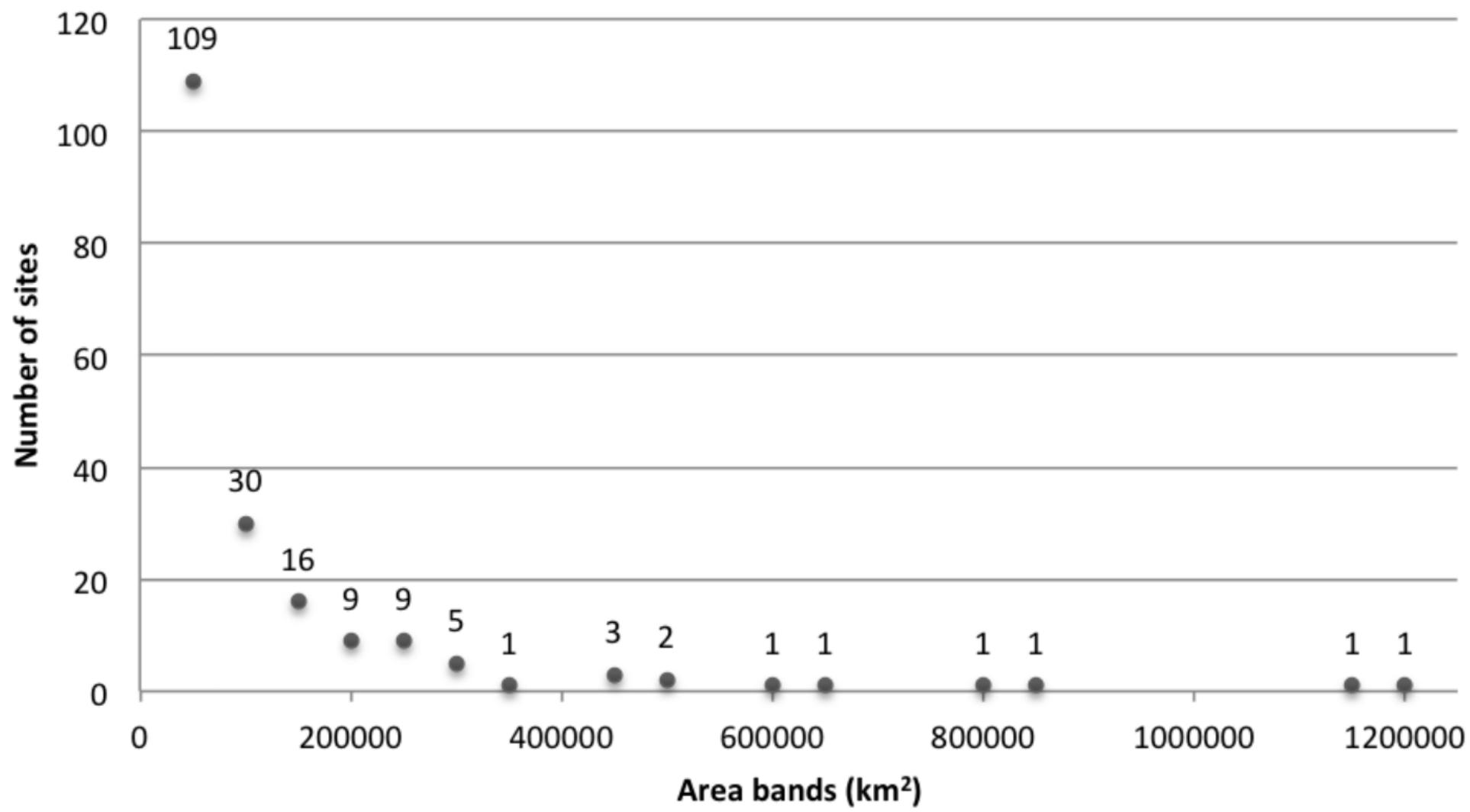
0 5 10 Km



(a)

0 5 10 Km ↑

(b)

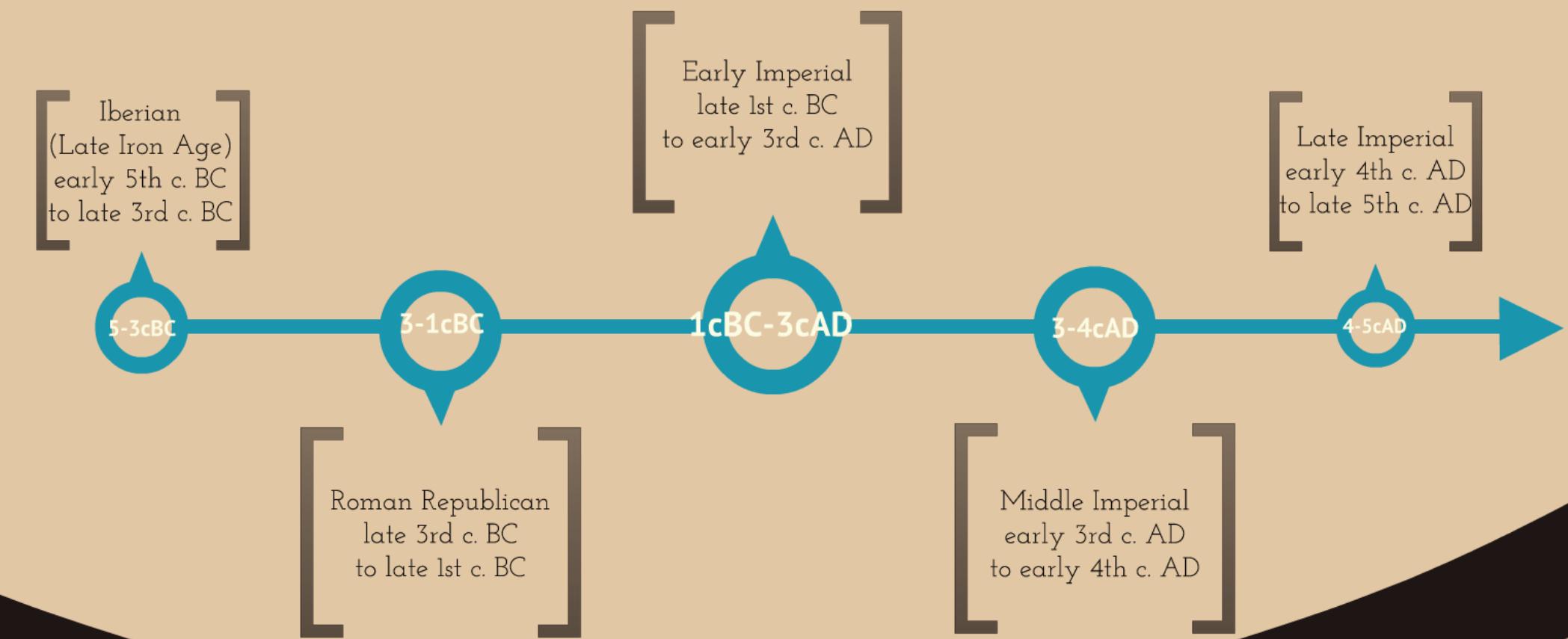


Chronolog

400000 600000 800000 1000000 1200000

Area bands (km²)

