SAGALASSOS ARCHAEOLOGICAL RESEARCH PROJECT

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KU LEUVEN

Connectivity and interaction: Networks as drivers of social complexity

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Connectivity – Interaction – Networks - Complexity

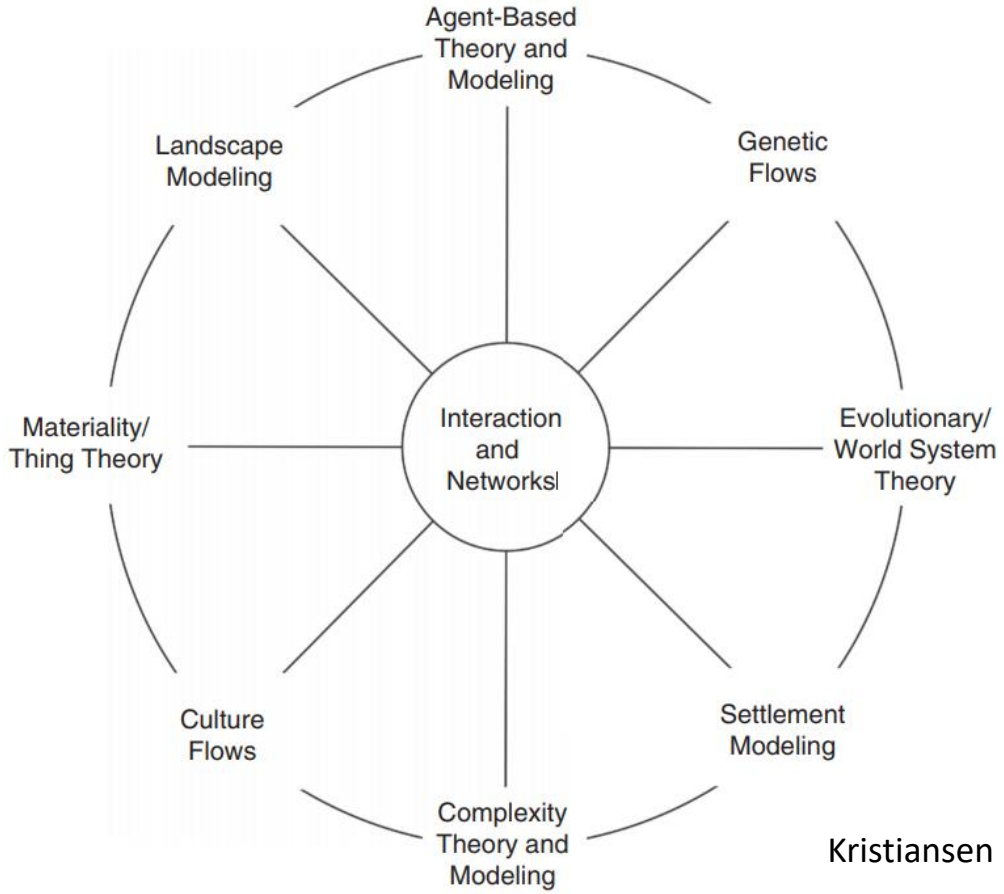
Connections generate networks and interactions shape connections

Networks not needed for studying connectivity

- Broodbank's *Making of the Middle Sea* (2013).
- Globalization (Pitts & Versluys 2016)
- World-systems theory (Korzeniewicz 2017)

Broader relational turn in humanities and social sciences

Connectivity + networks = formal methodology



Kristiansen 2014

Korzeniewicz, R.P., 2017. *The World-System As Unit of Analysis: Past Contributions and Future Advances*.
Kristiansen, K., 2014. Towards a New Paradigm? The Third Science Revolution and its Possible Consequences in Archaeology. *Current Swedish Archaeology* 22, p.11–40
Pitts, M. and Versluys, M.J. eds., 2016. *Globalisation and the Roman World: World History, Connectivity and Material Culture*.

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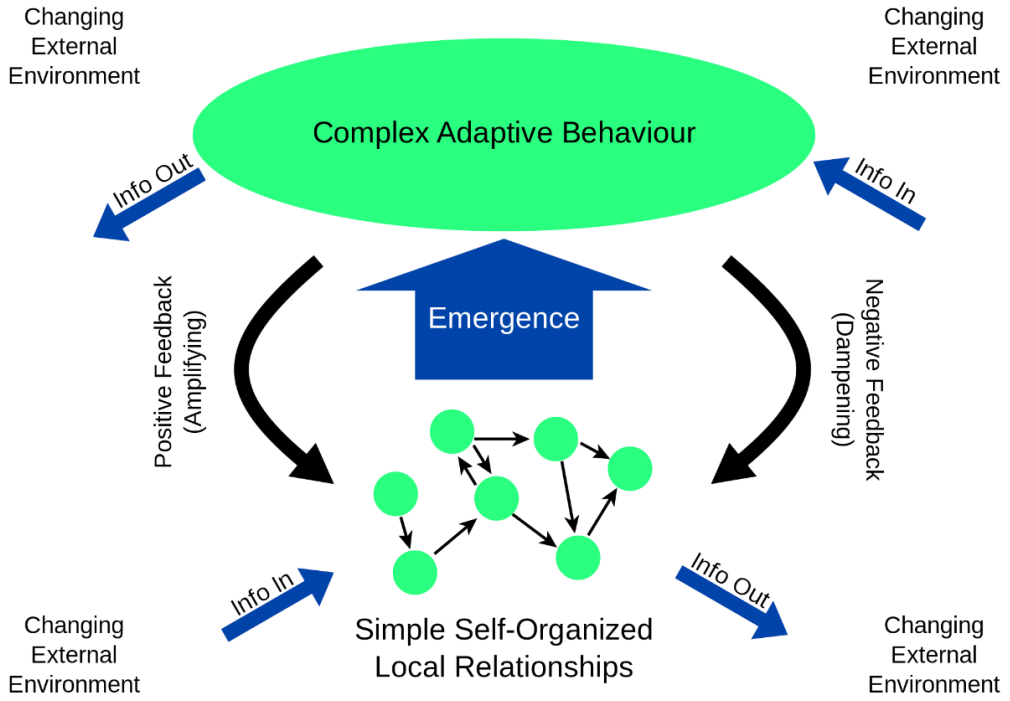
Central framework: Complexity theory

Social complexity entails the applications of the theories, concepts and methods of **complex systems thinking** to social entities

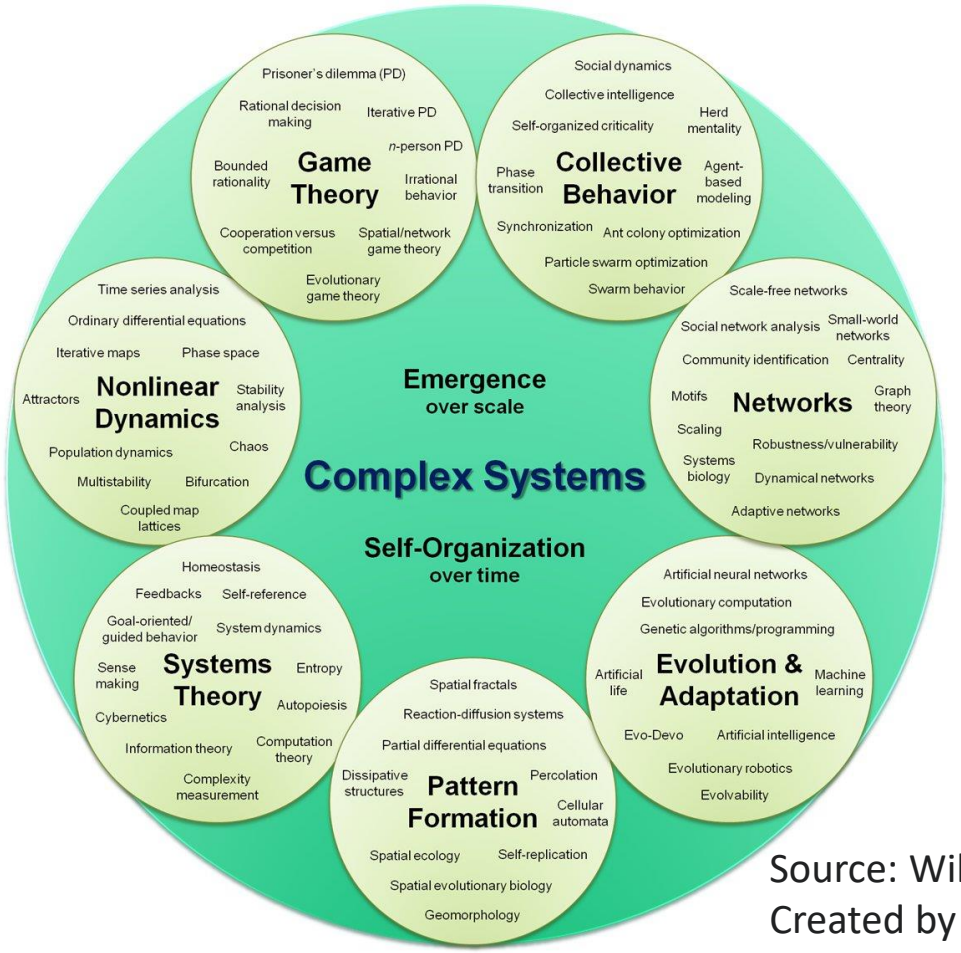
Complexity theory

- Interactions and information transmission
- Non-linearity
- Emergence
- Feedback

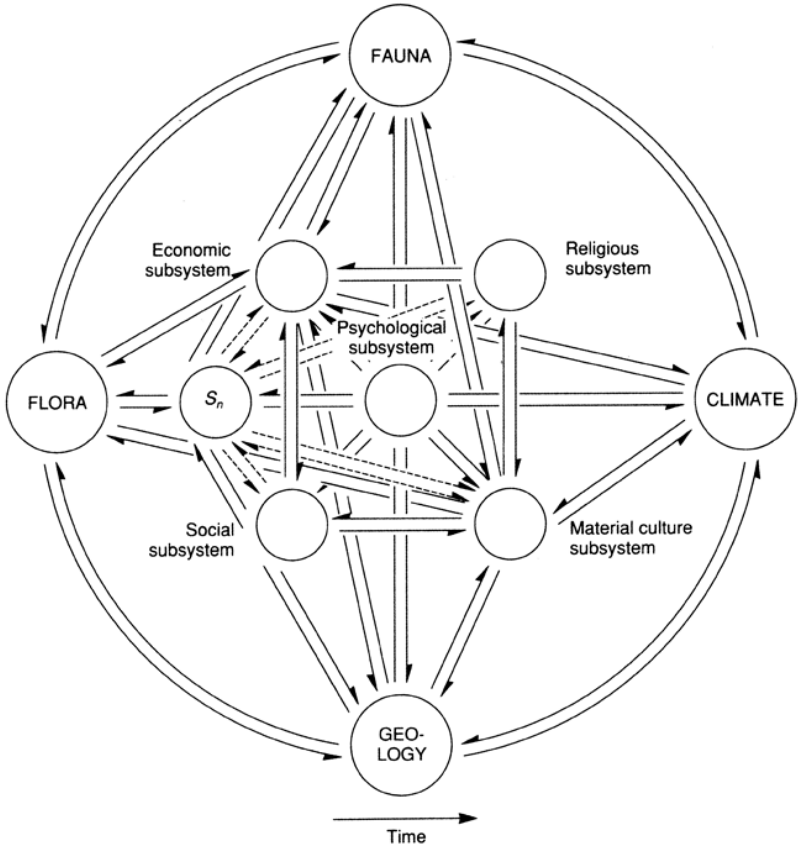
Facilitates interdisciplinarity by offering shared language and concepts



Complex systems and networks



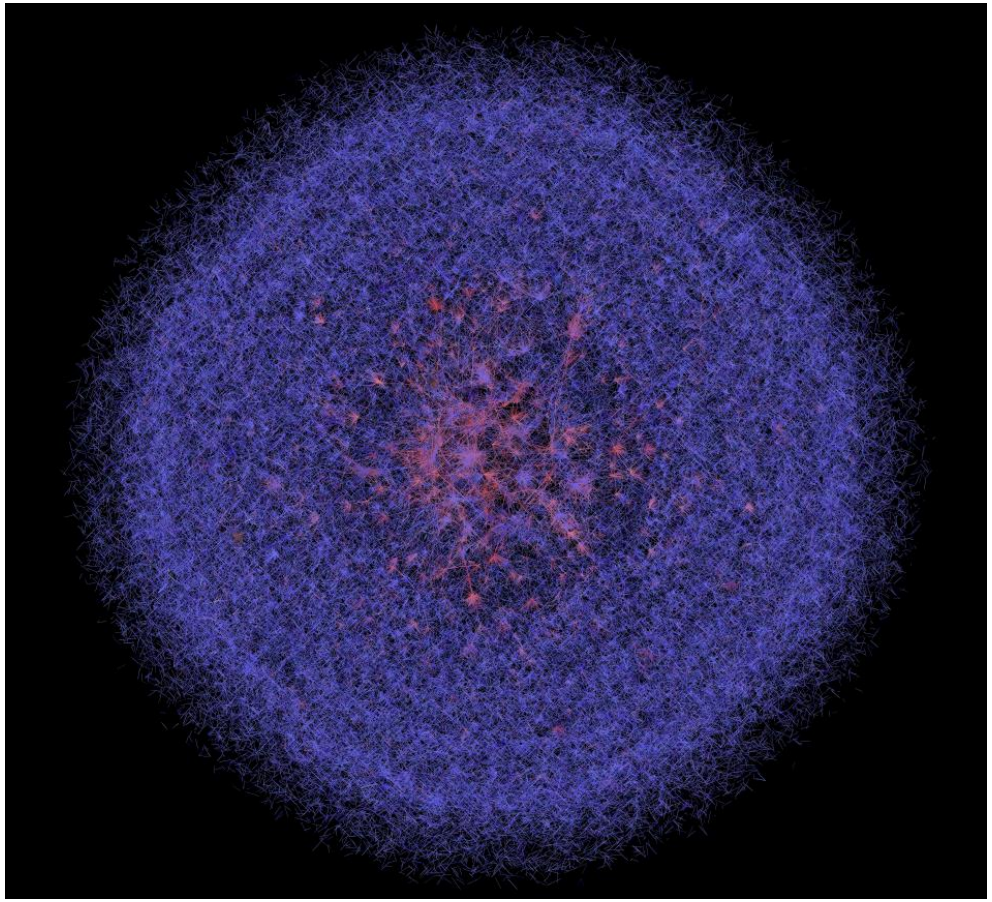
Source: Wikipedia.org
Created by Hiroki Sayama

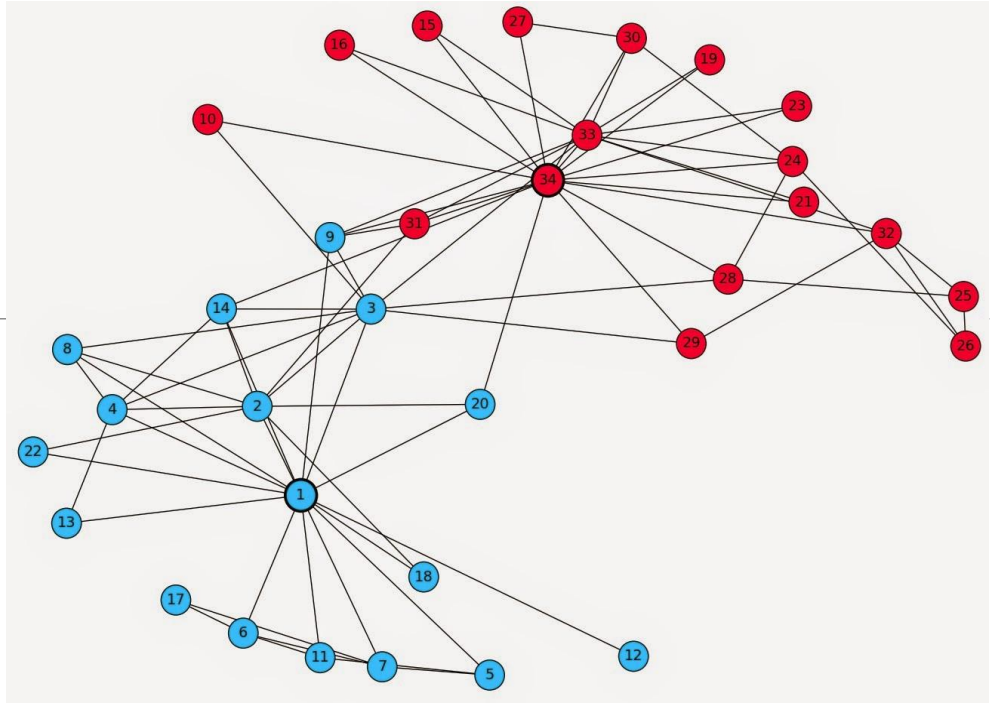


Clarke 1968

Clarke, D.L., 1968. Analytical archaeology.

Networks





What are networks?

- General approach
- Visualization
- Formal representation
- Quantitative analysis

https://dhs.stanford.edu/gephi-workshop/twitter-network-gallery/

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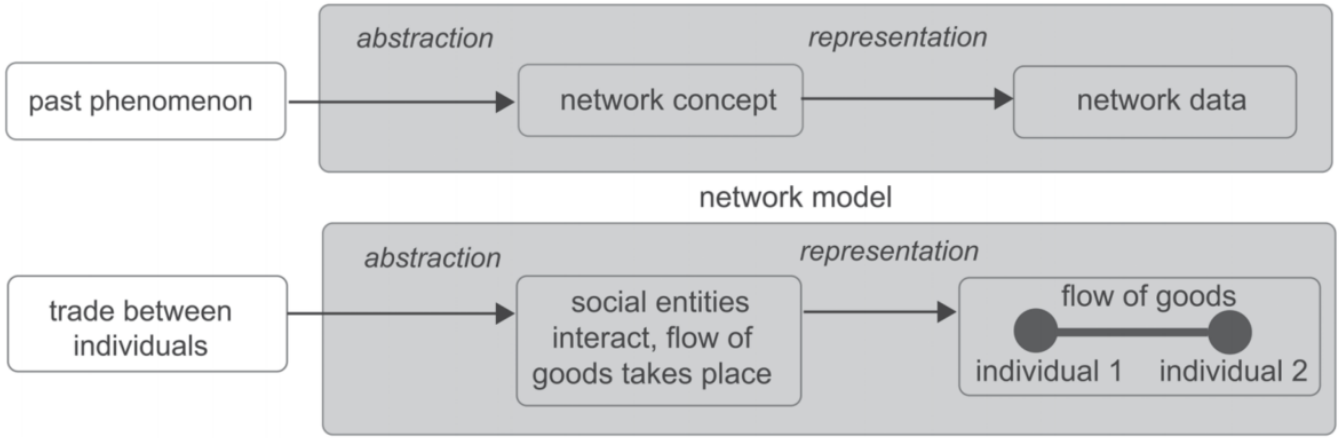
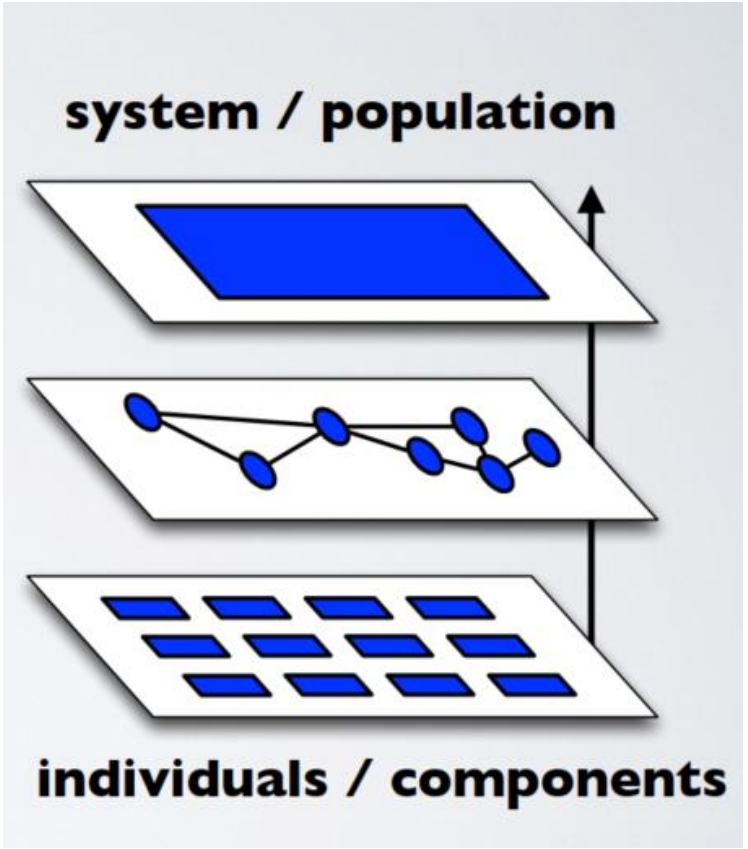
Network science



Collar et al. 2015



Abstraction

Representation

Analysis

- Node level
- Network level

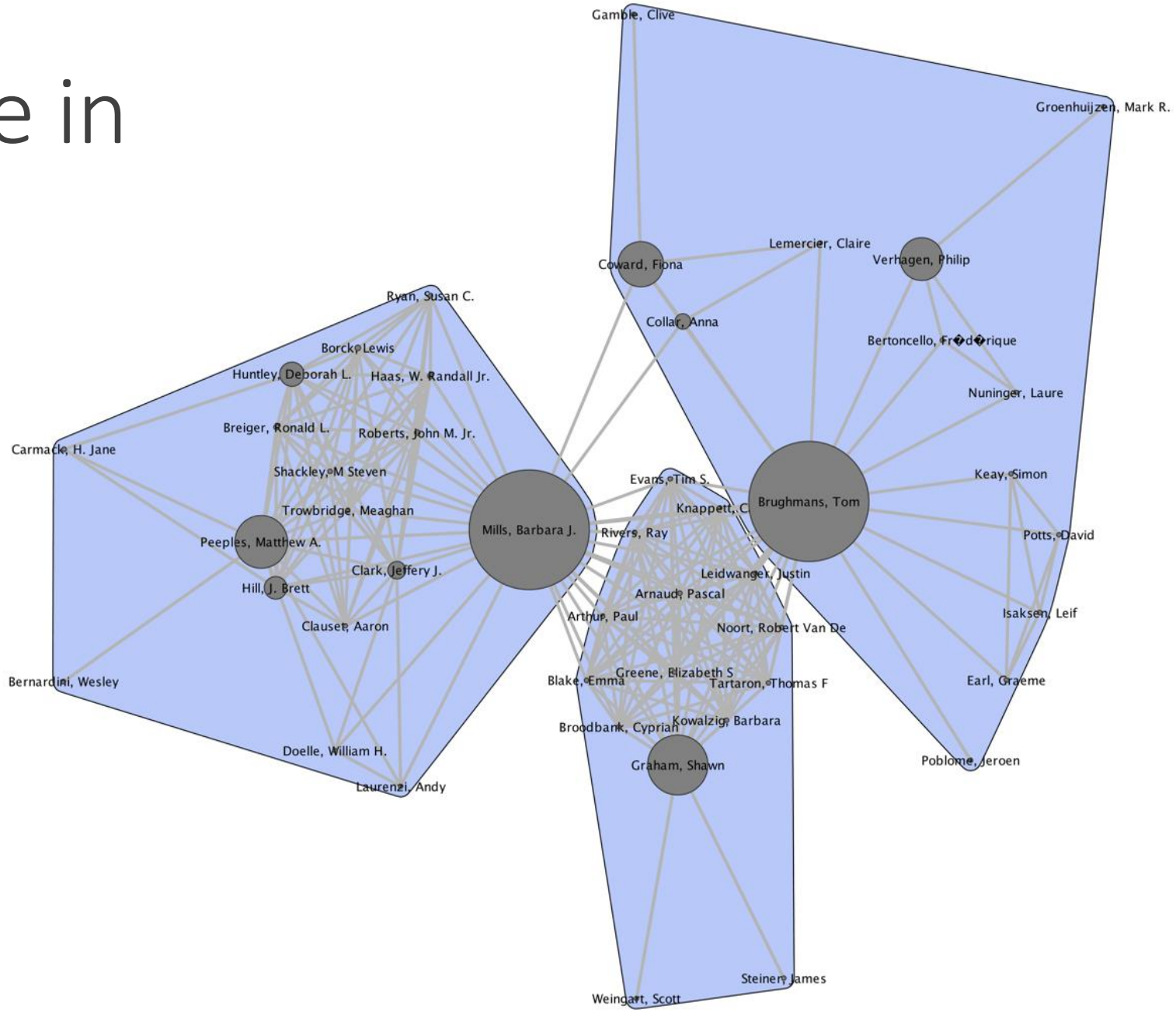
Network science in archaeology

Co-author networks
- Node size: betweenness centrality
- Clustering: Louvain algorithm

Methodological diversity
- Graph theory
- Social network analysis
- Complexity science

Dedicated research community

~ GIS: one more ‘tool in the box’



Brughmans & Peeples, 2017. Trends in Archaeological Network Research: A Bibliometric Analysis. 1 1, 1–24.
Peeples, M.A., 2019. Finding a Place for Networks in Archaeology. *Journal of Archaeological Research*.

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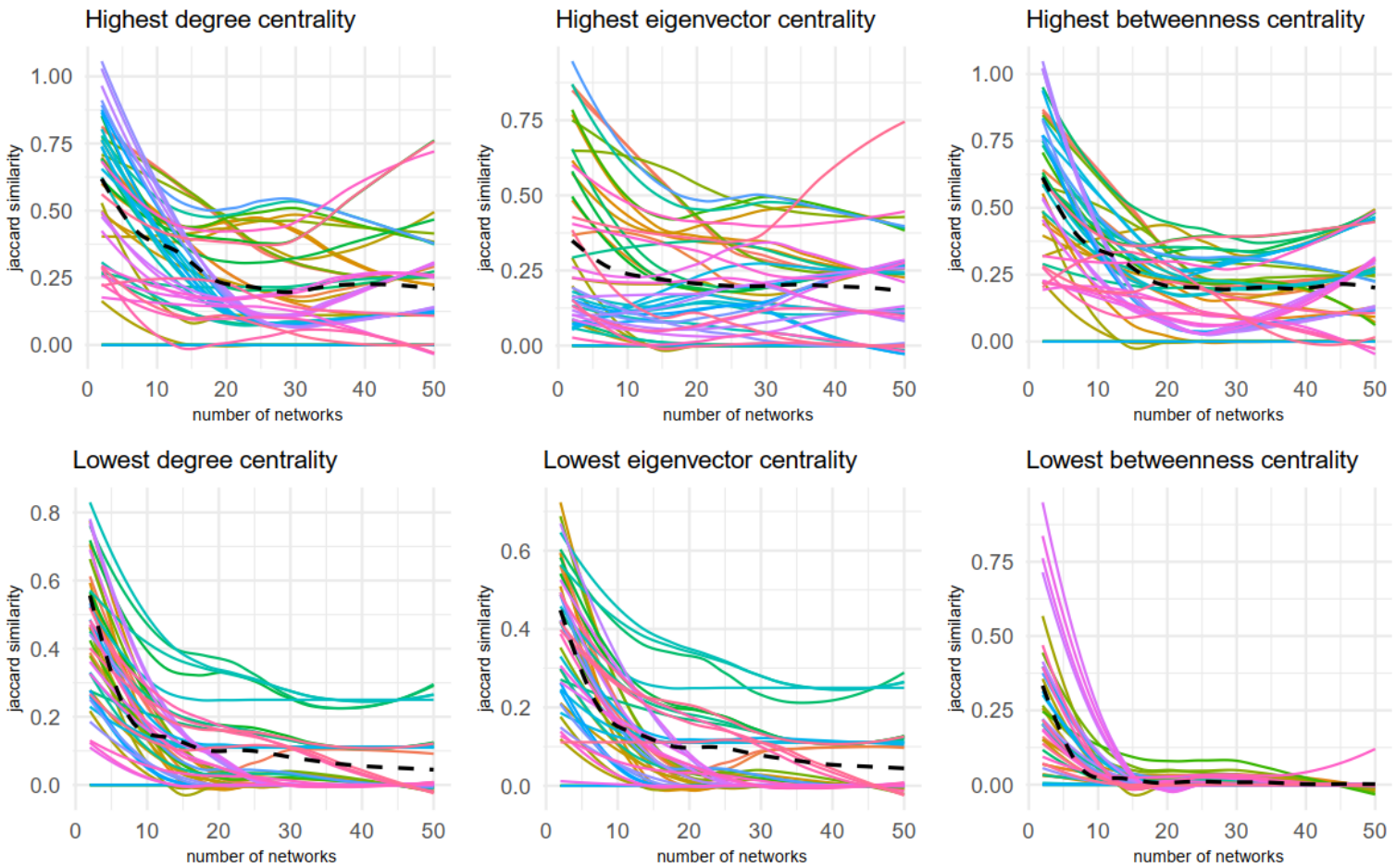
Challenges of archaeological networks: Time averaging

Time averaging
- Loss of temporal resolution

Icrates
- Hellenistic and Roman pottery
- 275 sites
- Eastern Mediterranean
- 20 year time slices



Daems, D., Coco, E., Gillreath-Brown, A. (In preparation) The Effects of Time-averaging on Archaeological Networks
Brughmans and Bach (2018) The Vistorian: exploring archaeological networks: https://archaeologicalnetworks.wordpress.com/resources/#vistorian

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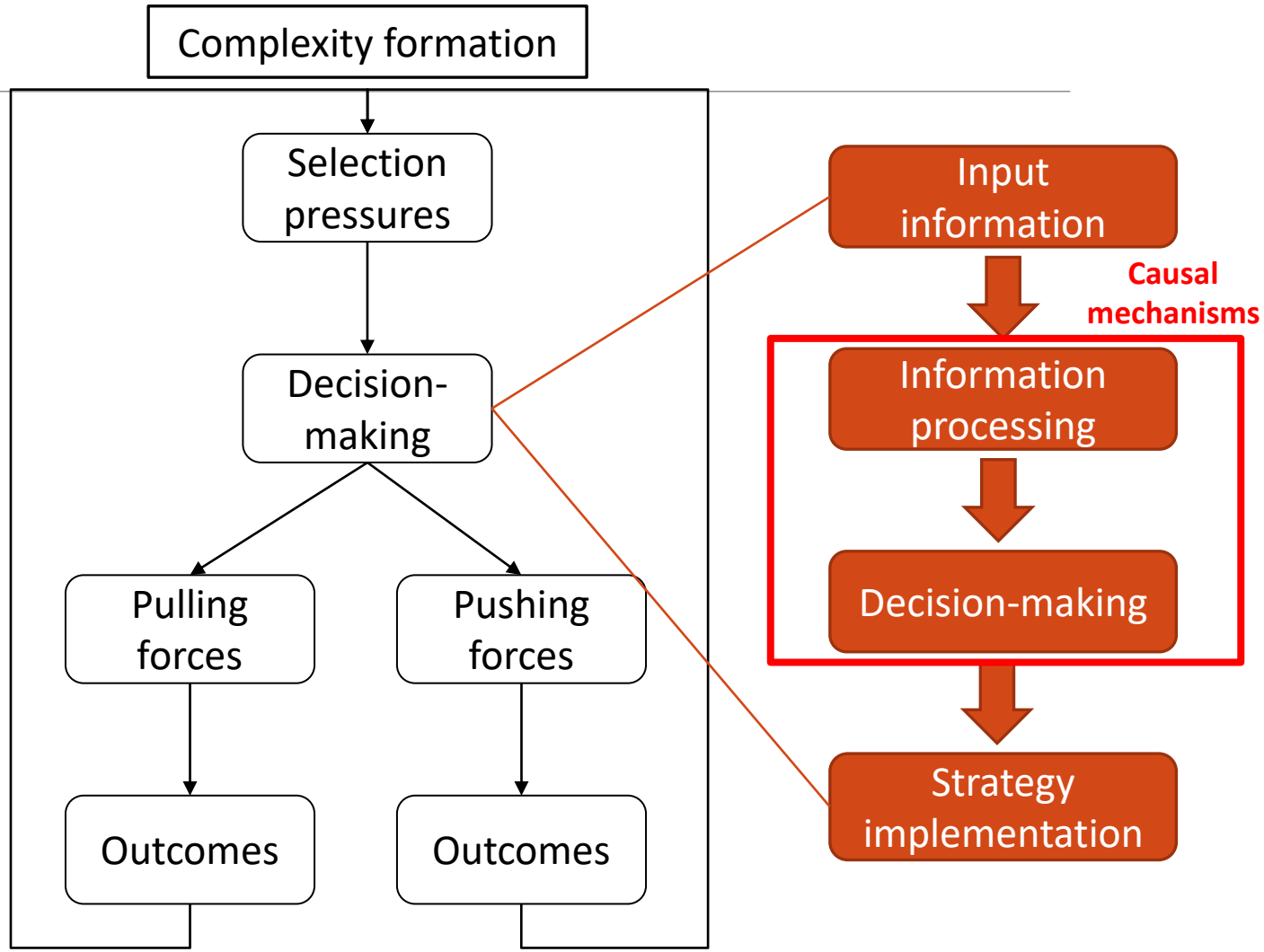
Social complexity

- Complexity not as property of ***complex*** societies but of ***human*** societies
- Flows of energy, resources and information
- Theoretical model:
  - Internal and external selection pressures
  - Causal mechanisms of decision-making: diversification, specialization and integration
  - Pushing and pulling forces
  - Outcomes of complexity formation



Daems, D., 2019. On complex archaeologies: conceptualizing social complexity and its potential for archaeology. *Adaptive Behavior*.
Daems, D., 2021. *Social Complexity and Complex Systems in Archaeology.* Routledge.