Chronology

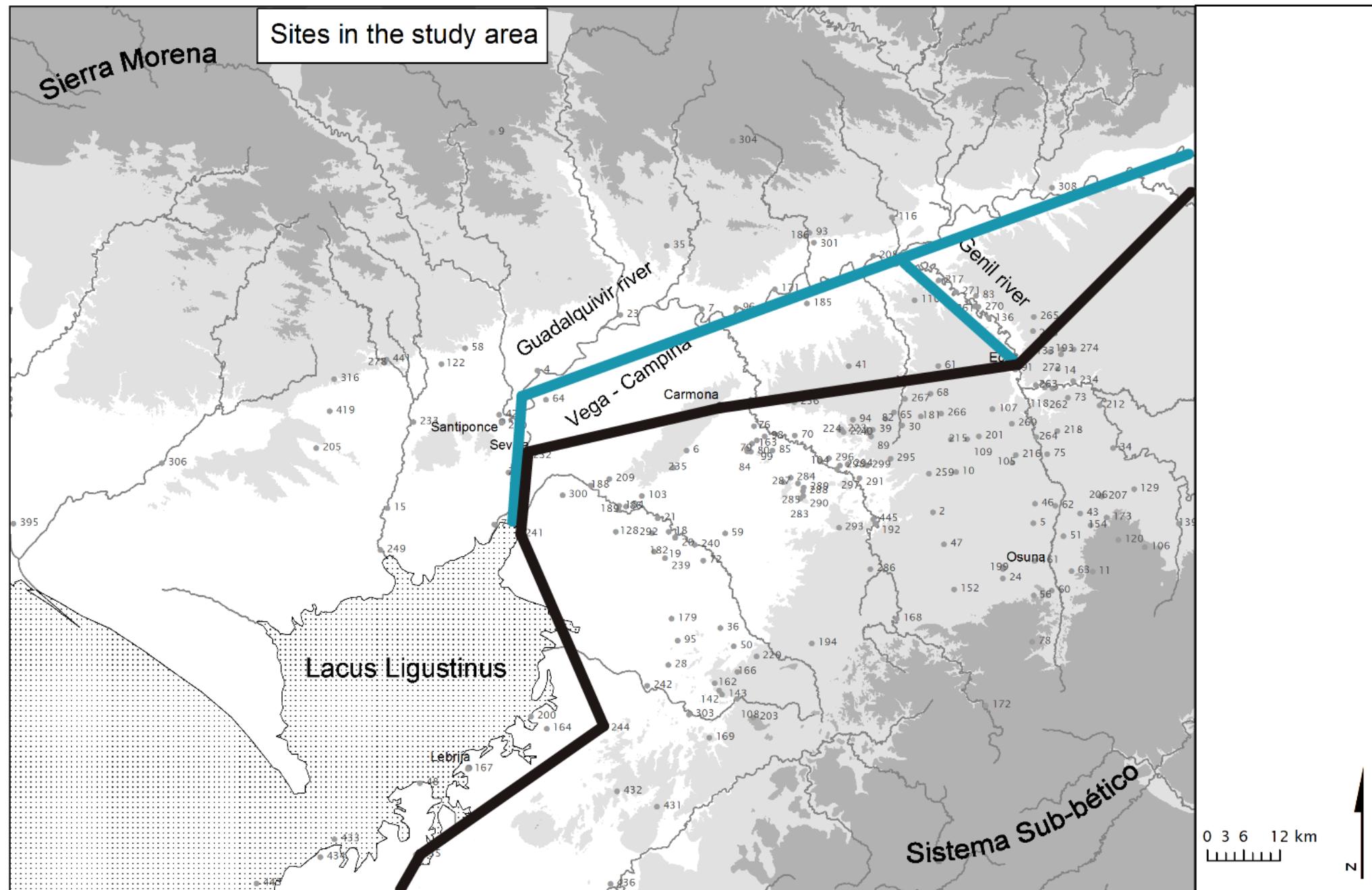


Site Attributes

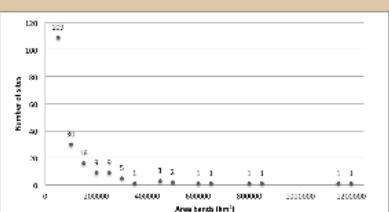
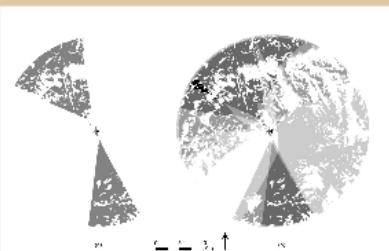
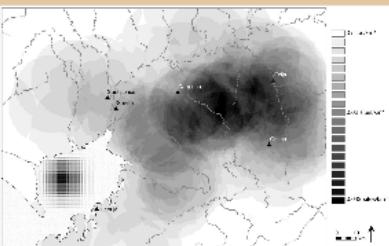
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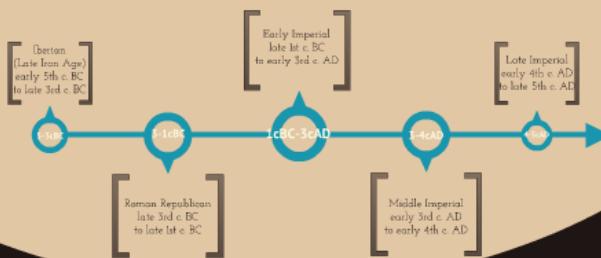
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DEM interpolated from points and contours
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Single observation point per site

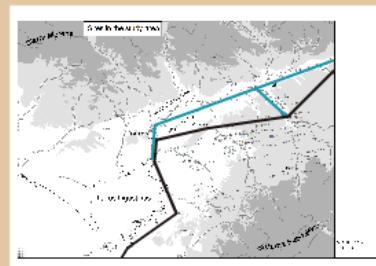


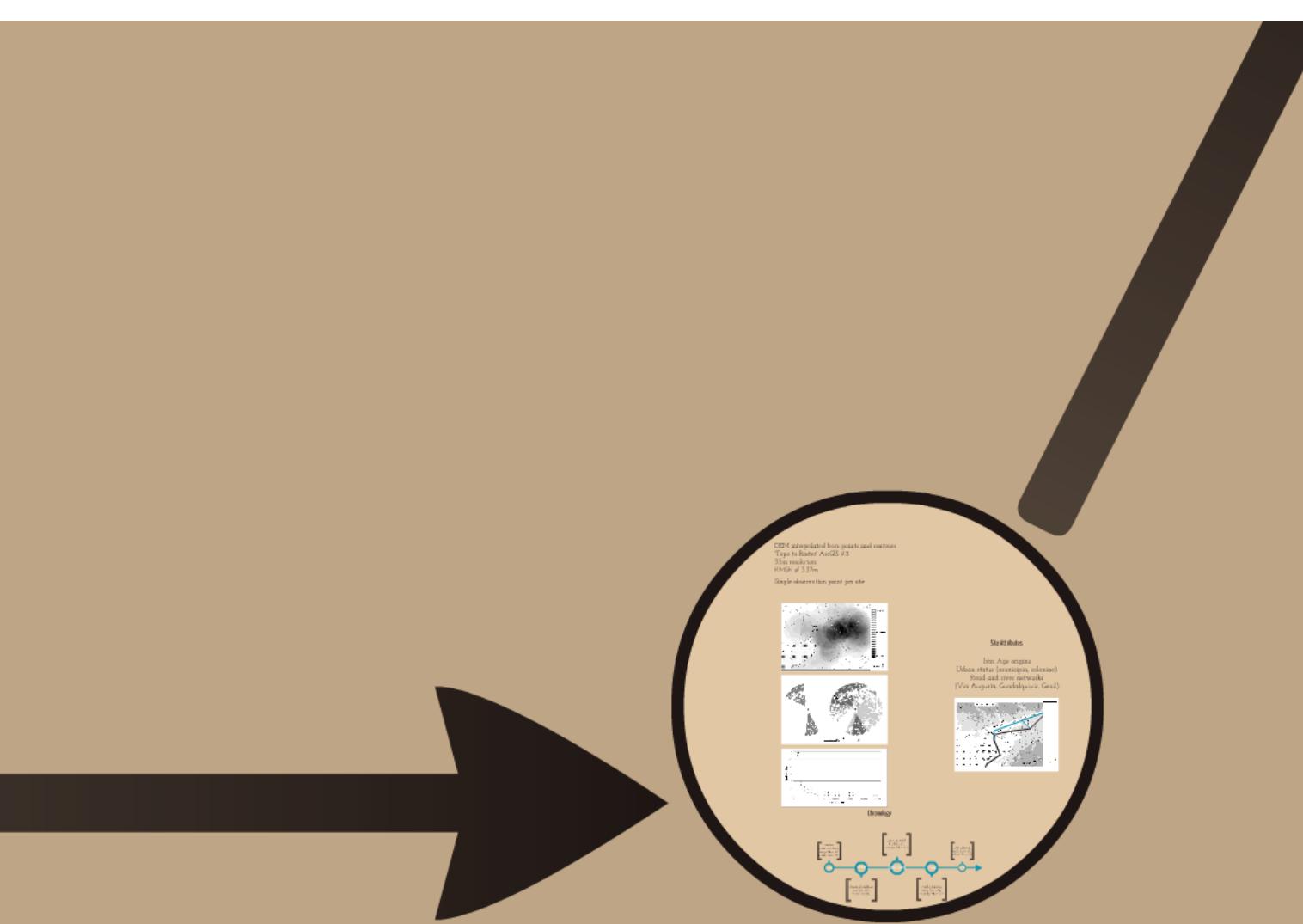
Chronology



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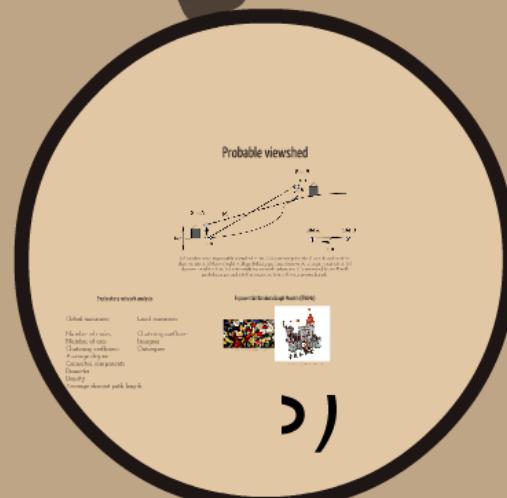
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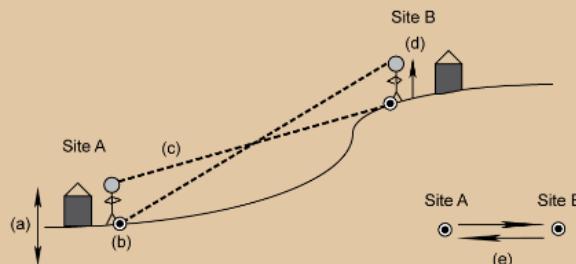


Data

Method



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_{ab} and site B is connected to site A with probability p_{ba} .

Exploratory network analysis

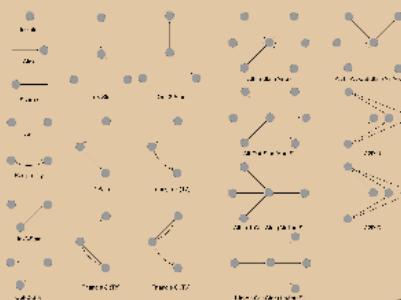
Global measures:

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

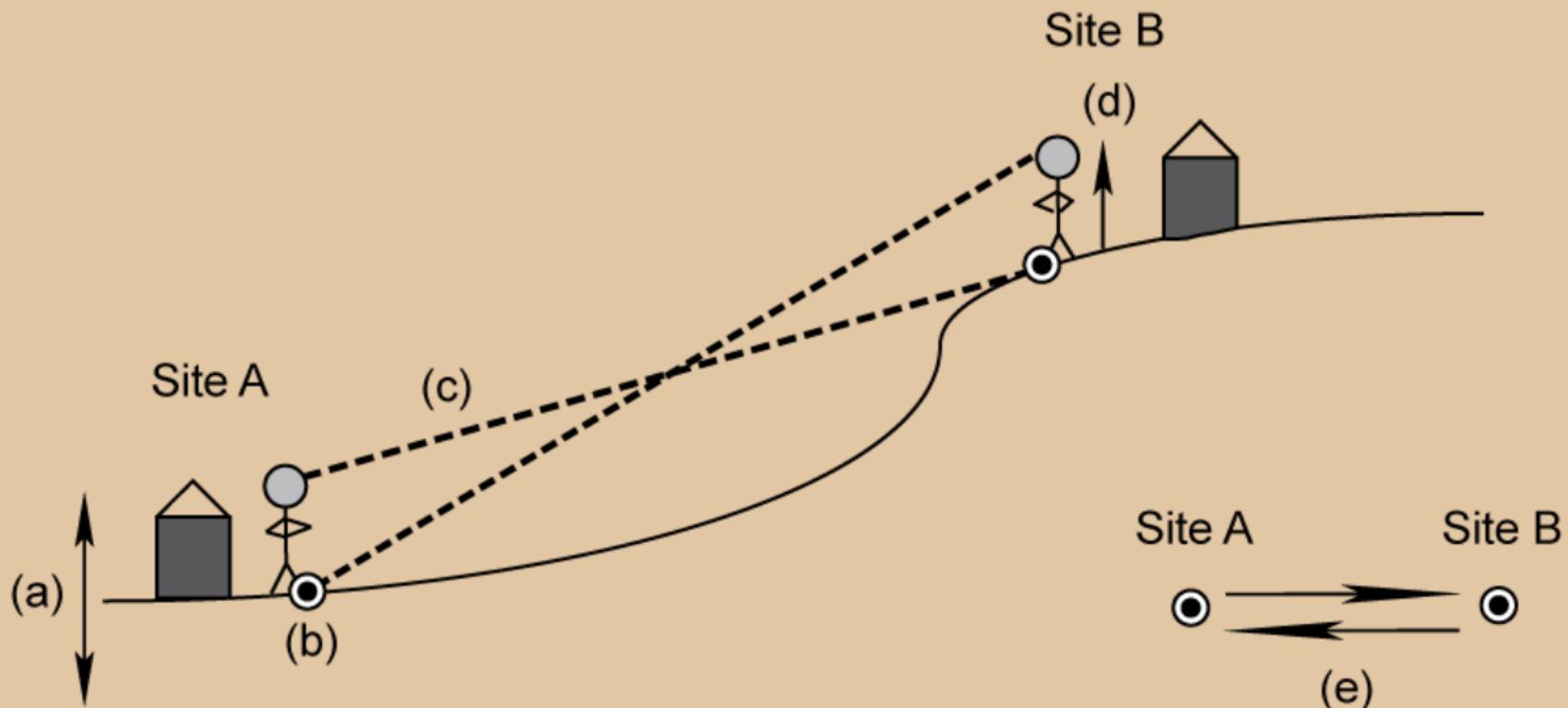
Local measures:

- 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 .

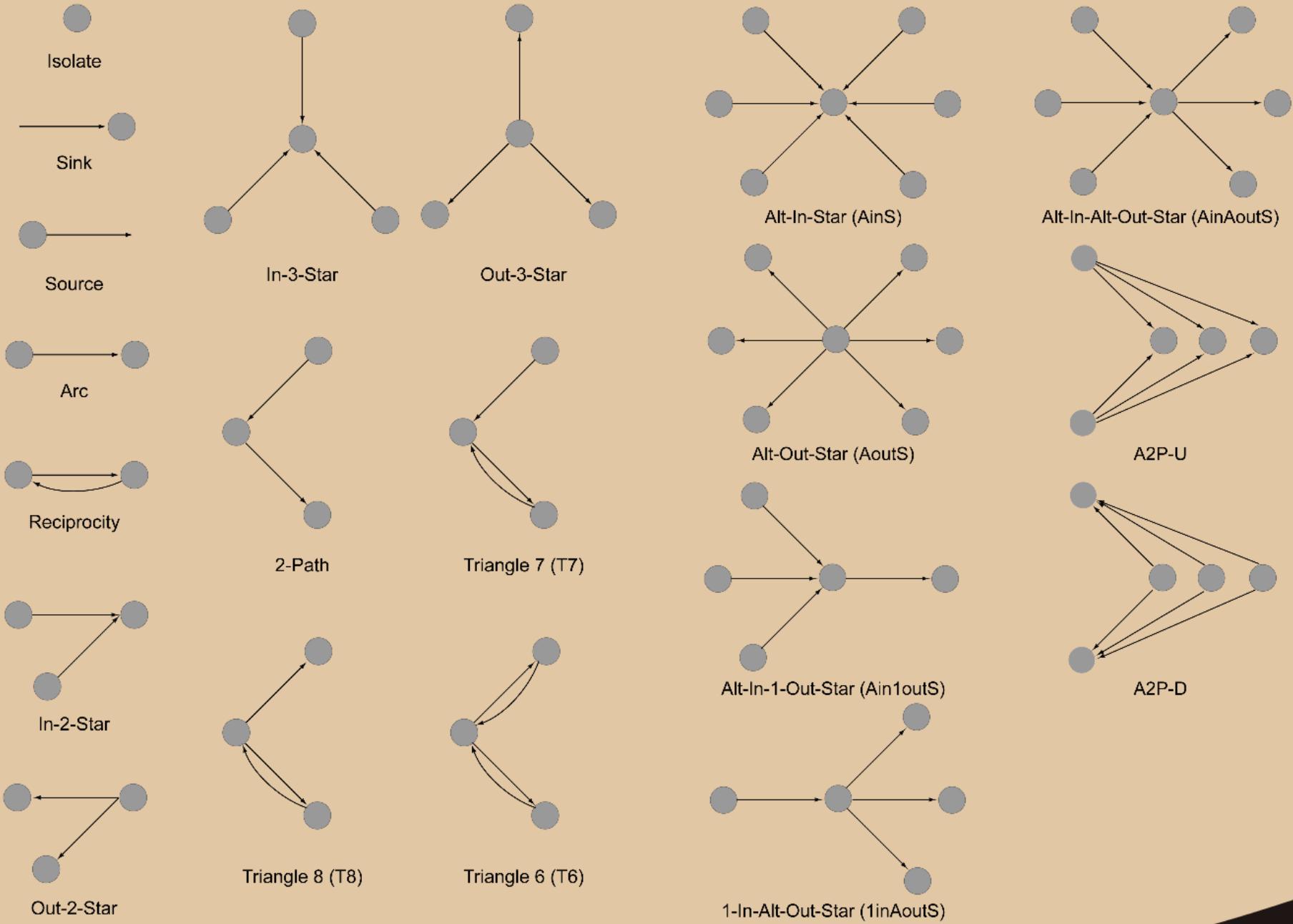
Exponential Random Graph Models (ERGMs)



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

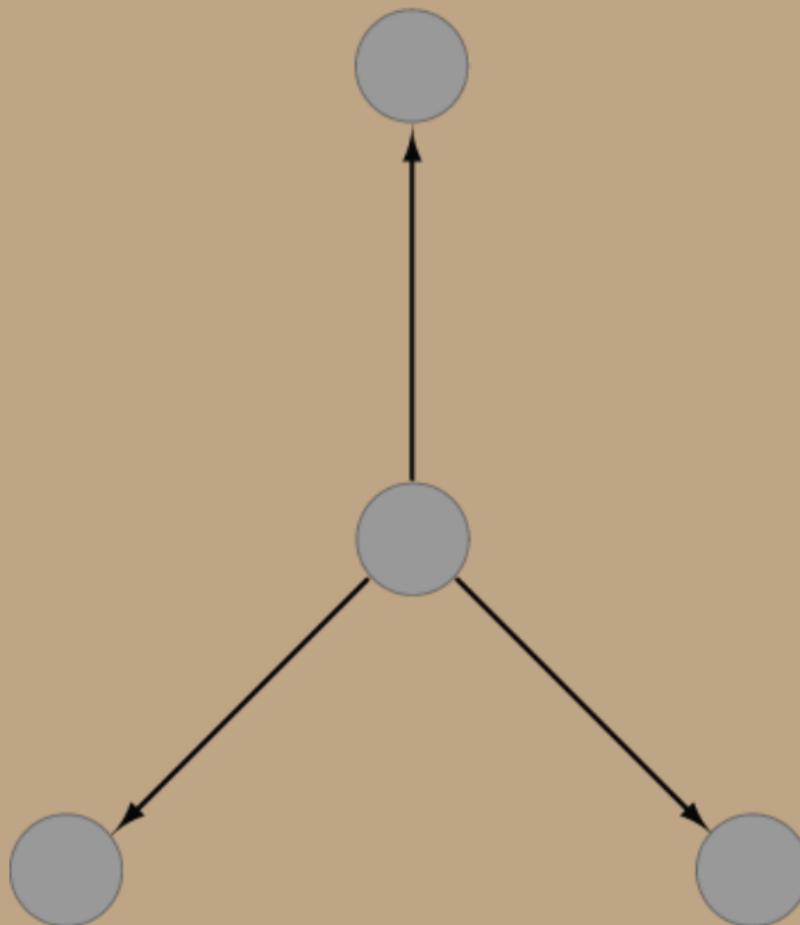
- (i) Iron Age settlements continuing in occupation
- (ii) Roman urban status
- (iii) river and road transport network