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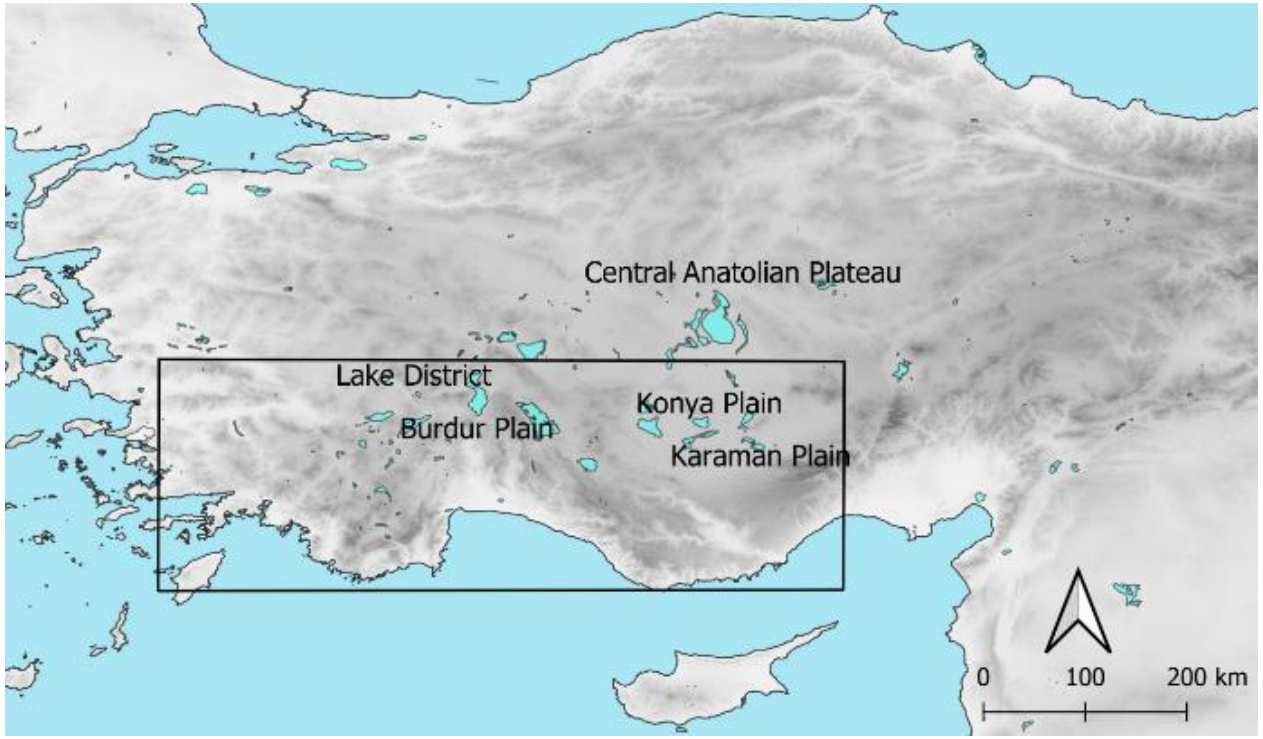
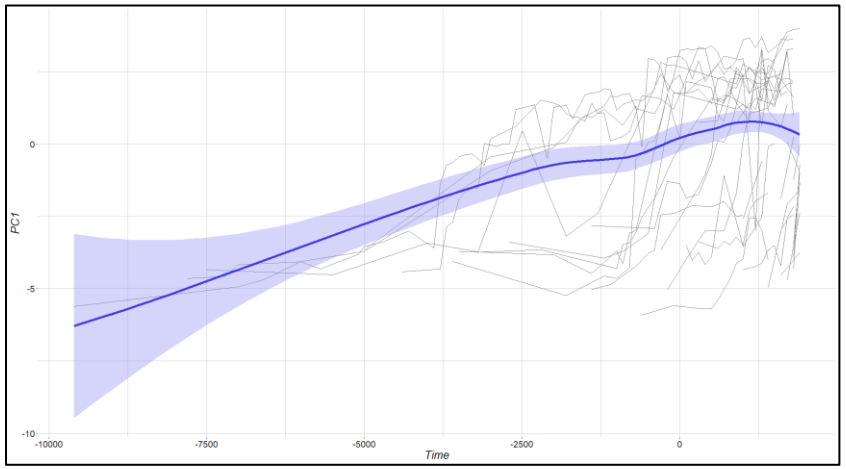
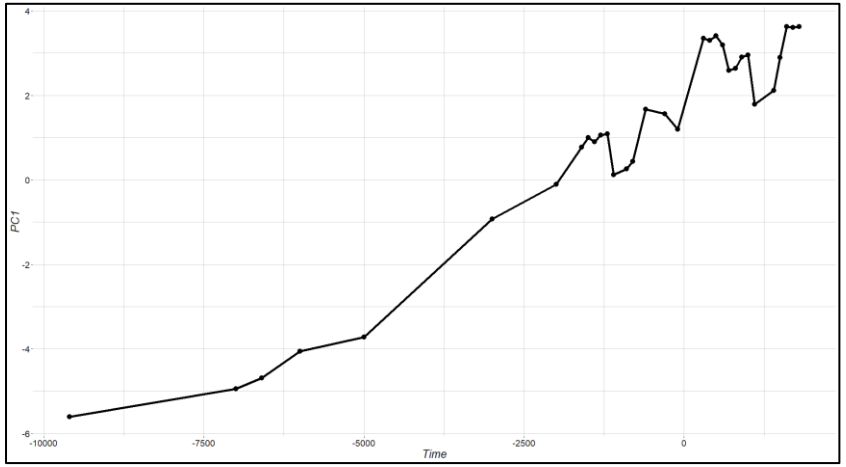
Social complexity in Anatolia

Late Chalcolithic to Hellenistic period (4000 – 100 BCE)

Global and regional complexity trajectories







Daems, D., 2021. *Social Complexity and Complex Systems in Archaeology.* Routledge.
Turchin, P. et al. 2018. Quantitative historical analysis uncovers a single dimension of complexity that structures global variation in human social org. *PNAS*, 115(2).

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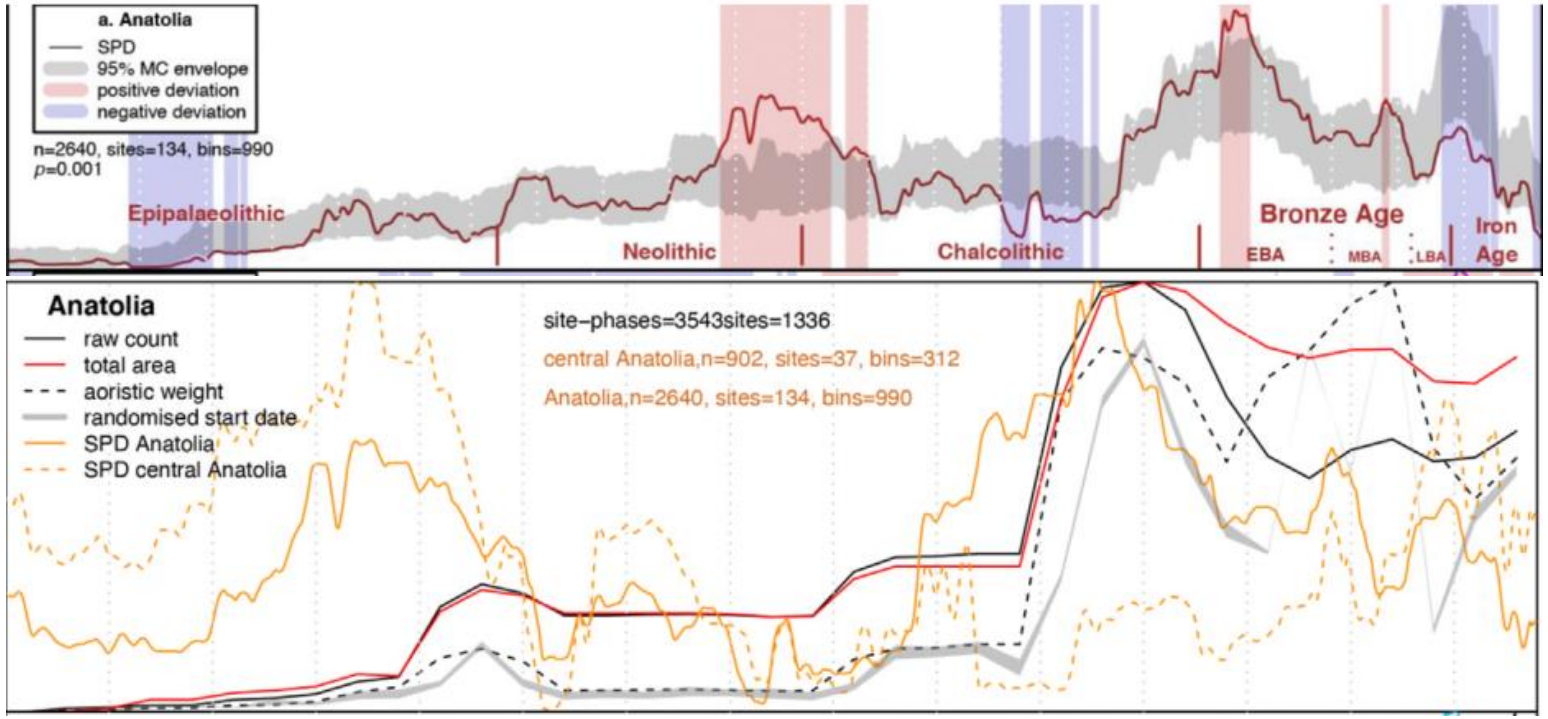
LCH and EBA: Complexity and demography

Population estimates
- SPD's of calibrated radiocarbon dates
- Demographic proxies

Population growth in LCH and peak in EBA

Decoupling climate & demography from Middle Holocene
- Social organization
- Technology
- Infrastructure



Palmisano, A., Lawrence, D., de Gruchy, M.W., Bevan, A. and Shennan, S., 2021. Holocene regional population dynamics and climatic trends in the Near East: A first comparison using archaeo-demographic proxies. *Quaternary Science Reviews*, 252, p.106739.

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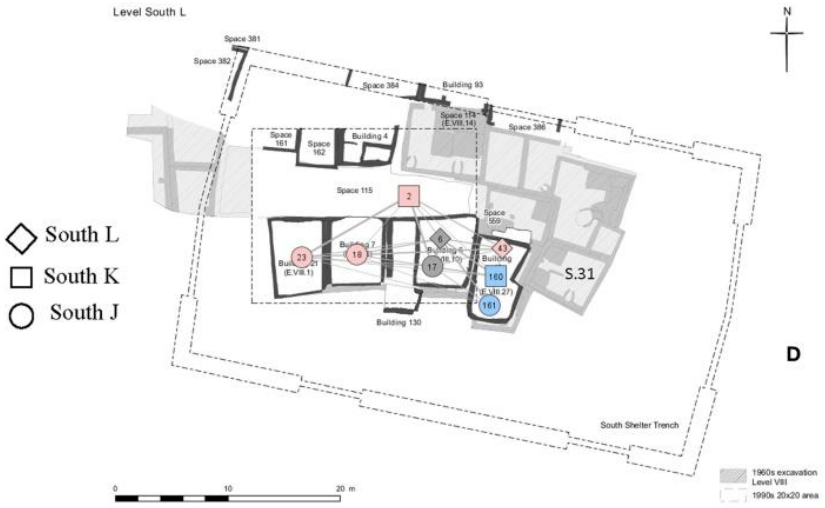
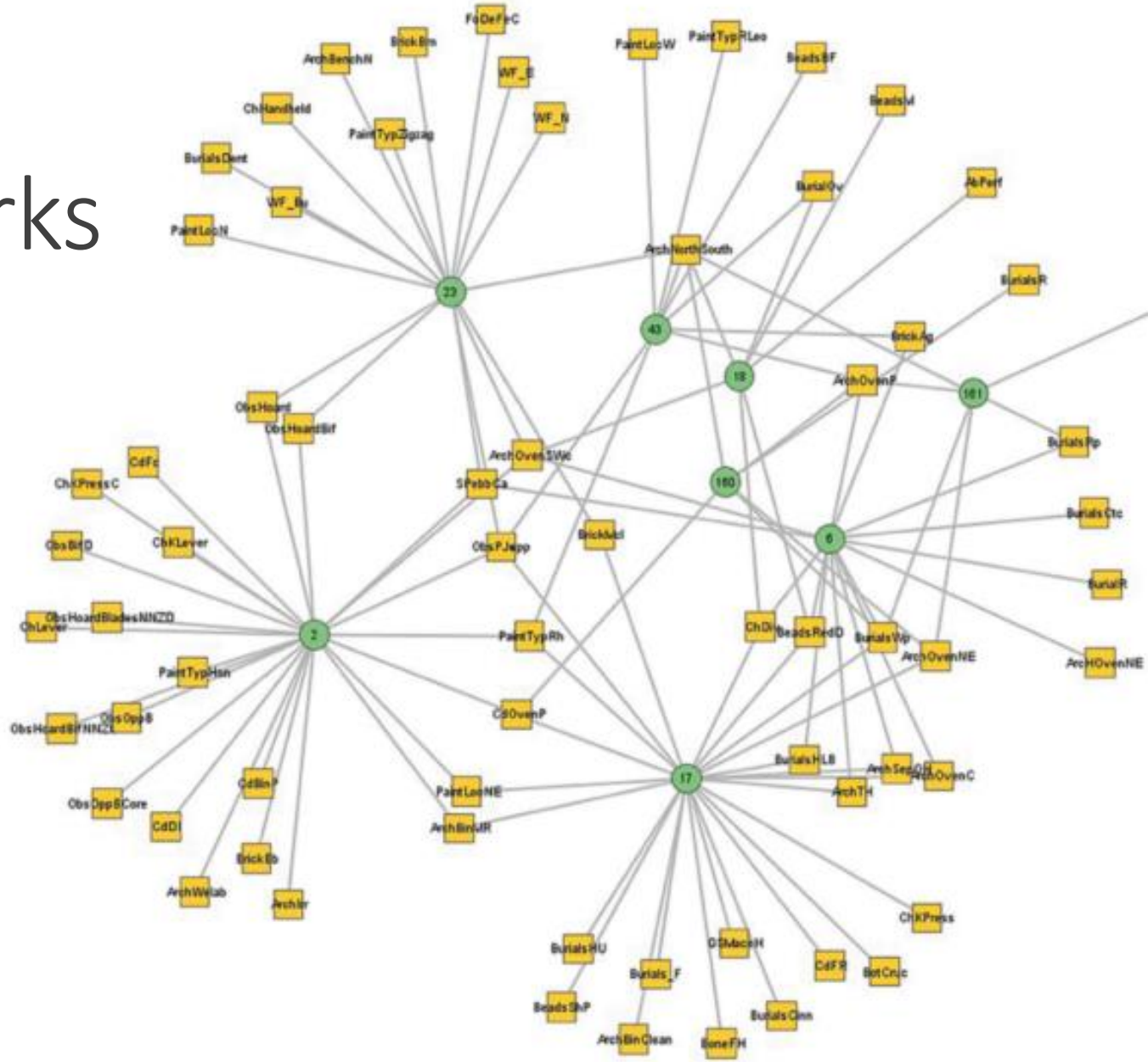
Community networks

Social networks and communities in Çatal Höyük (7100-6300 BCE)

Similarity networks of archaeological data

Modularity and Louvain community detection algorithm





Mazzucato, C., 2019. Socio-Material Archaeological Networks at Çatalhöyük a Community Detection Approach. Frontiers in Digital Humanities 6.

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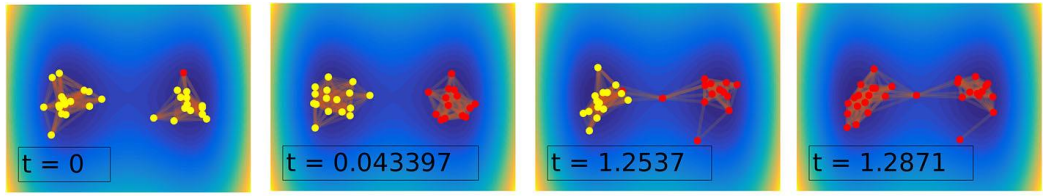
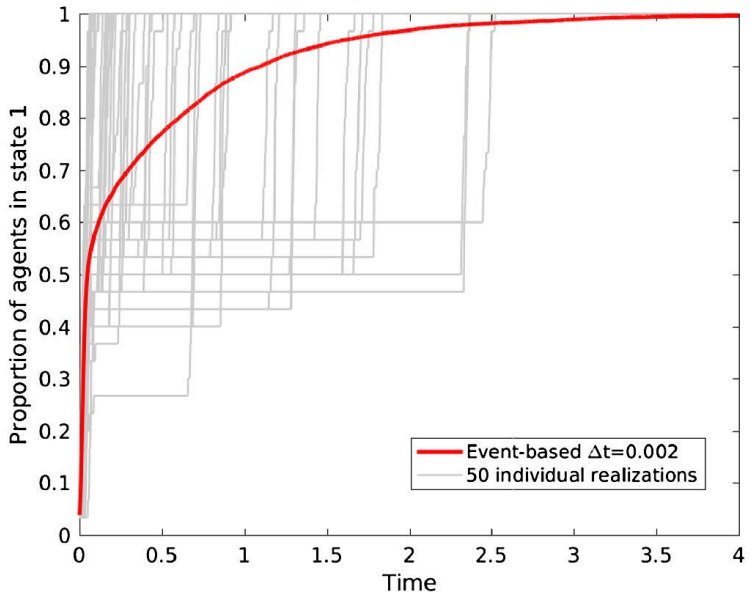
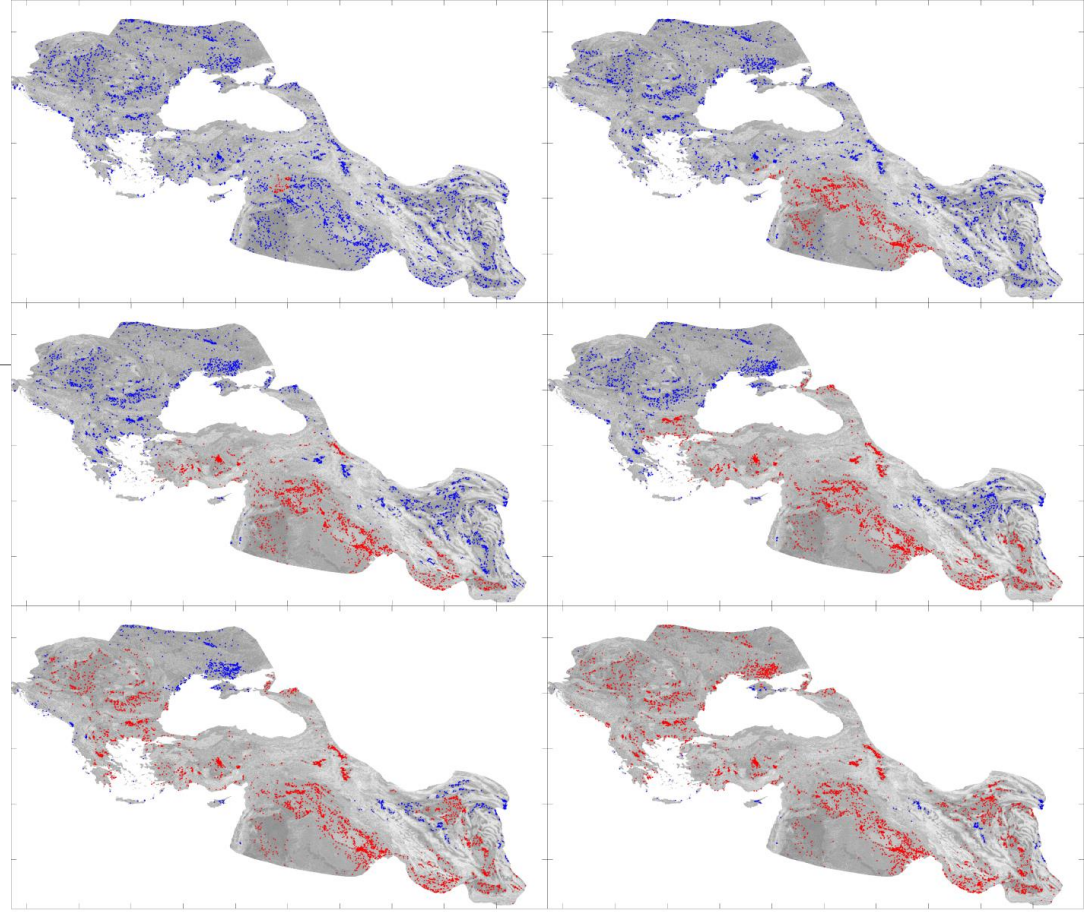
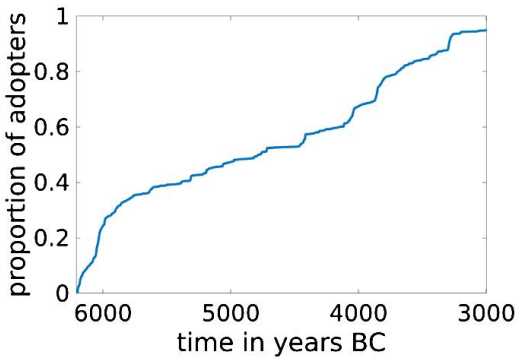
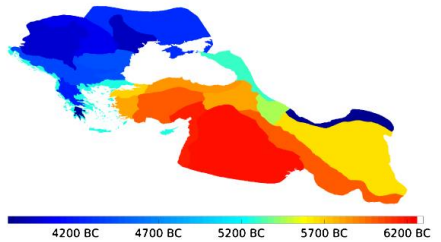
Innovation networks