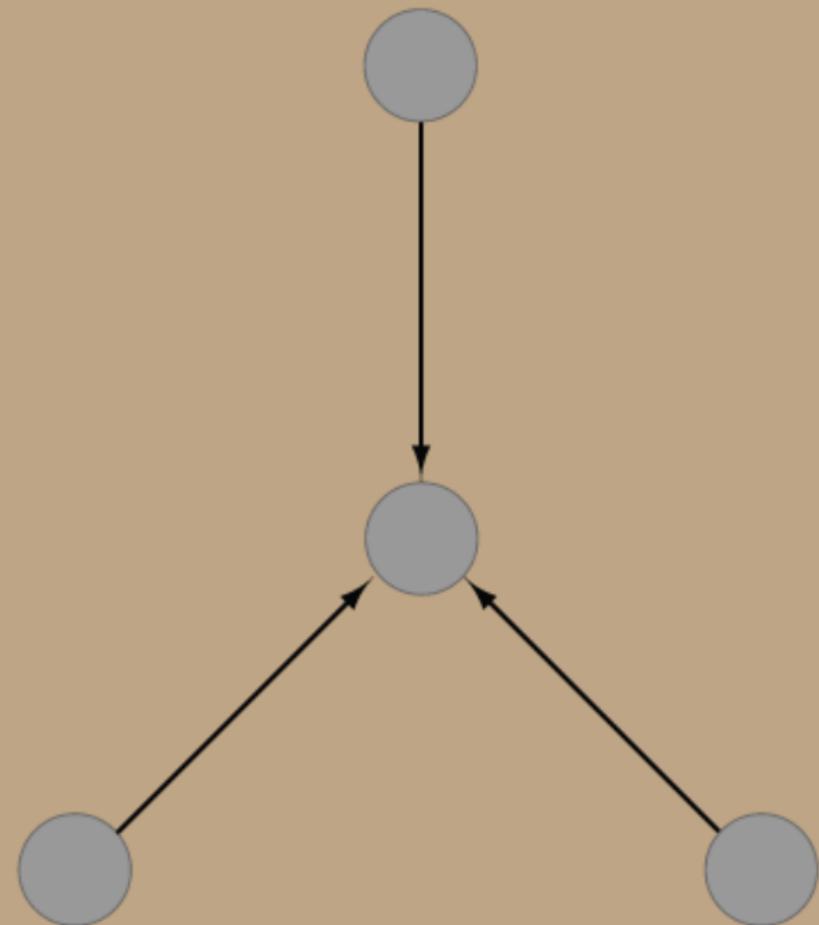
(a)



(d)

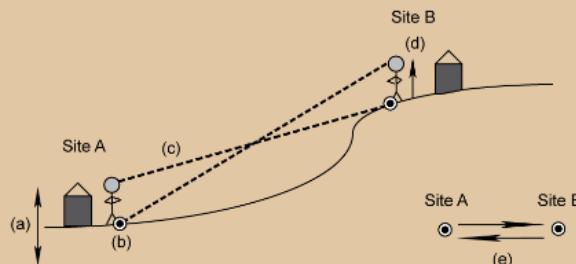


(b)



(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_o and site B is connected to site A with probability p_b .

Exploratory network analysis

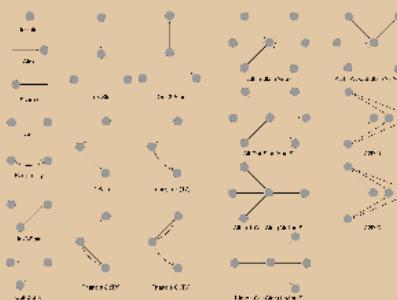
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Local measures:

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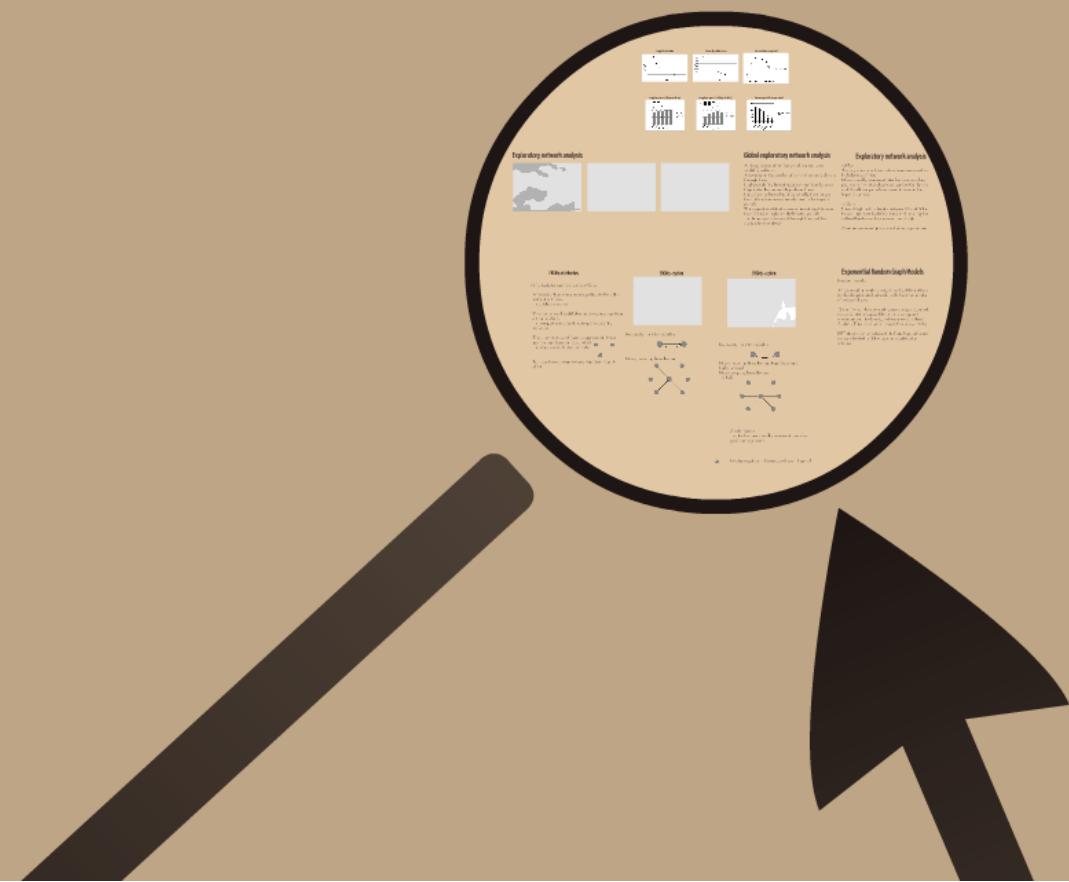
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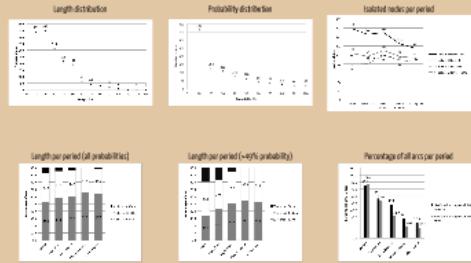


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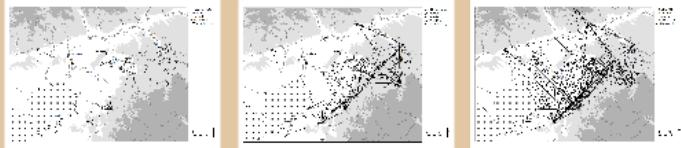


Results





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.

Colonies and municipia are not visually prominent

ERGMs attributes

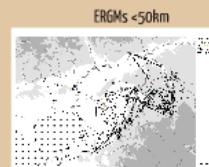
Only Early Imperial networks <20km

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.