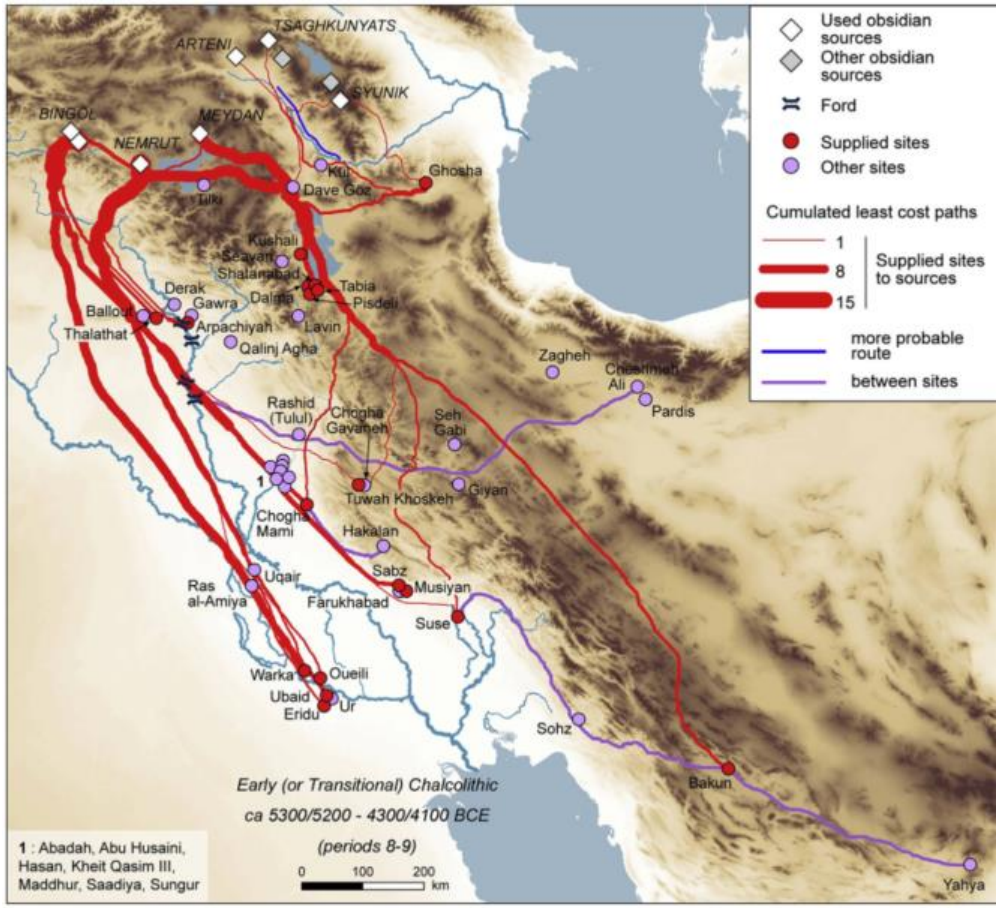


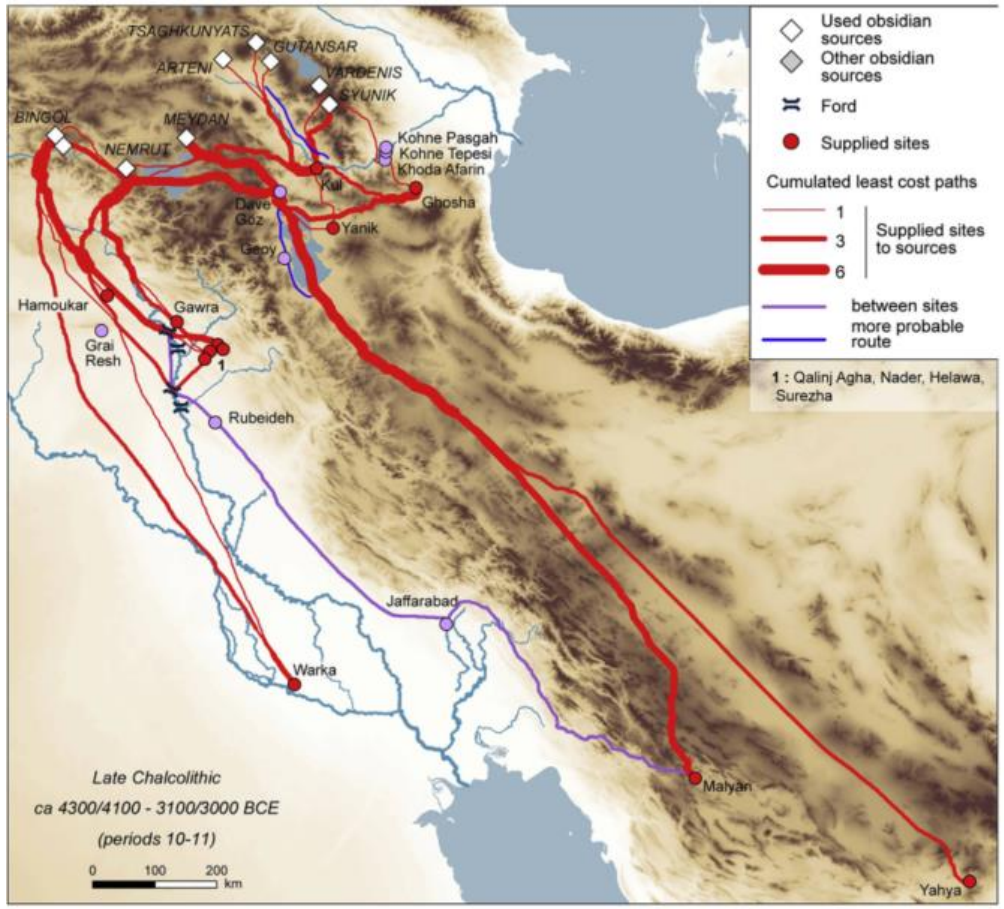




Conrad, N.D., Helfmann, L., Zonker, J., Winkelmann, S., Schütte, C., 2018. Human mobility and innovation spreading in ancient times: a stochastic agent-based simulation approach. EPJ Data Science 7, 24.

Networks of resource distribution





Barge, O., et al. 2018. Diffusion of Anatolian and Caucasian obsidian in the Zagros Mountains and the highlands of Iran: Elements of explanation in 'least cost path' models. *Quaternary International*, 467, pp.297–322.

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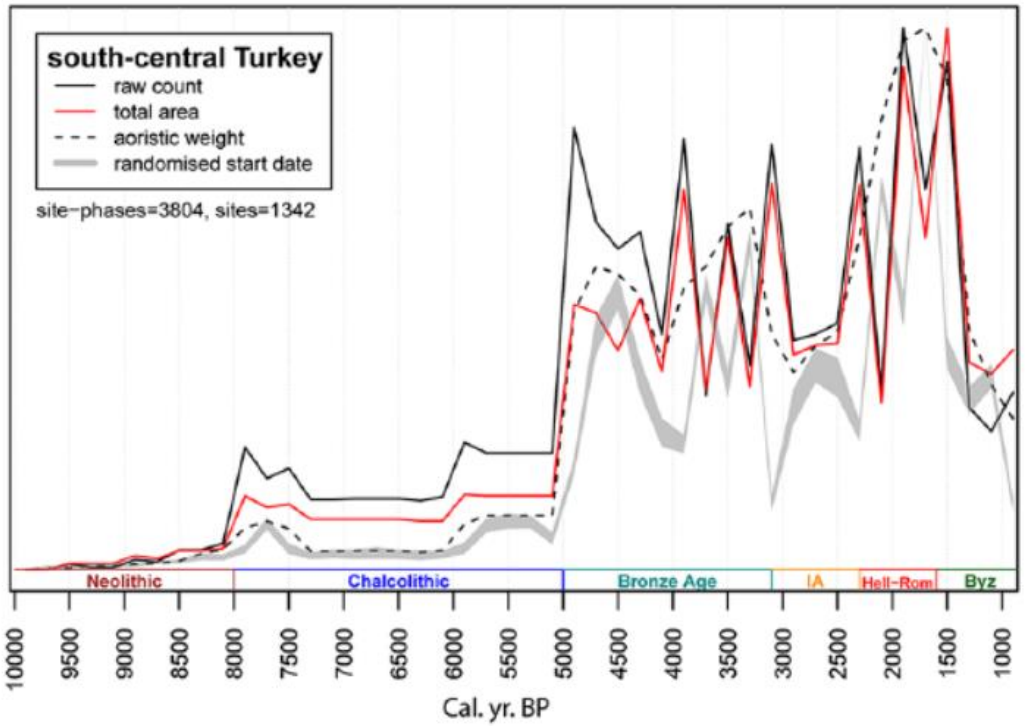
Interaction, information processing and complexity

Population growth in Late Chalcolithic through emergence of new sites

Population peak in Bronze Age through increasing settlement sizes

- Social organization allows more people to interact by overcoming limits to information processing
- Integration in wider networks of interaction and competition



Woodbridge, J., Roberts, C.N., Palmisano, A., et al. 2019. Pollen-inferred regional vegetation patterns and demographic change in Southern Anatolia through the Holocene. *The Holocene*, 29(5), pp.728–741.

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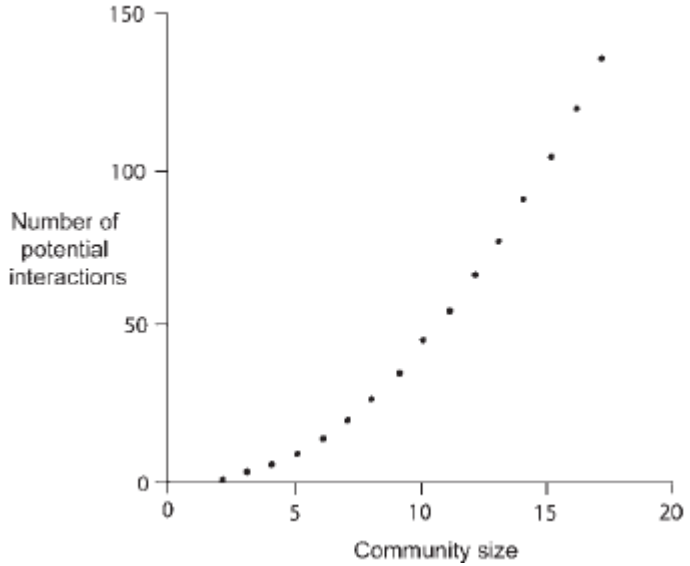
Interaction, information processing and complexity

Correlation between community size and social complexity (Feinman 2011)

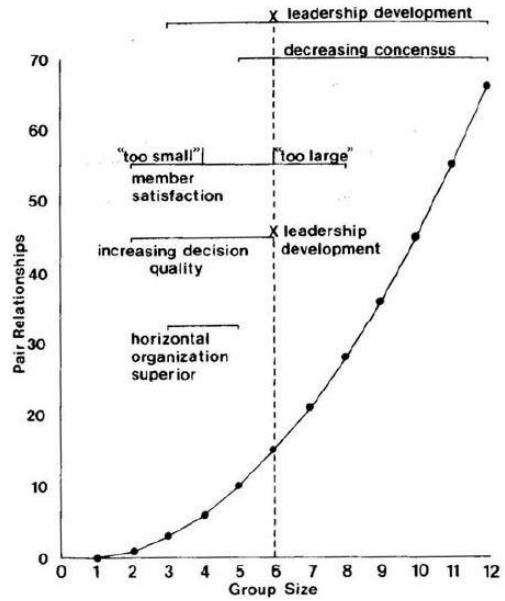
Cognitive limits to information processing

- Face-to-face communities ~ 150 people

“As social groups grow, they do not simply get larger but rather self-organize to better process socially transmitted information and more effectively make decisions”
(Auban *et al.* 2013)



Feinman 2011



Johnson 1982

Auban, J. et al. 2013. Complex Systems, Social Networks, and the evolution of Social Complexity in the East of Spain. In: *The Prehistory of Iberia: Debating Early Social Stratification and the State*.
Feinman, G.M., 2011. Size, Complexity, and Organizational Variation: A Comparative Approach. *Cross-Cultural Research*, 45(1), pp.37–58.
Johnson, G.A., 1982. Organizational Structure and Scalar Stress. In: C. Renfrew, M. Rowlands and B. Segraves, eds. *Theory and Explanation in Archaeology.*

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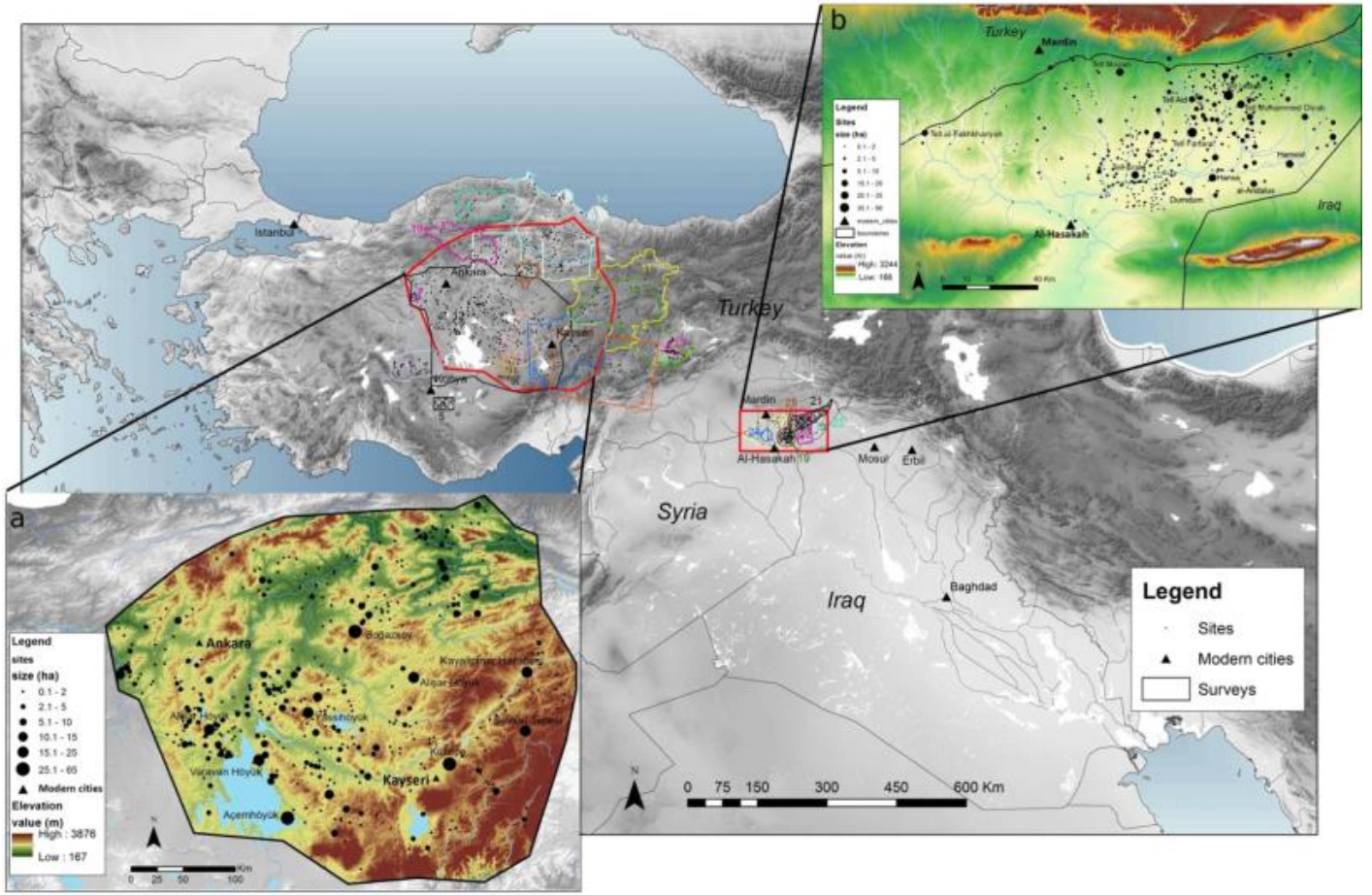
Middle Bronze Age: Interaction in settlement hierarchies

Settlement hierarchies in Central Anatolia during MBA (2000-1600 BCE)

- 440 sites
- Rank-size distribution and K-means clustering
- Spatial interaction entropy maximization and network metrics



Palmisano, A., 2017. Confronting scales of settlement hierarchy in state-level societies: Upper Mesopotamia and Central Anatolia in the Middle Bronze Age. J. of Arch. Sc.: Reports 14, 220–240.
Palmisano, A., Altaweel, M., 2015. Landscapes of interaction and conflict in the Middle Bronze Age: From the Khabur Triangle to Central Anatolia. J. of Arch. Sc.: Reports 3, 216–236.

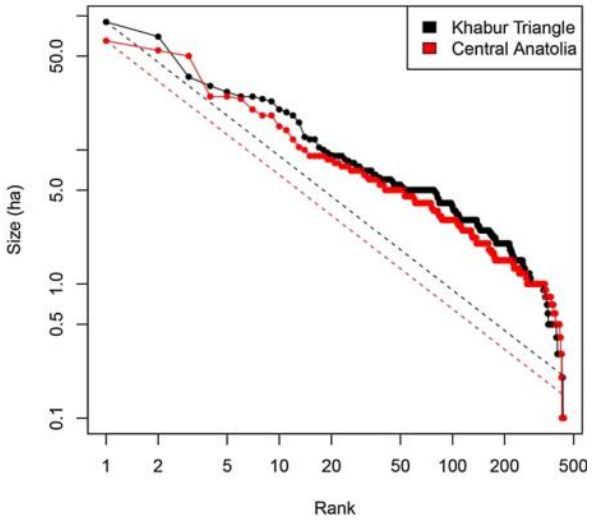
Middle Bronze Age: Interaction in settlement hierarchies

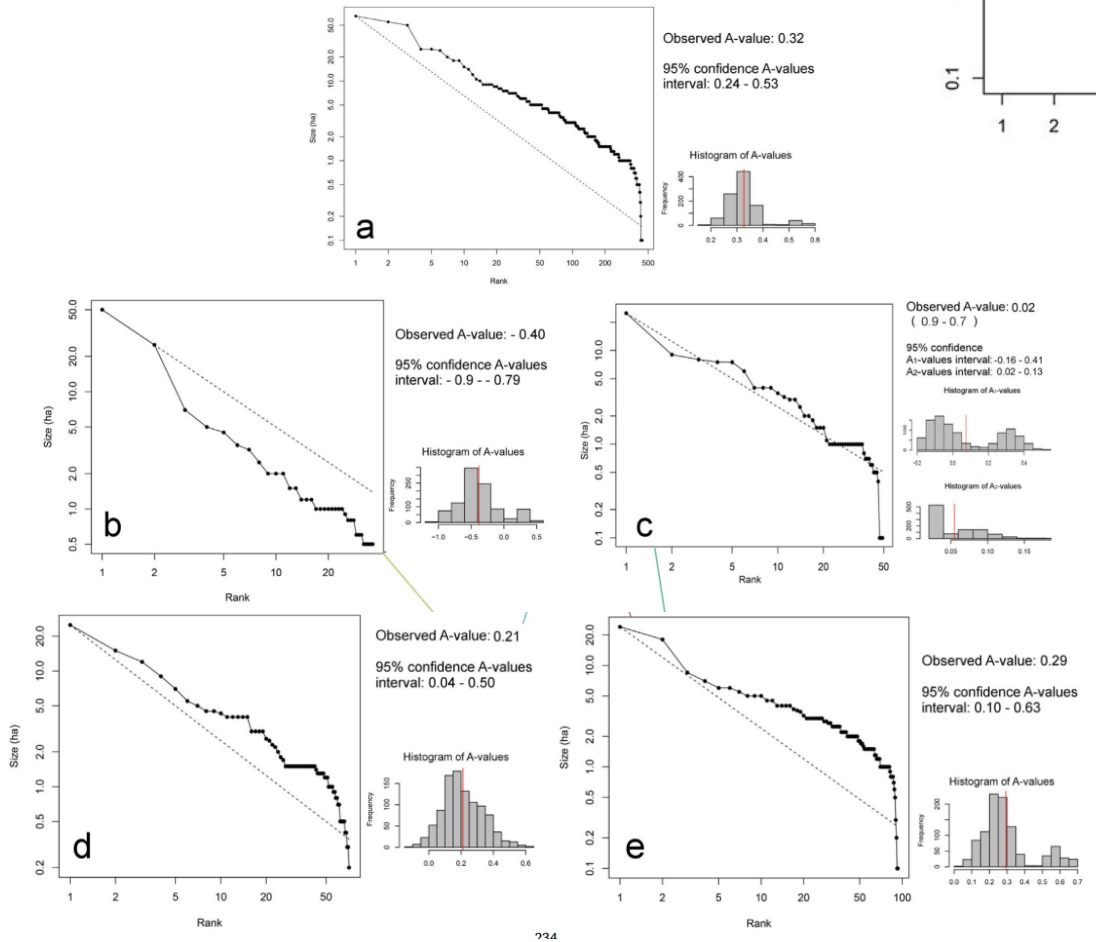
Rank-size distributions
- Integration versus dispersal

Overall convex distribution
- More larger sites
- ‘Peer-polity’ system

Regional clusters
- Predominance of primate systems

Regional settlement systems
- Competition versus integration?





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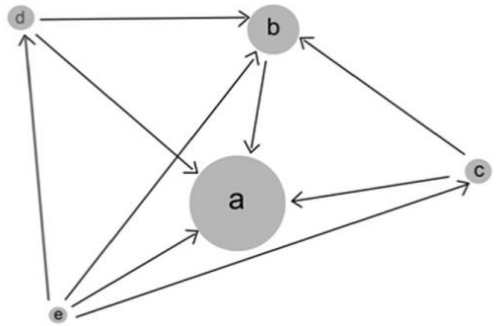
Middle Bronze Age: Interaction in settlement hierarchies

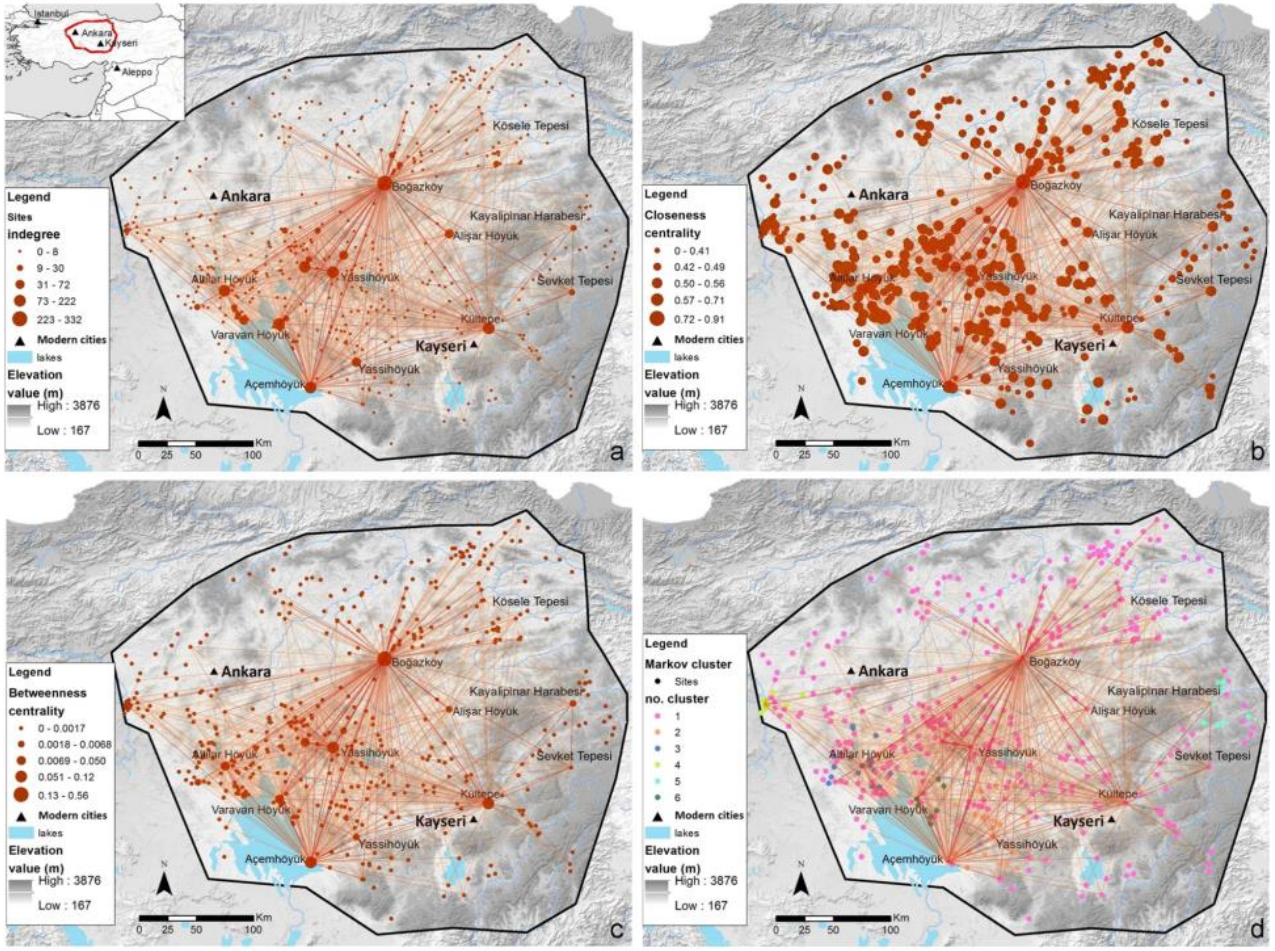


Spatial interaction entropy maximization
- Flows of goods and people in spatial systems
- Archaeological sites and textual data

Pull factors: geography, environment, transport, economy, and social institutions

N-D graphs
- Degree and centrality: detect regional hubs
- Markov clusters: identify sub-areas of interaction

Multi-scalar networks of interaction and competition



Palmisano, A., 2017. Confronting scales of settlement hierarchy in state-level societies: Upper Mesopotamia and Central Anatolia in the Middle Bronze Age. J. of Arch. Sc.: Reports 14, 220–240.
Palmisano, A., Altaweel, M., 2015. Landscapes of interaction and conflict in the Middle Bronze Age: From the Khabur Triangle to Central Anatolia. J. of Arch. Sc.: Reports 3, 216–236.

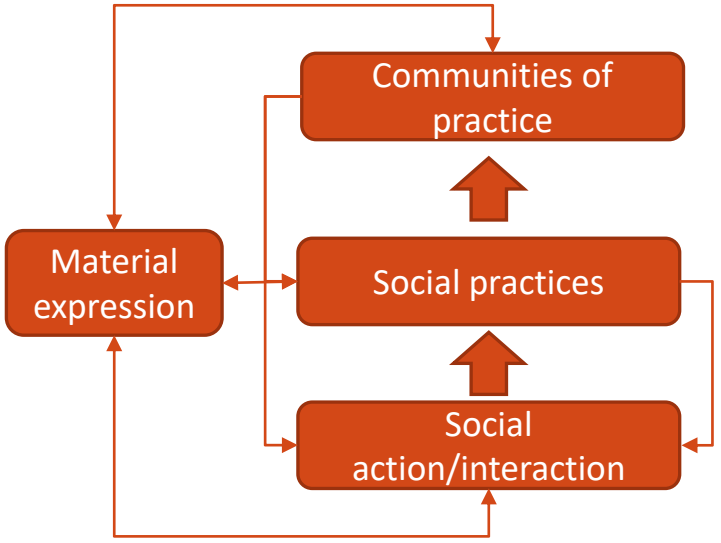
Late Bronze Age and Early Iron Age communities of practice

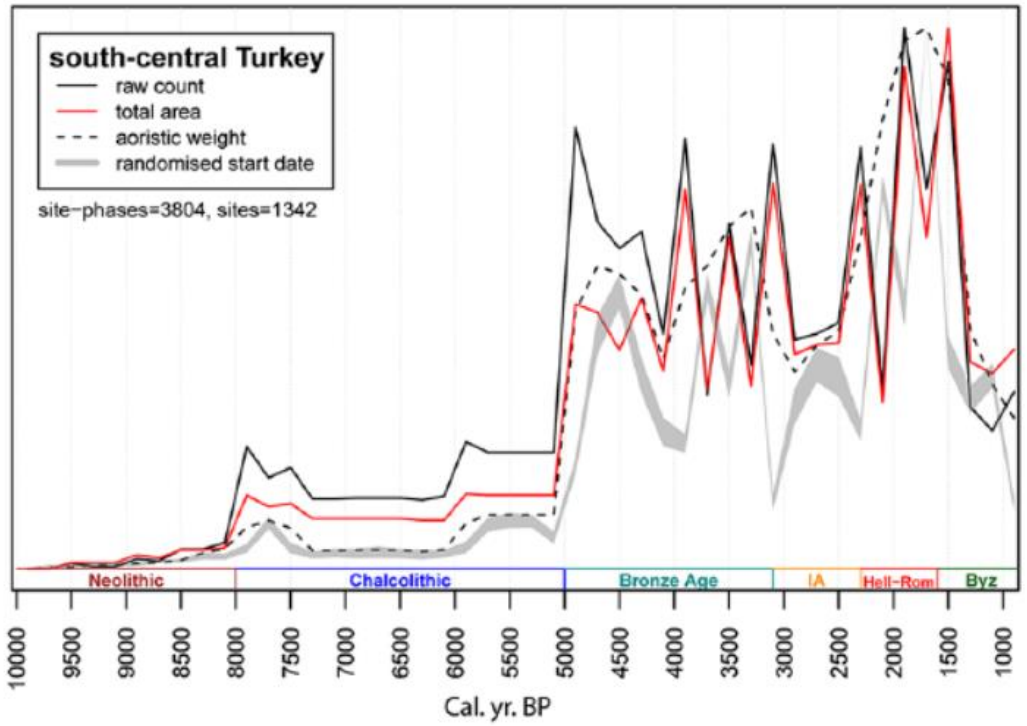
Late Bronze Age collapse(?) around 1200 BCE

Lack of material evidence

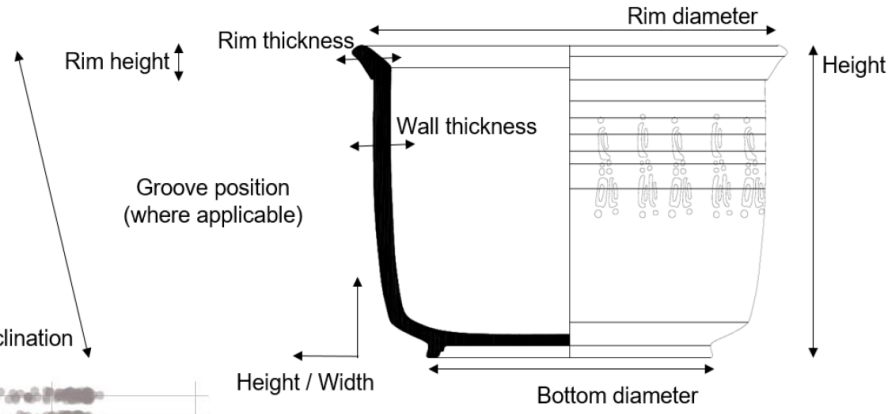
Similarity networks of material culture

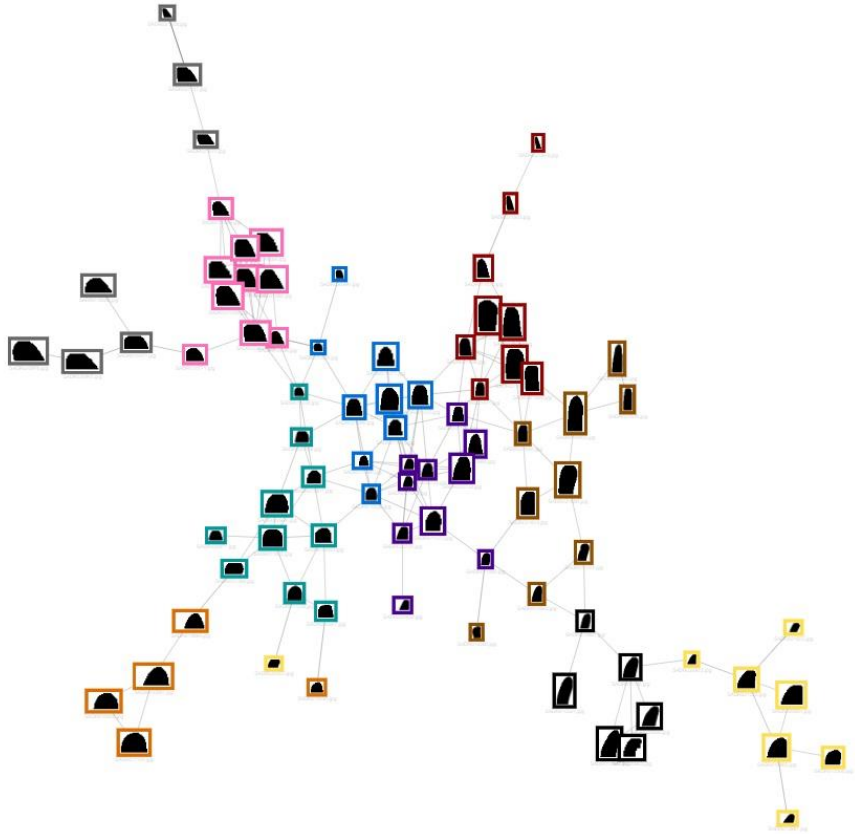
- Typo-chronology
- Communities of practice





Material culture morphometrics





[1] "Brushed points appear here (double-click to clear)"

- Shape outline
- Distance matrix
- K-means clustering
- Parameter measurements
  - Fuzzy ruleset
- Typological classification
  - Size = archetypical type
- Assemblage classification

Alcaide, D., & Aerts, J. (2020). Spanning Trees as Approximation of Data Structures. *IEEE Transactions on Visualization and Computer Graphics*.