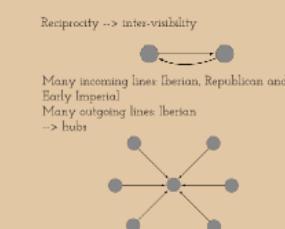
ERGMs <20km



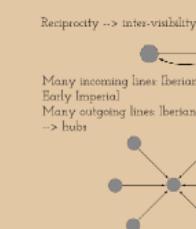
Reciprocity → inter-visibility



Many incoming lines Iberian



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

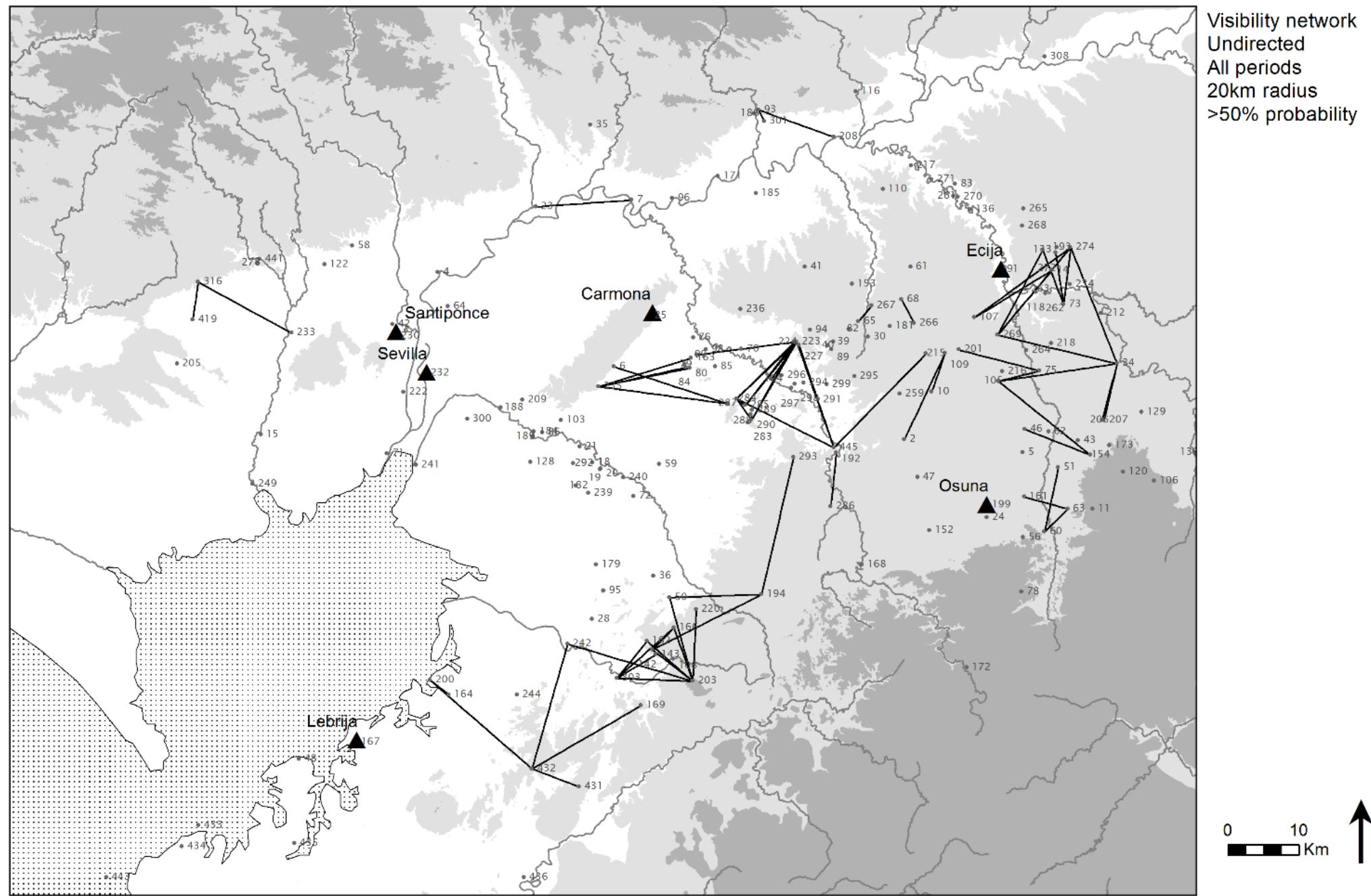
Exponential Random Graph Models

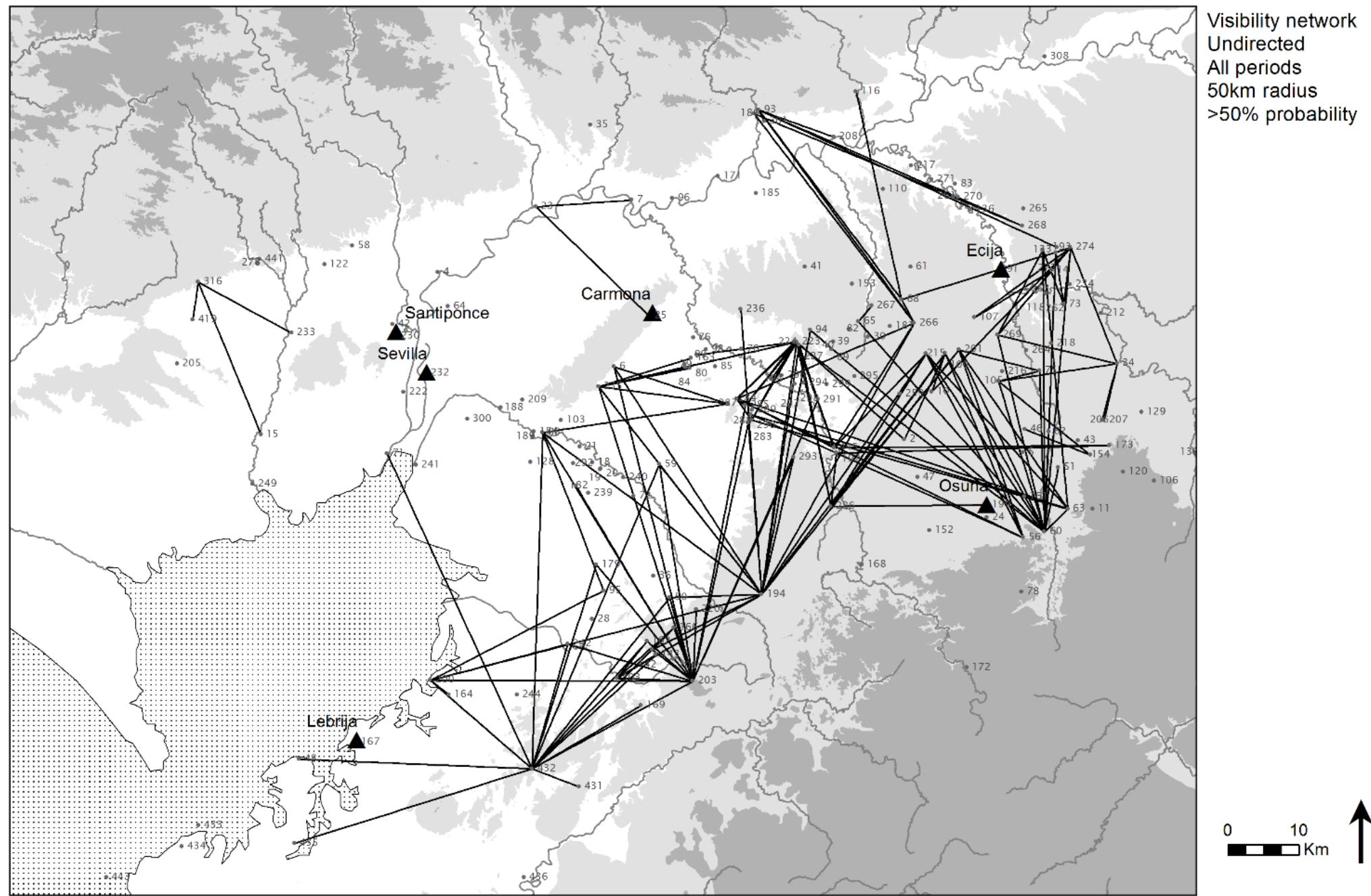
Random models

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

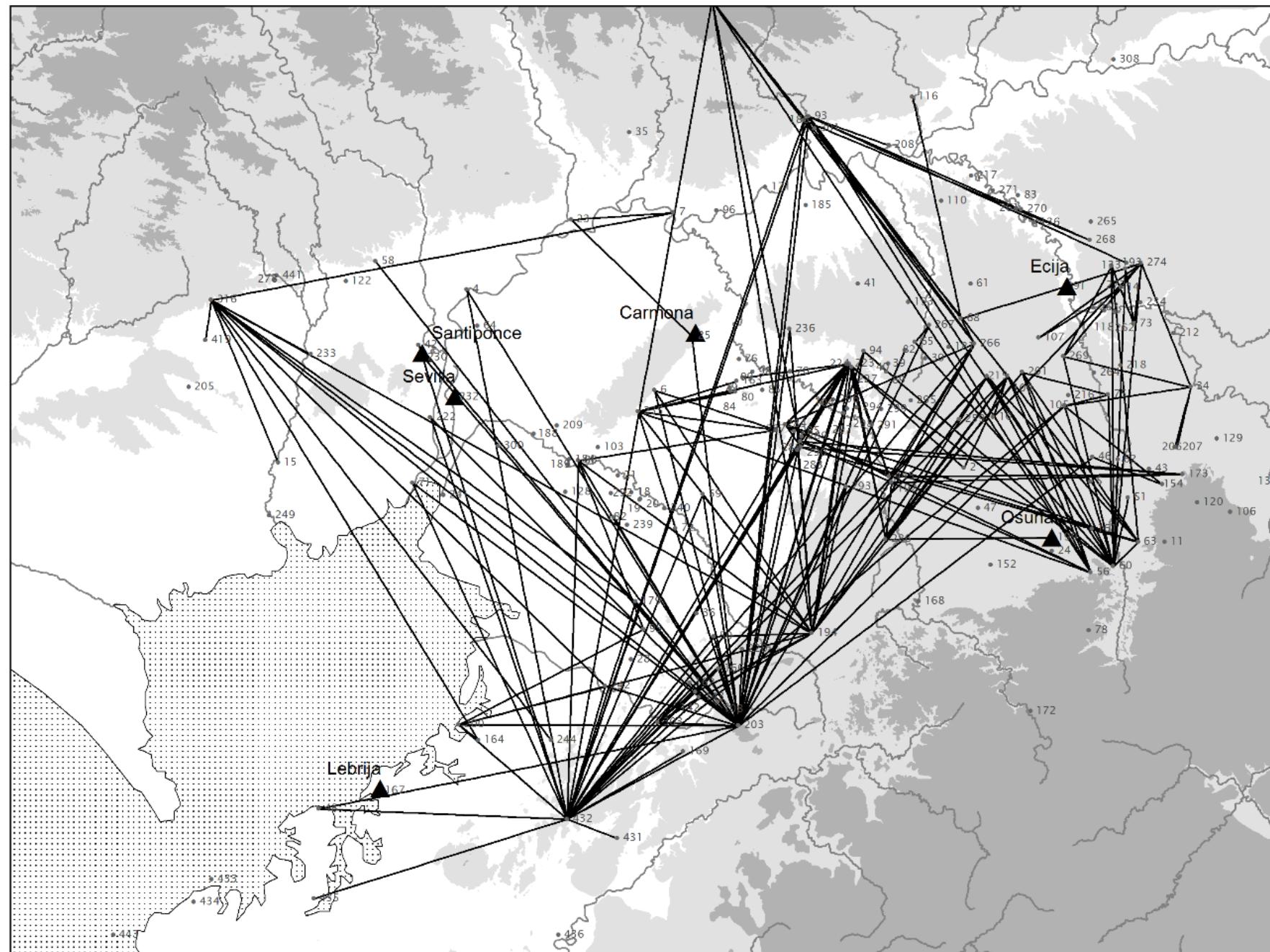
(50 million random networks generated per observed network, 1000 samples. Minimum, average and maximum counts of configurations were considered. Student's T-test p-values all lower than a-level 0.05)

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





Visibility network
Undirected
All periods
Unlimited radius
>50% probability



Global exploratory network analysis

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Exponential Random Graph Models

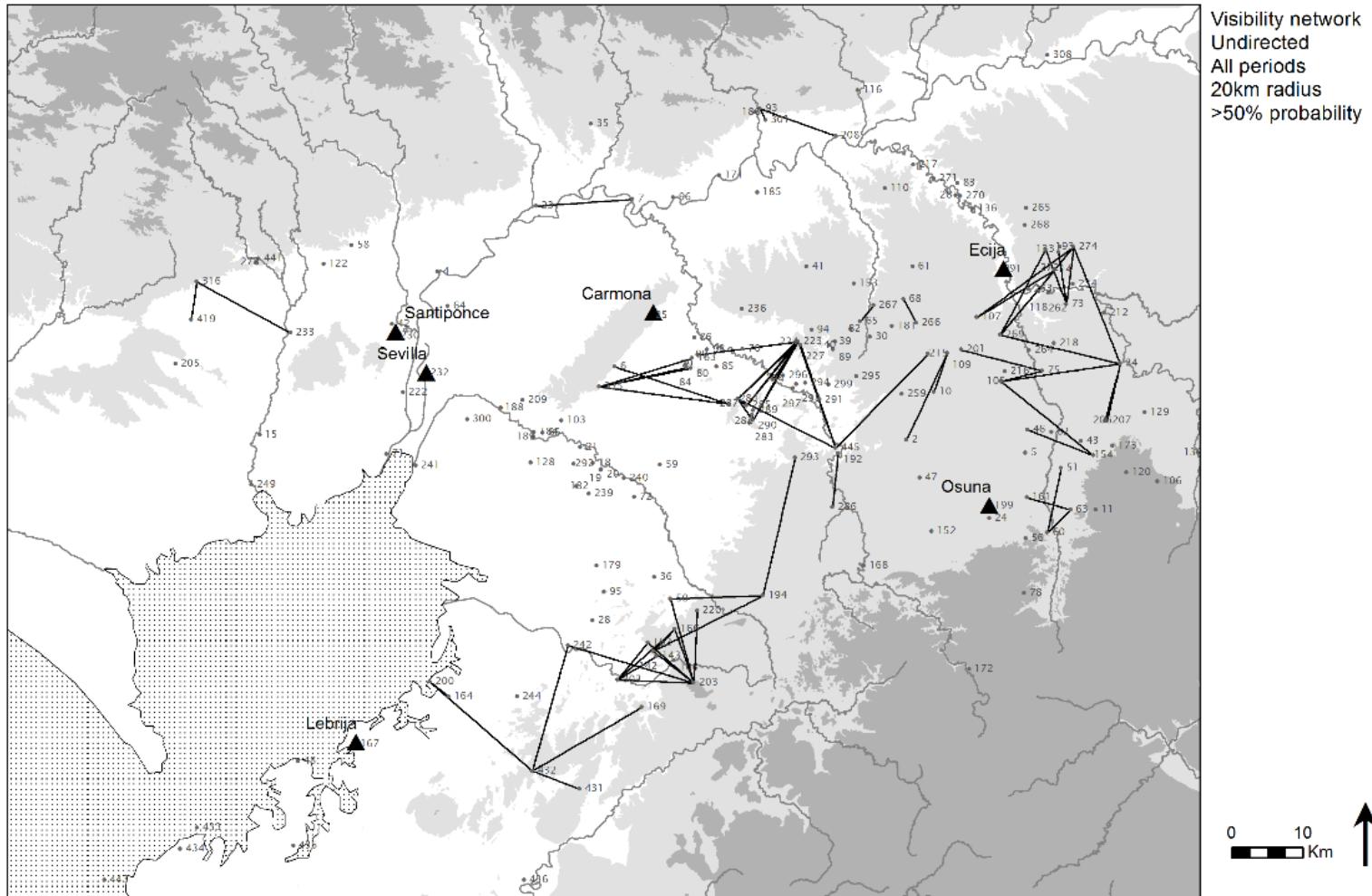
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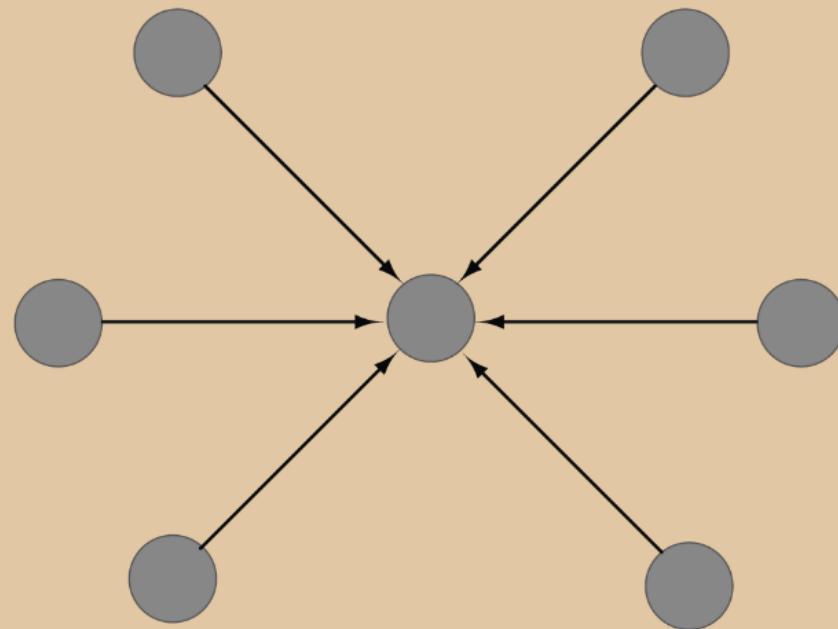


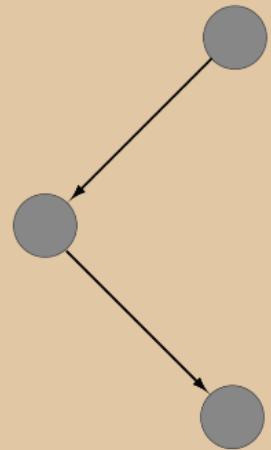
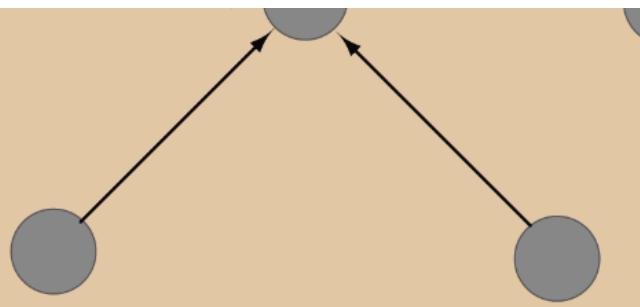
Reciprocity --> inter-visibility