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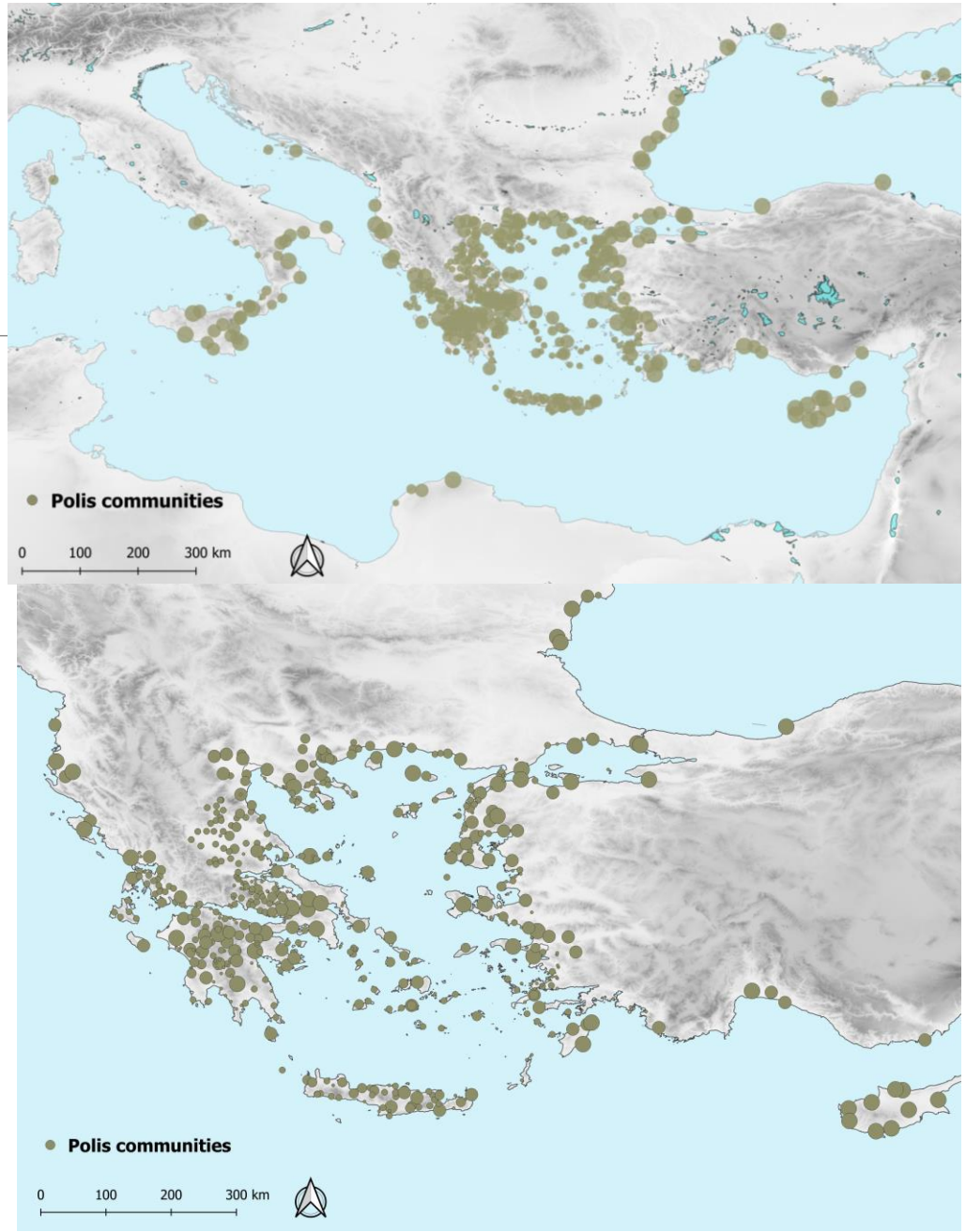
The origin of *polis* in Iron Age Anatolia

The *polis* as a nucleated urban and political centre with associated hinterland

Greek polis versus general phenomenon

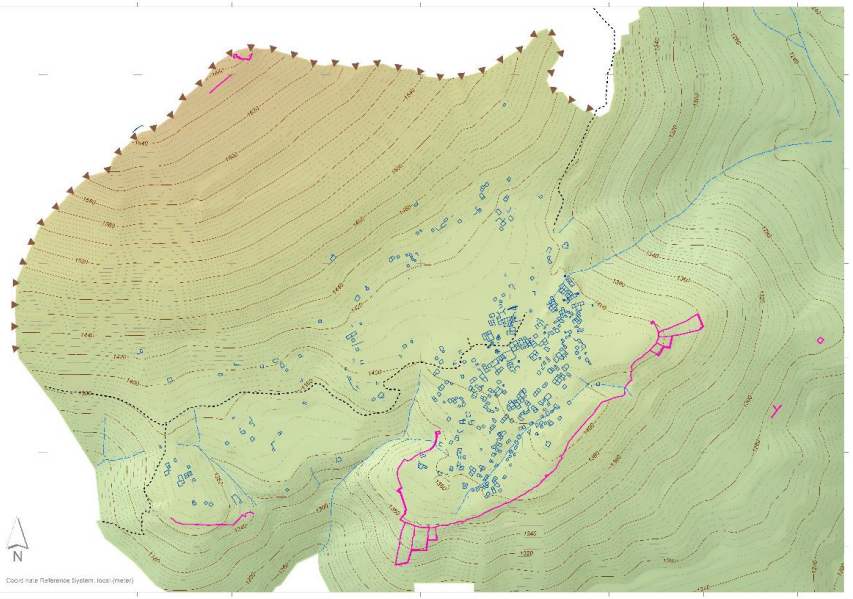
Class	Size	Average population	Count	%	% Cumul
0	?	?	358	34,96	34,96
1	< 25 km²	600	200	19,53	54,49
2	25-100 km²	1575	219	21,39	75,88
3	100-200 km²	2025	81	7,91	83,79
4	200-500 km²	3675	104	10,16	93,95
5	> 500 km²	9100	63	6,05	100

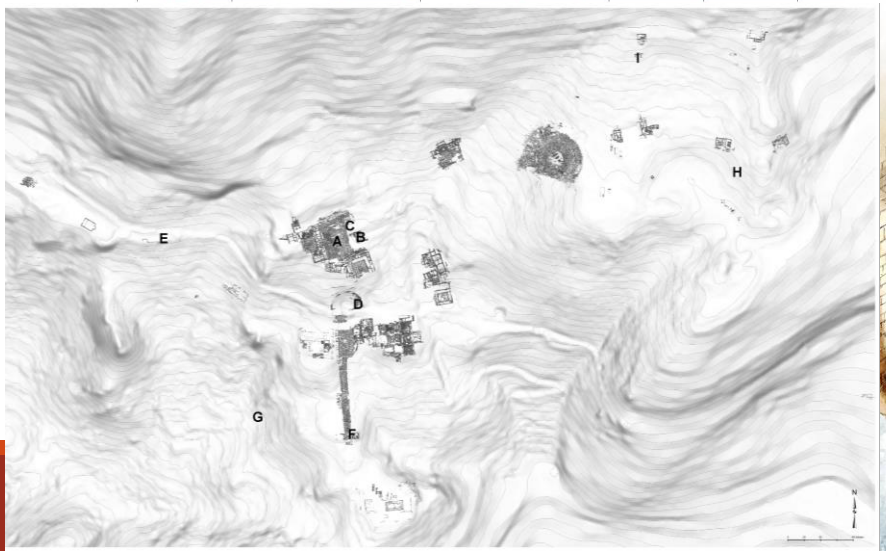


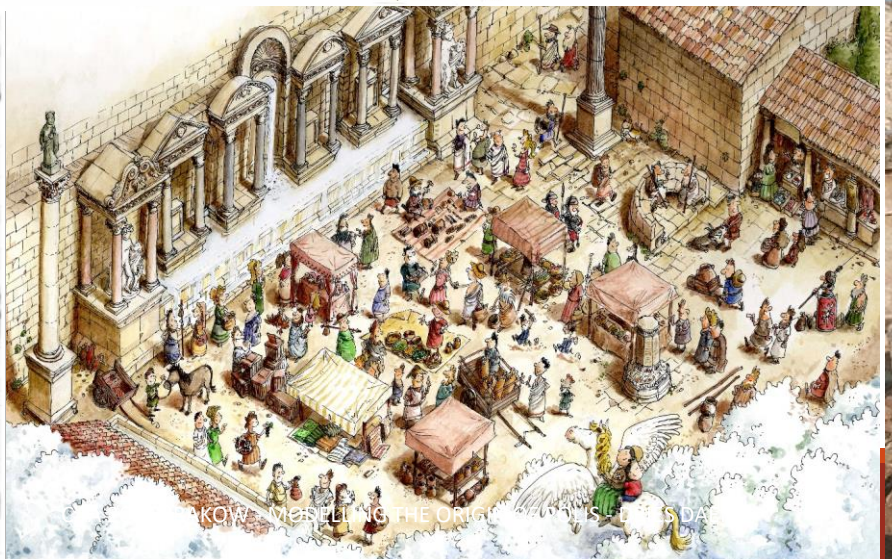
Hansen & Nielsen (2004) An Inventory of Poleis
Hansen (2006) The Shotgun Method: The Demography of the Ancient Greek City-State Culture

Made by author with dataset from http://polis.stanford.edu/; based on Hansen and Nielsen 2004.

The *polis* in Anatolia: Düzen Tepe and Sagalassos

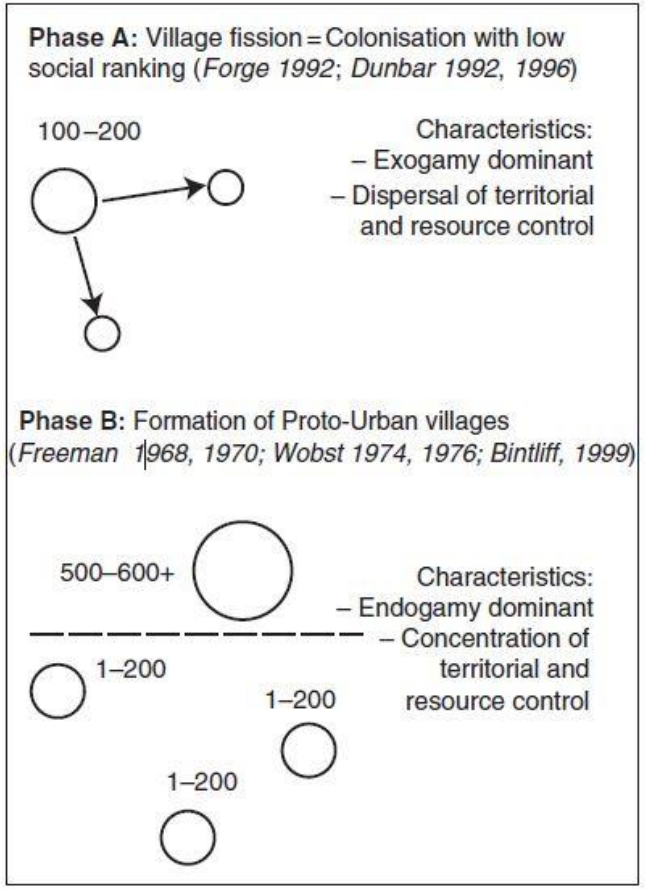


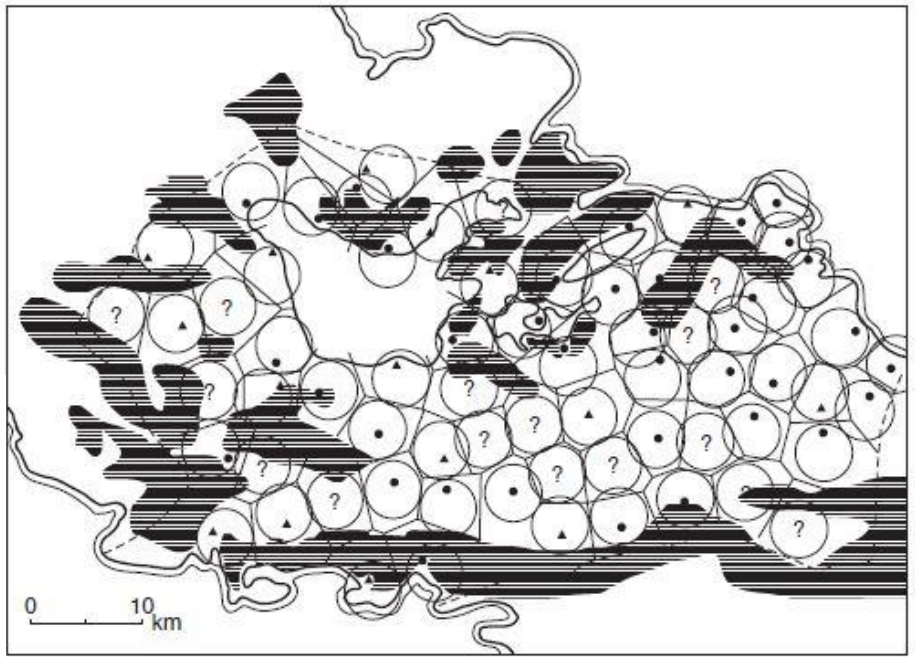


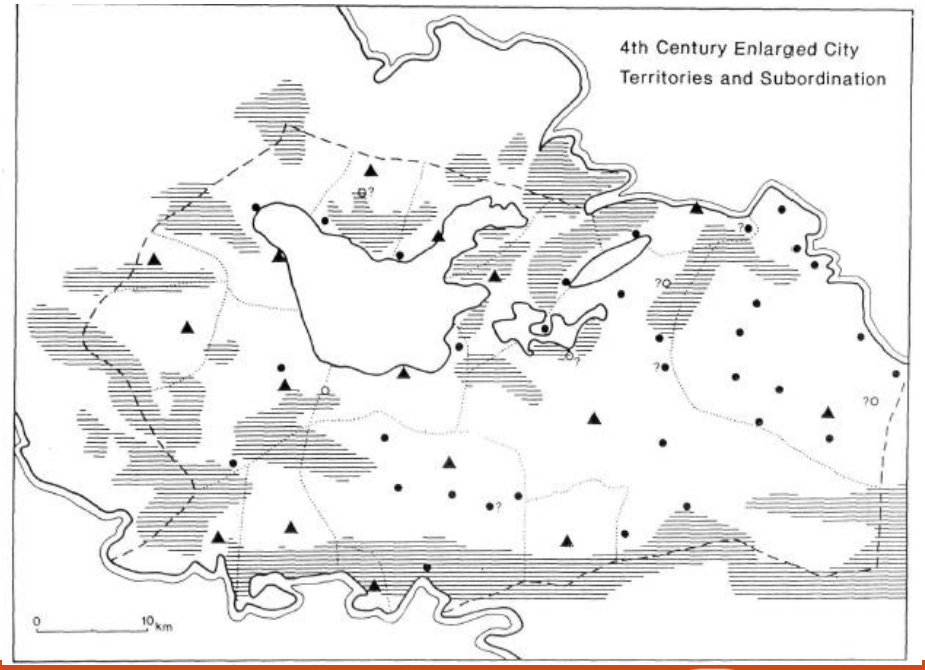


A model of *polis* formation

- Cross-cultural attractor states
  - Cognitive limits to information processing
  - Intra-group endogamy and resource control
  - Walking distances
- Fission-fusion dynamics
- Selection pressures for small, nucleated settlements
- Gradual landscape filling
- Emergence of corporate communities and settlement hierarchies







Bintliff (1994) Territorial behaviour and the natural history of the Greek polis.
Bintliff et al. (2007) Emergent complexity in settlement systems and urban transformations.