Many incoming lines: Iberian, Republican and Early Imperial

Many outgoing lines: Iberian
--> hubs





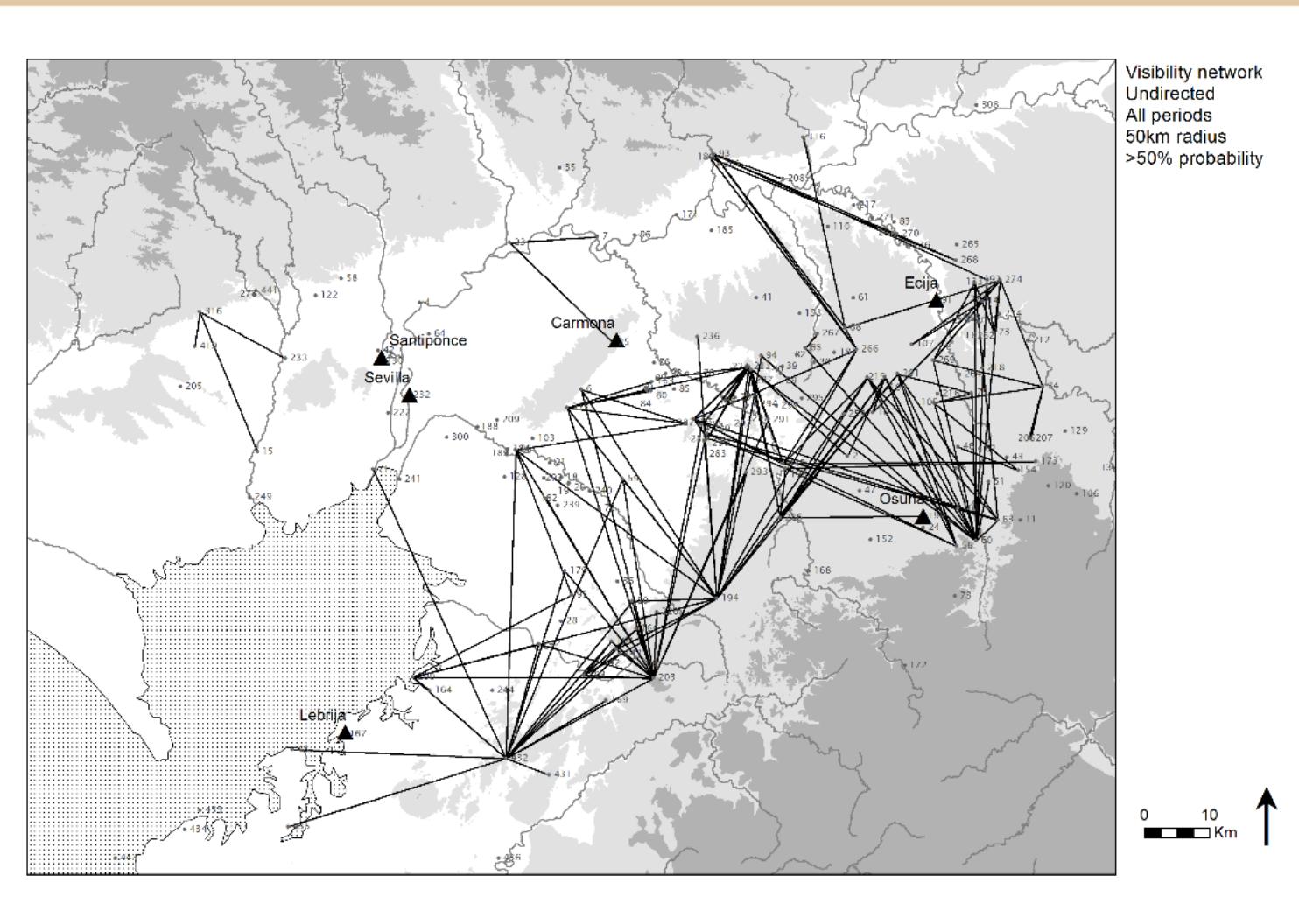
2-path: Iberian

--> sites that are visually prominent are also
good vantage points

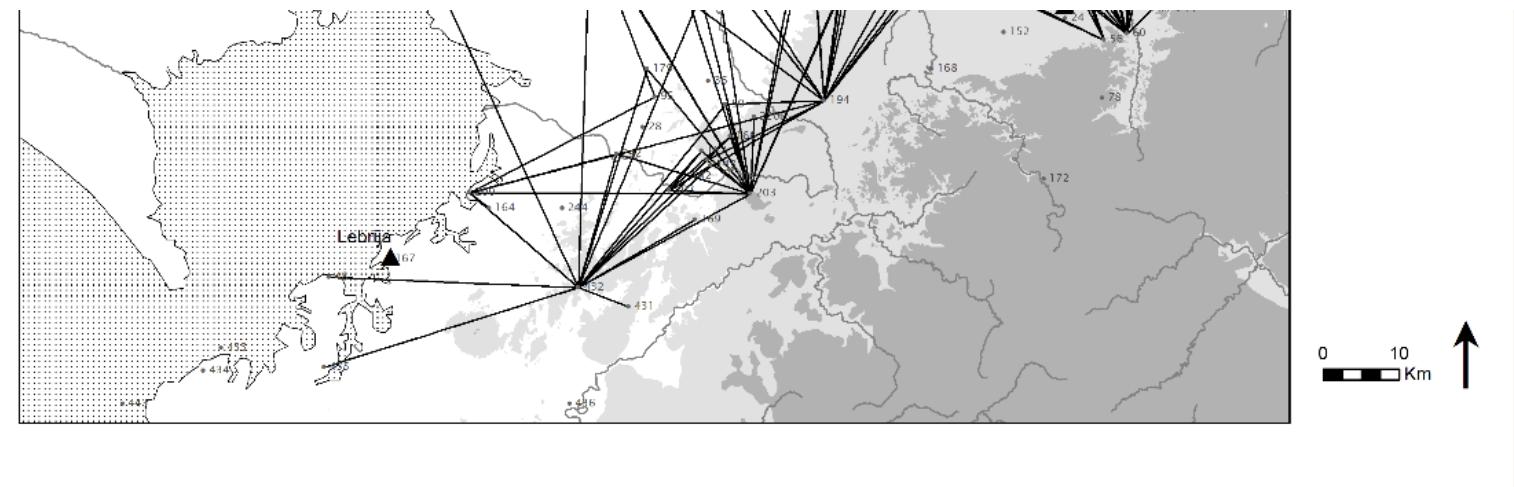


Isolates: negative in Iberian, positive in Imperial

ERGMs <50km



Reciprocity --> inter-visibility



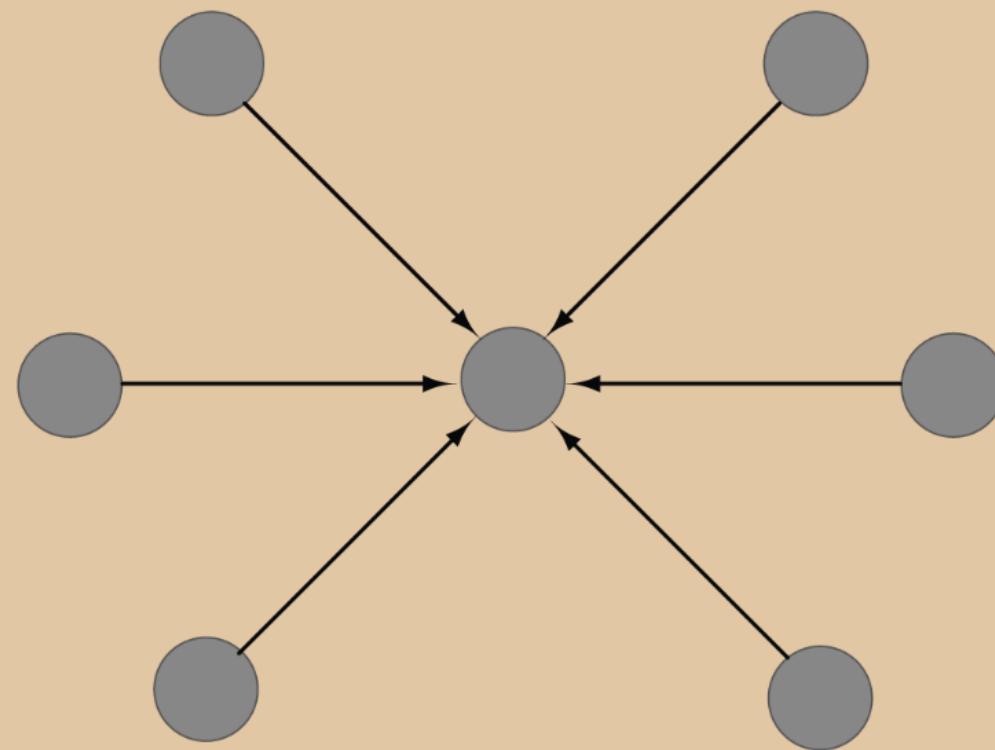
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Many incoming lines: Iberian



Many incoming lines: Iberian



ERGMs attributes

Only Early Imperial networks <20km

All models show many more significant effects than without attributes.

--> attributes matter

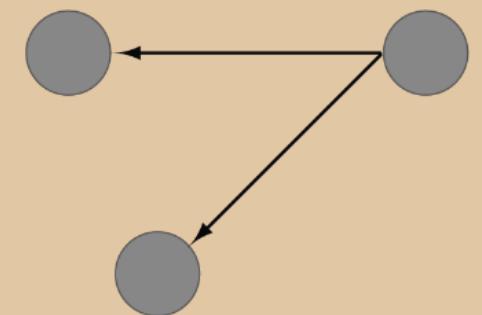
The river or road model does not show any significant attribute effects.

--> transport networks do not explain visibility networks

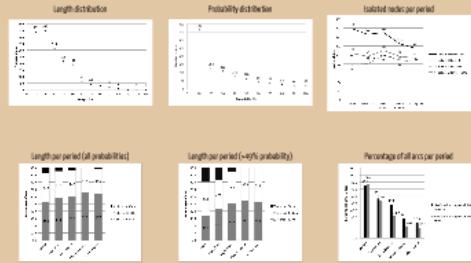
The urban status and Iberian origins model has a positive significant out-2-star effect.