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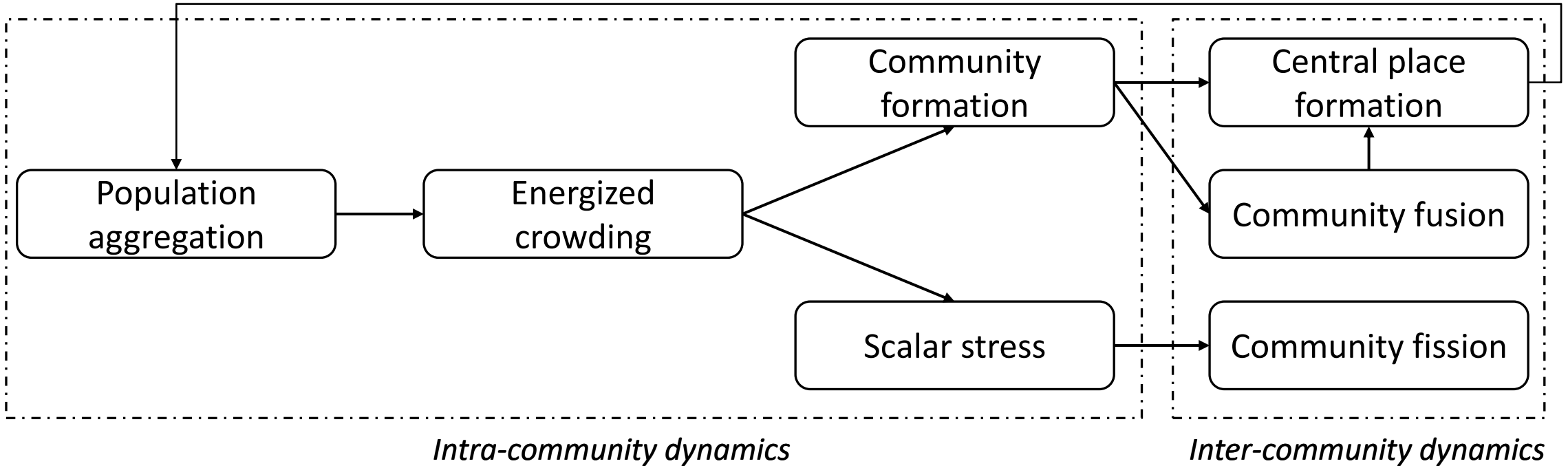
A model of *polis* formation



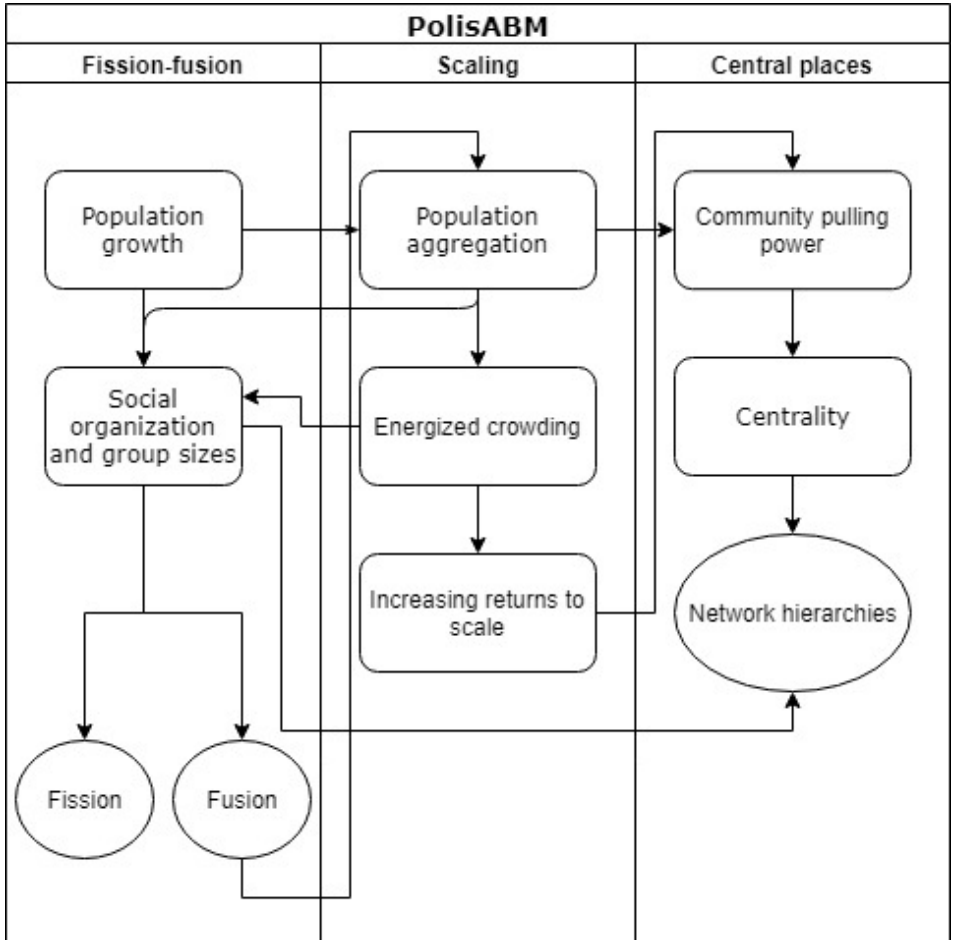
Daems, D., 2021. Social Complexity and Complex Systems in Archaeology. Routledge.

PolisABM: Model

- Initialisation of face-to-face communities
  - 100-200 people
- Communities expand through population growth

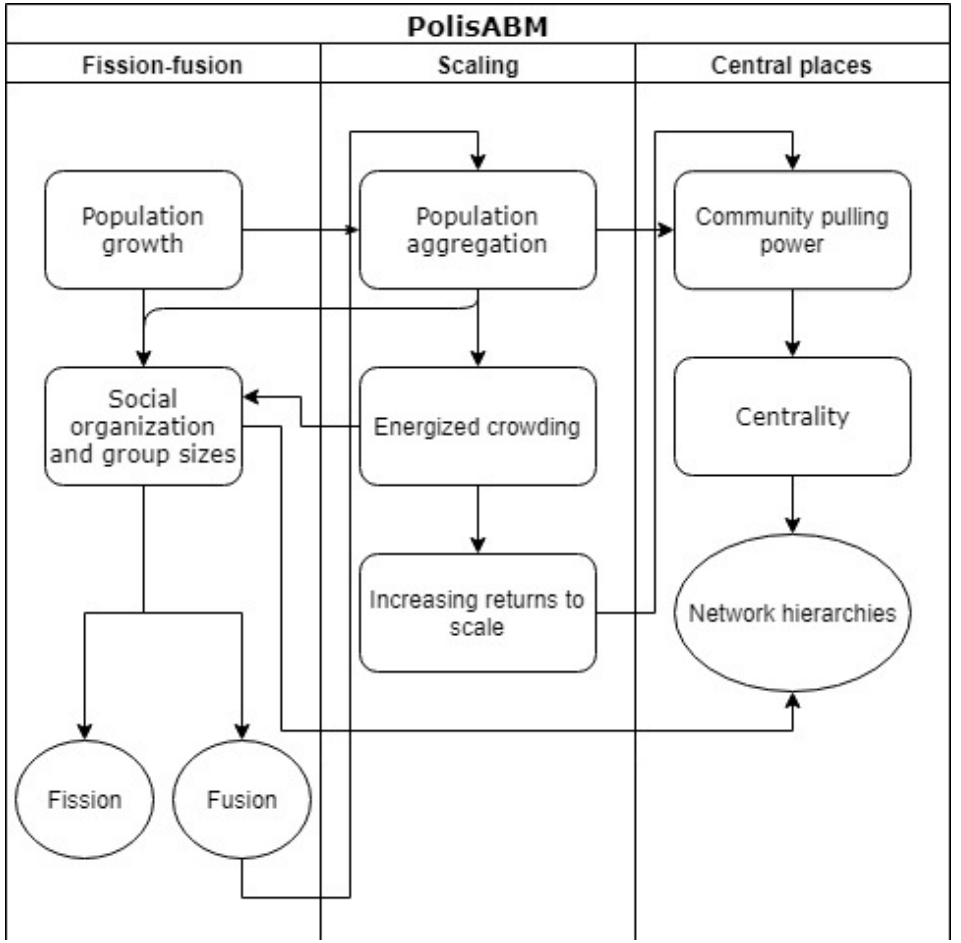
$$\frac{\delta N}{\delta t} = rN\left(1 - \frac{N}{K}\right) + W$$

  - N = Population size
  - r = Population growth rate
  - K = Carrying capacity
  - W = Settlement pulling force



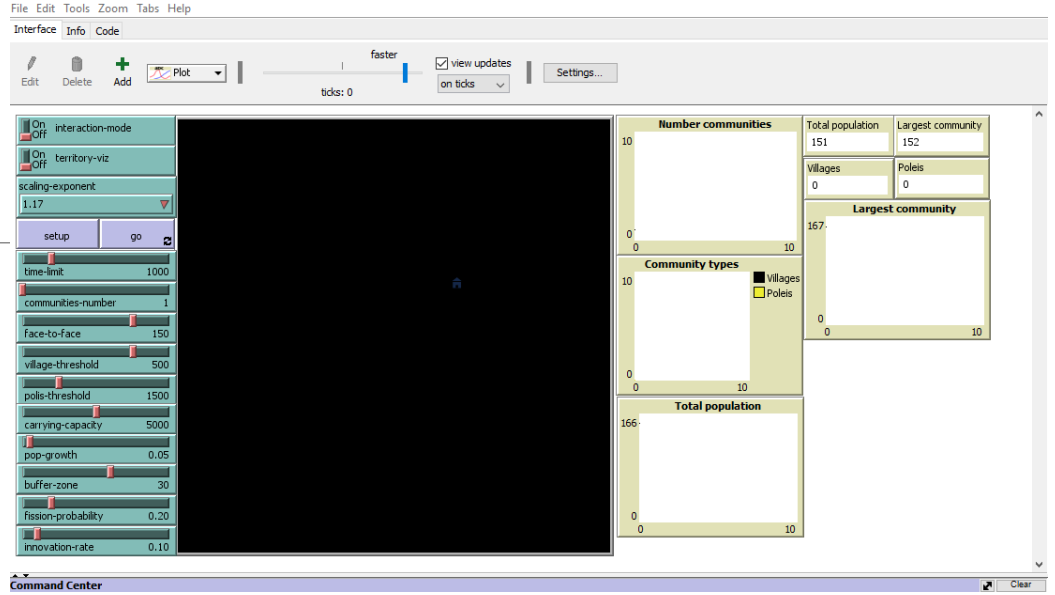
PolisABM: Model

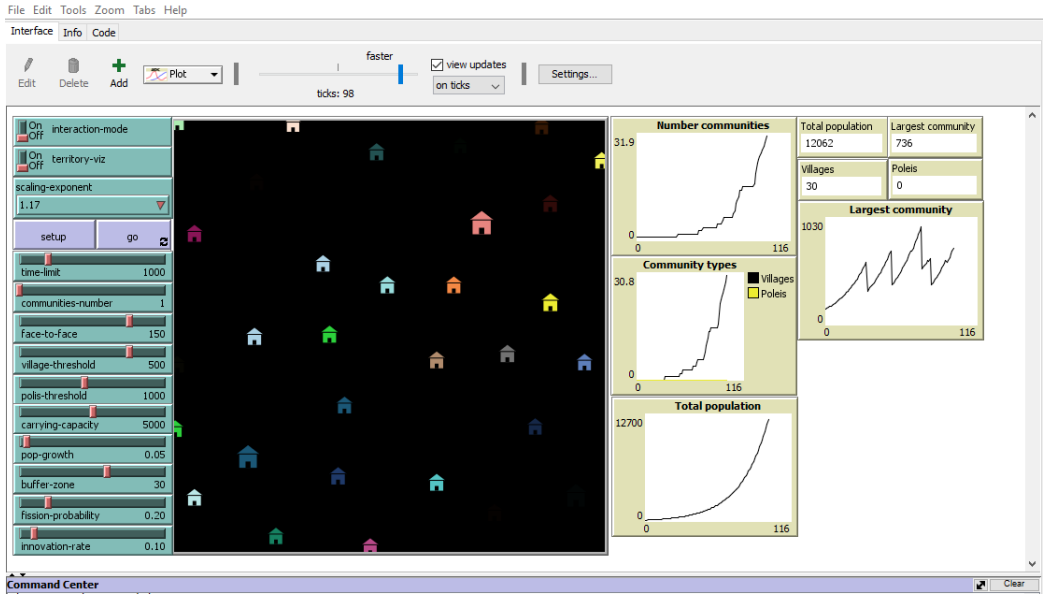
- Community thresholds
  - Village threshold: ± 500 people
  - Polis threshold: ± 1000 people
- Fission occurs (with certain chance) once population threshold is reached and empty space is available
- Fusion occurs (with certain chance) between adjacent polities when no empty land is available for expansion



PolisABM: Simulations

- Initialisation of a single face-to-face community
- Filling of landscape with face-to-face communities as long as space is available
- Settlement growth results in hierarchy formation
  - Smaller number of large sites surrounded by smaller villages
- Interplay between village and polis site numbers
- Boom-bust cycles as system reaches thresholds
- Main output: rank-size distributions





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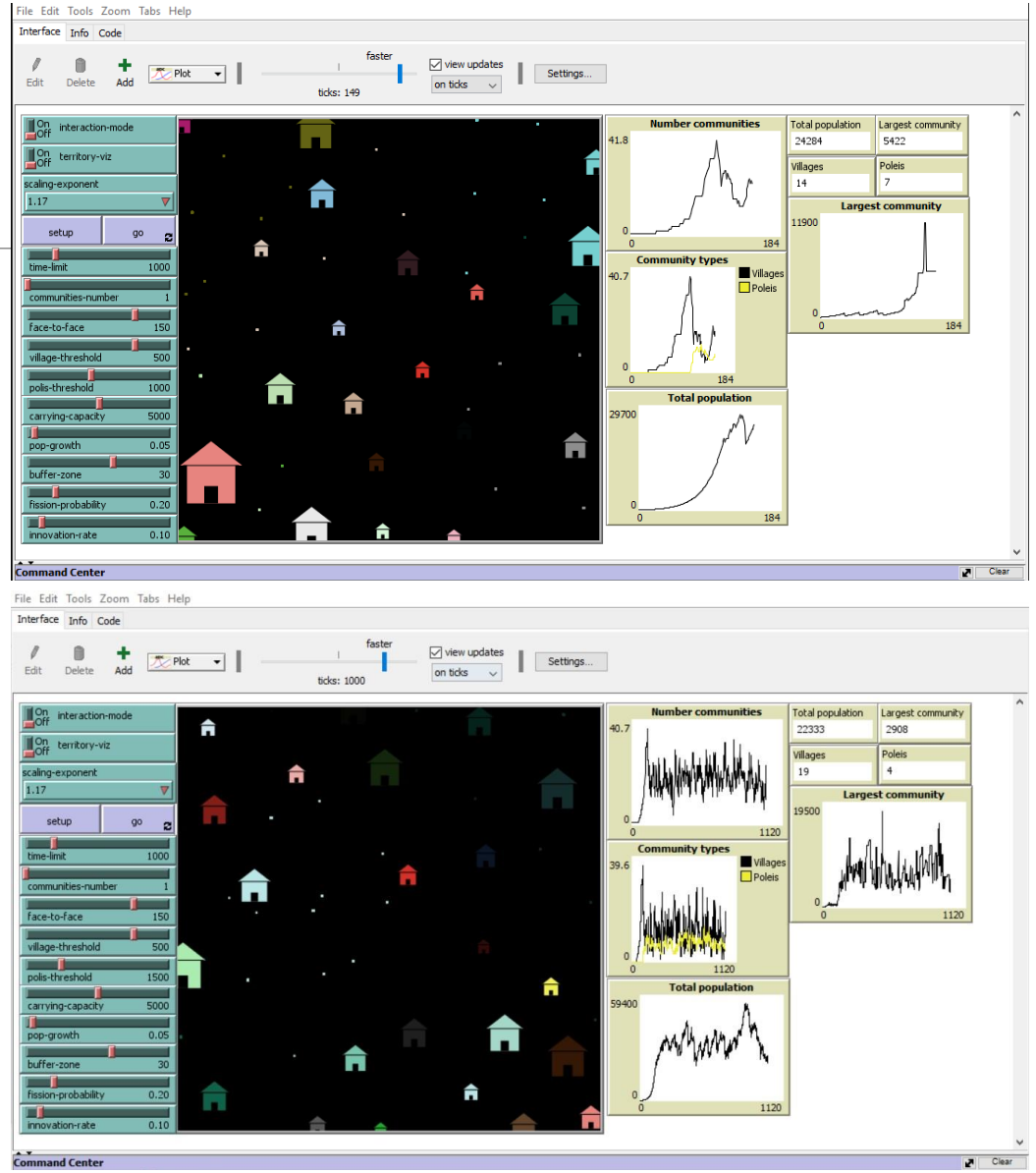
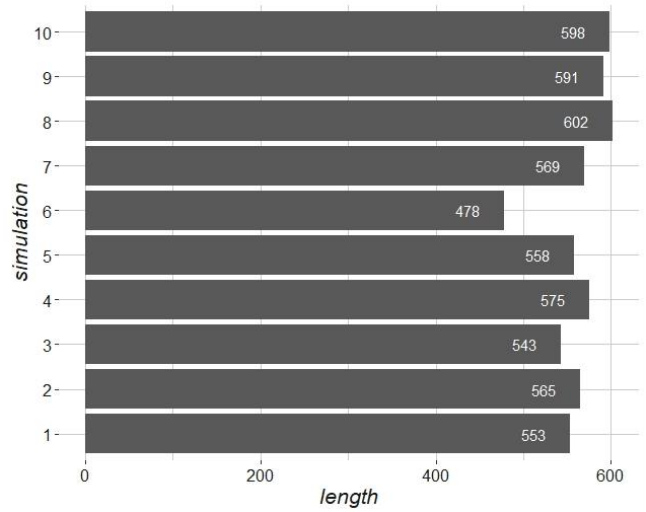
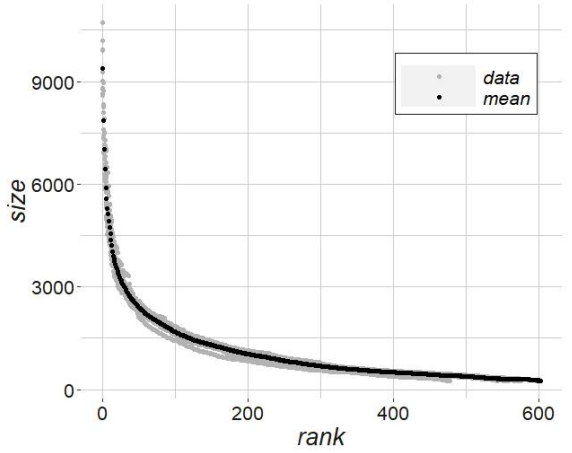
Code and model documentation available:
https://github.com/driesdaems10/PolisABM