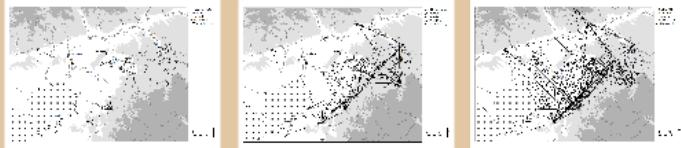
The urban status and Iberian origins model has a positive significant out-2-star effect.
--> visual control but not as hubs



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



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.

Colonies and municipia are not visually prominent

ERGMs attributes

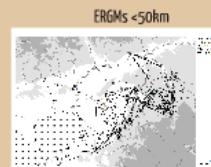
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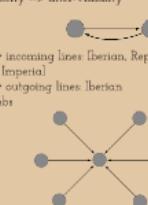
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Reciprocity → inter-visibility



Reciprocity → inter-visibility



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

Isolates negative in Iberian, positive in Imperial

Exponential Random Graph Models

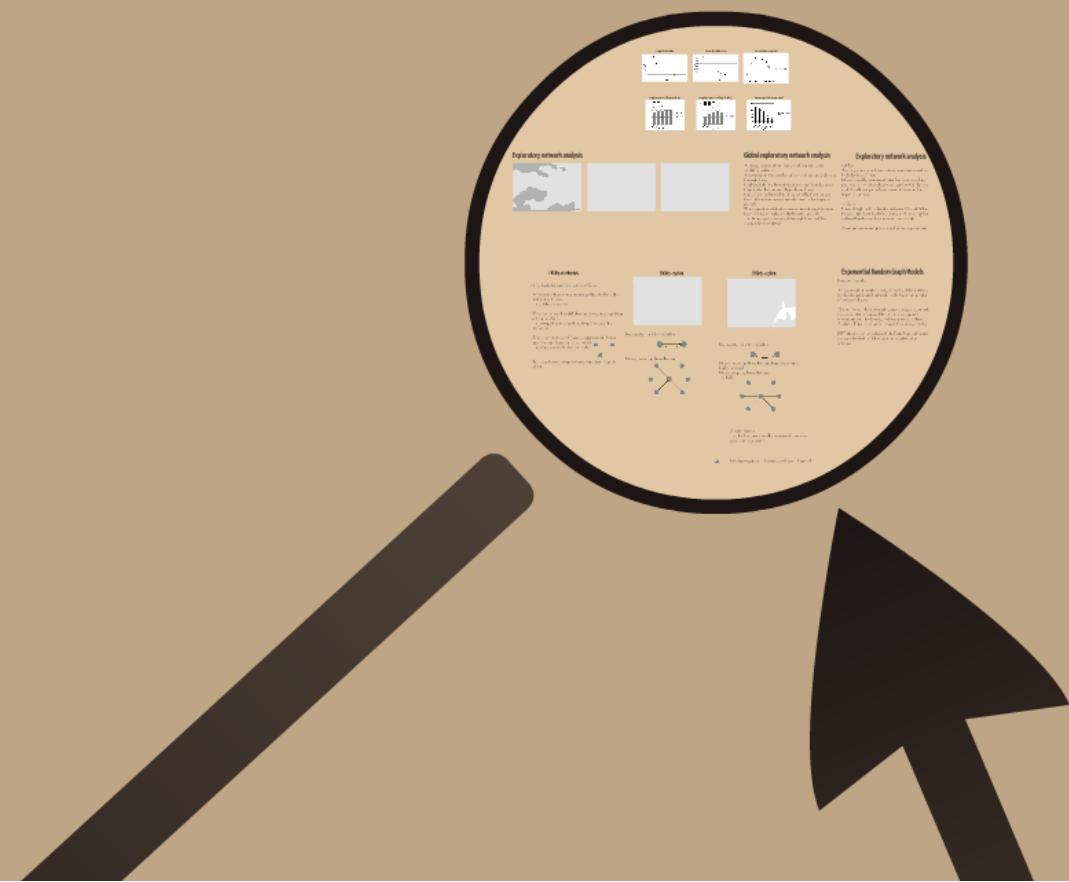
Random models

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 a-level 0.05)

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

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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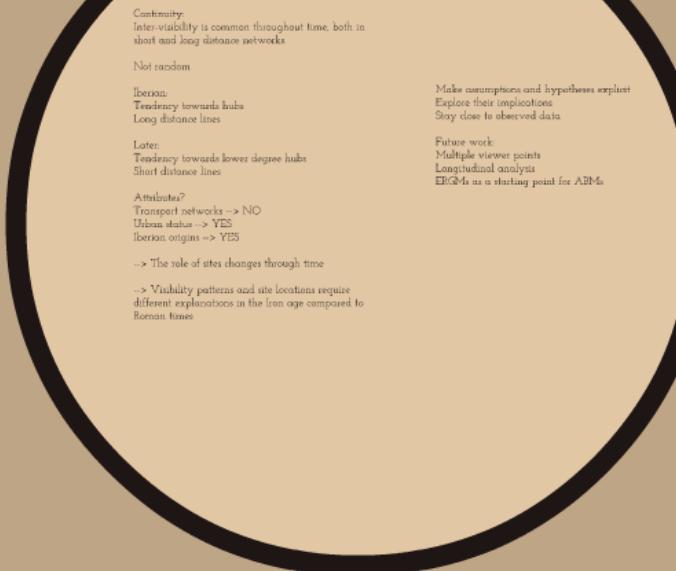
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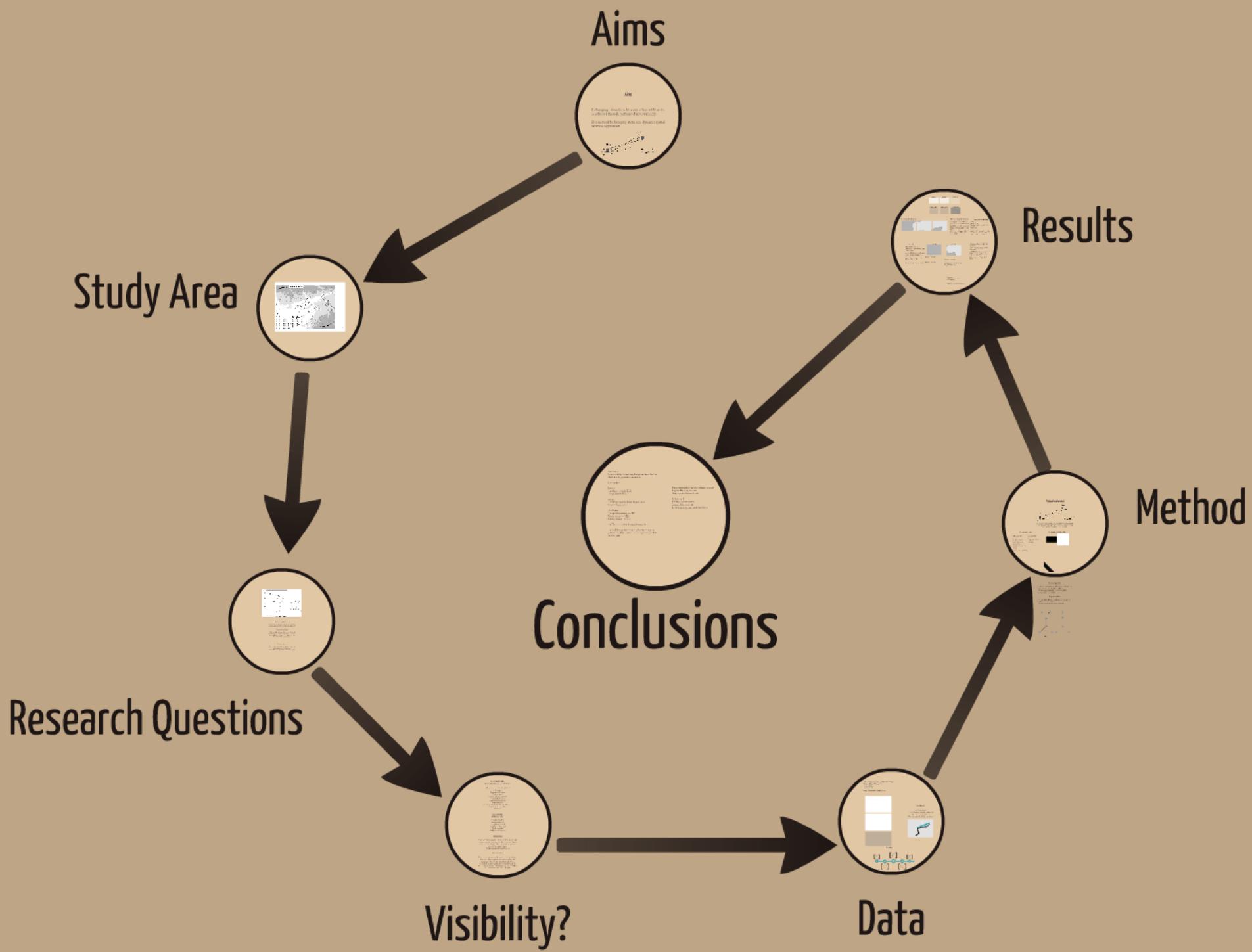
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THANK YOU!

<http://connectedpast.soton.ac.uk/>

<http://archaeologicalnetworks.wordpress.com/>

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