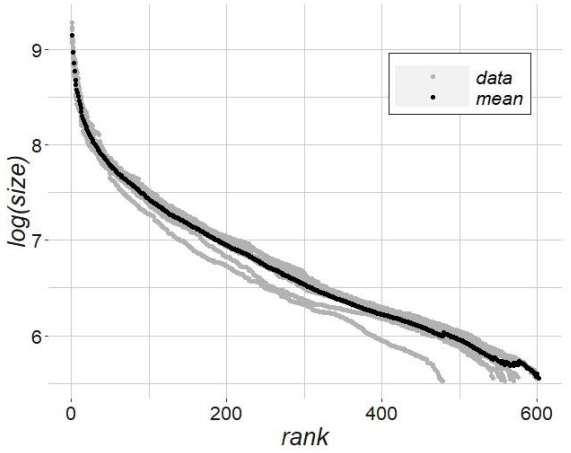


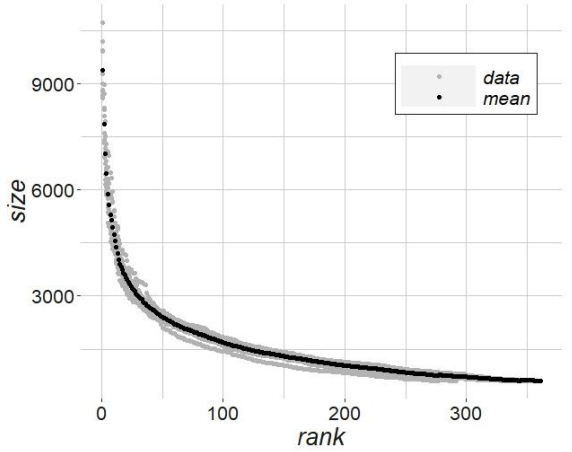
PolisABM: Results

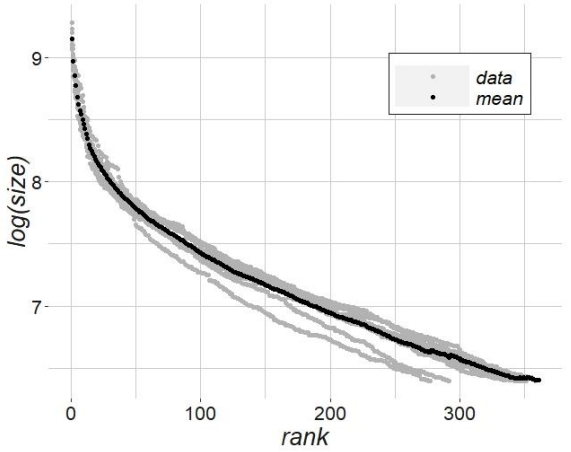
- 10 simulation runs
- 500 time steps
- Primate distribution
  - Full site distribution (top)
  - Only *polis* communities (below)











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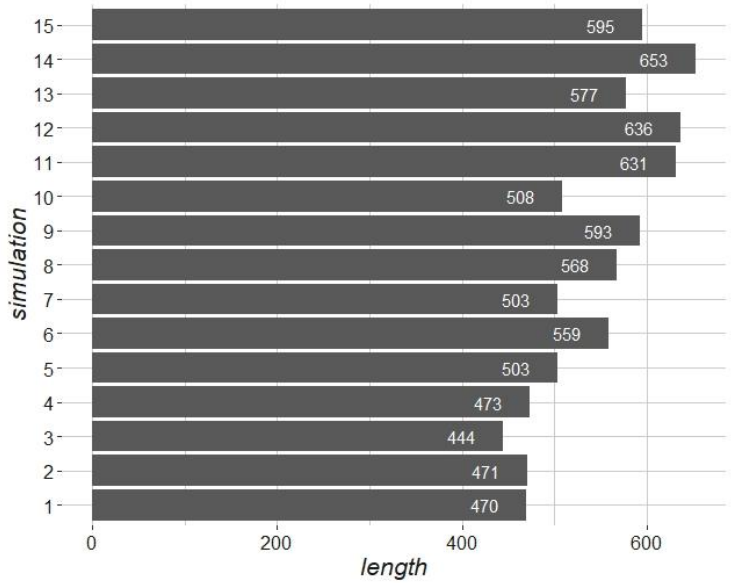
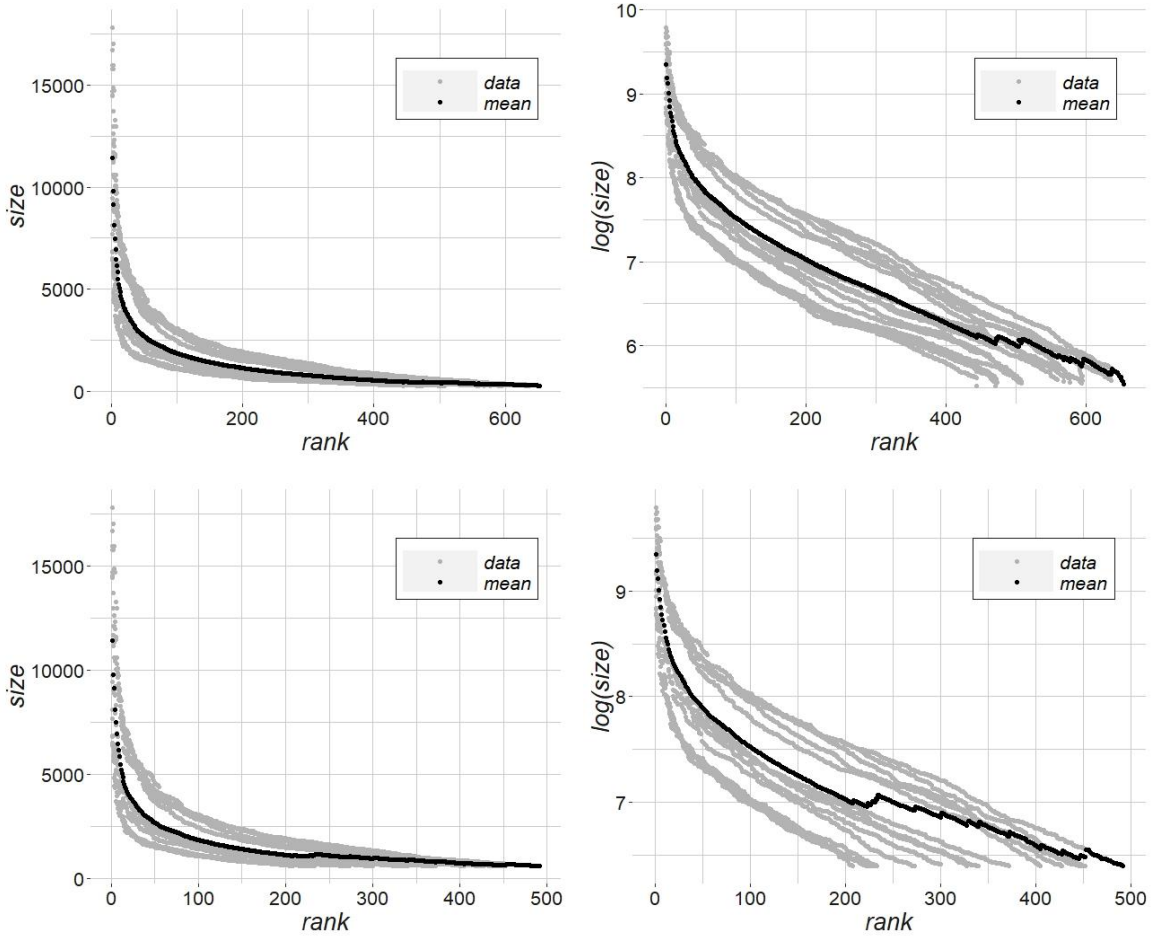
PolisABM: Results

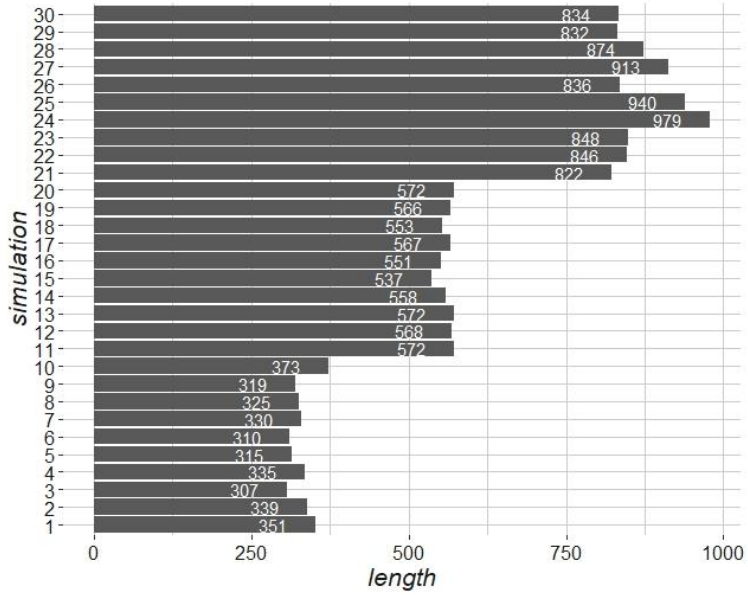
- 15 simulation runs
- 500 time steps
- Carrying capacity

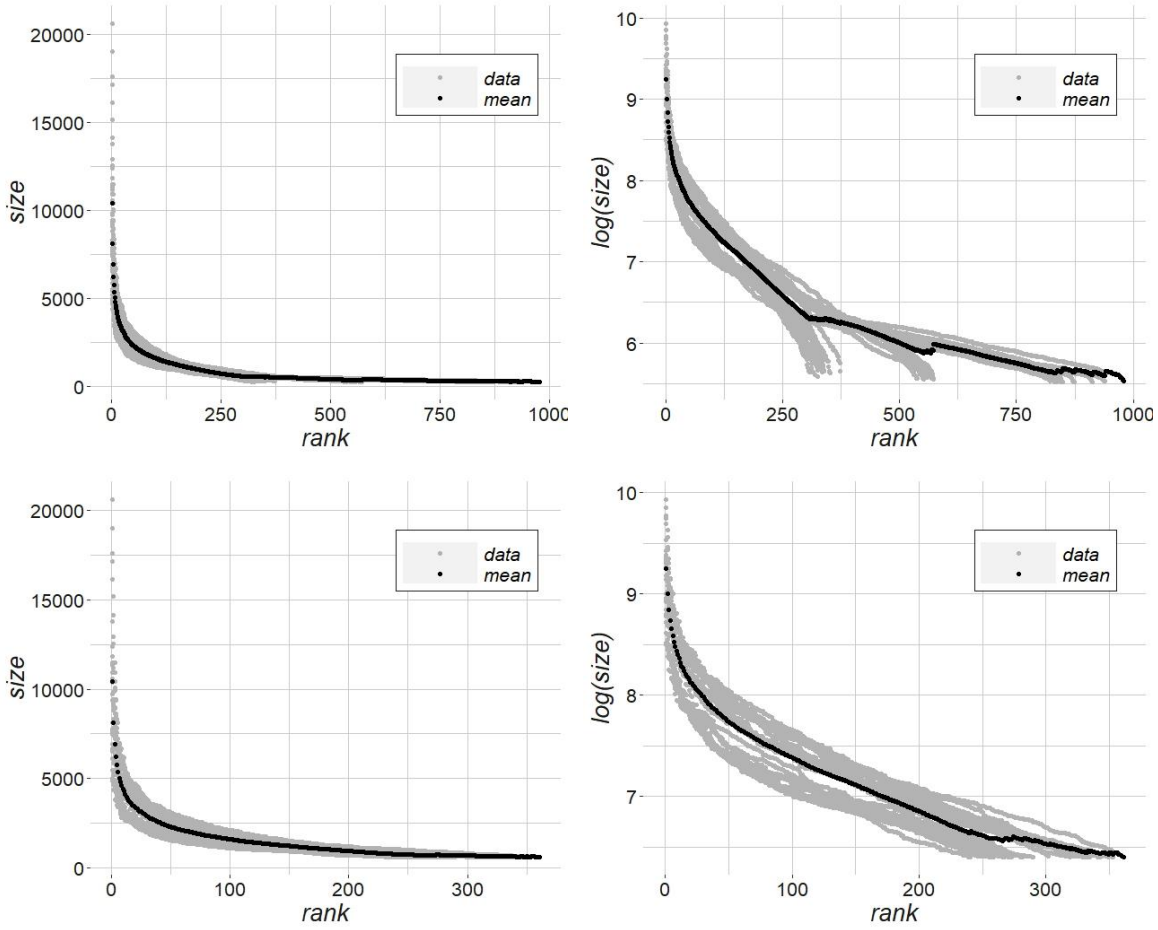




PolisABM: Results

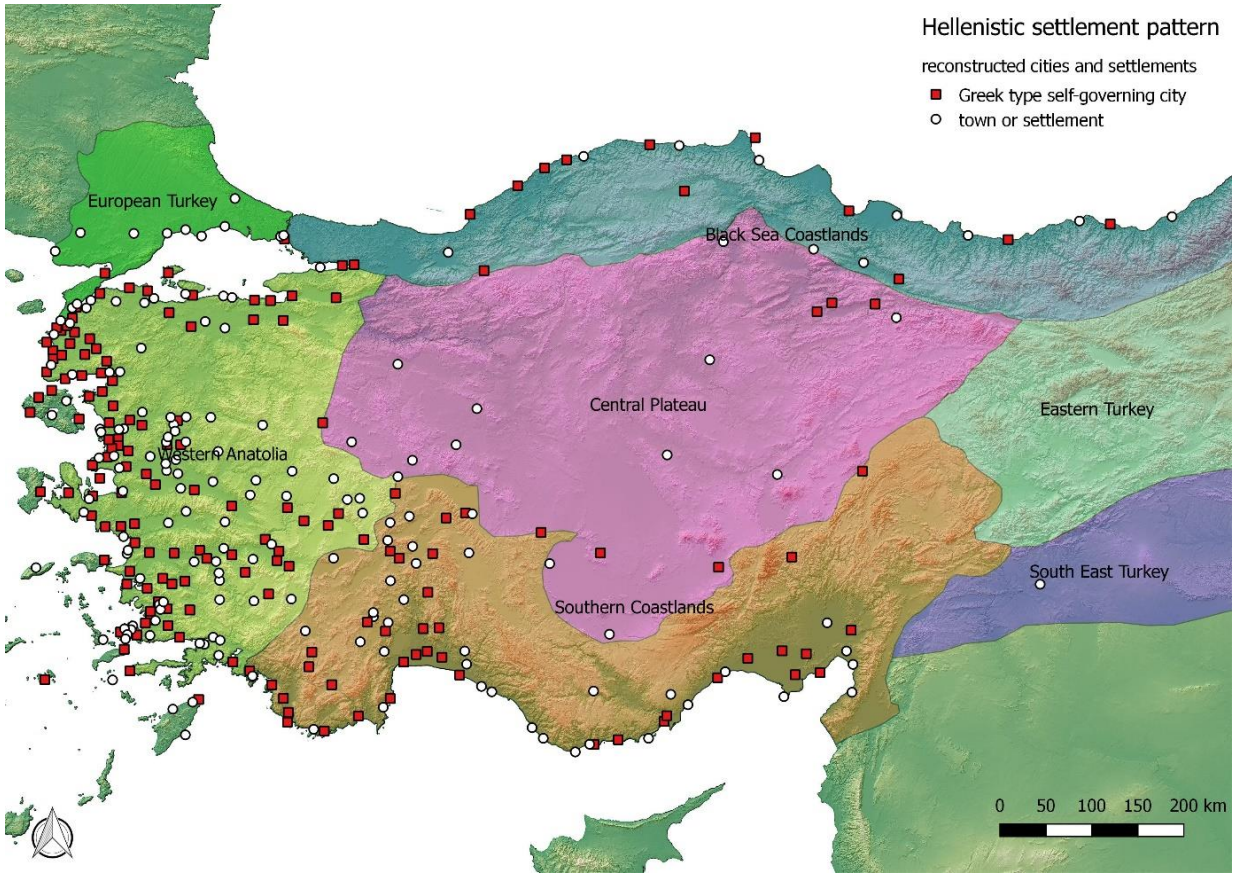
- 30 simulation runs
- 500 time steps
- Fission rate





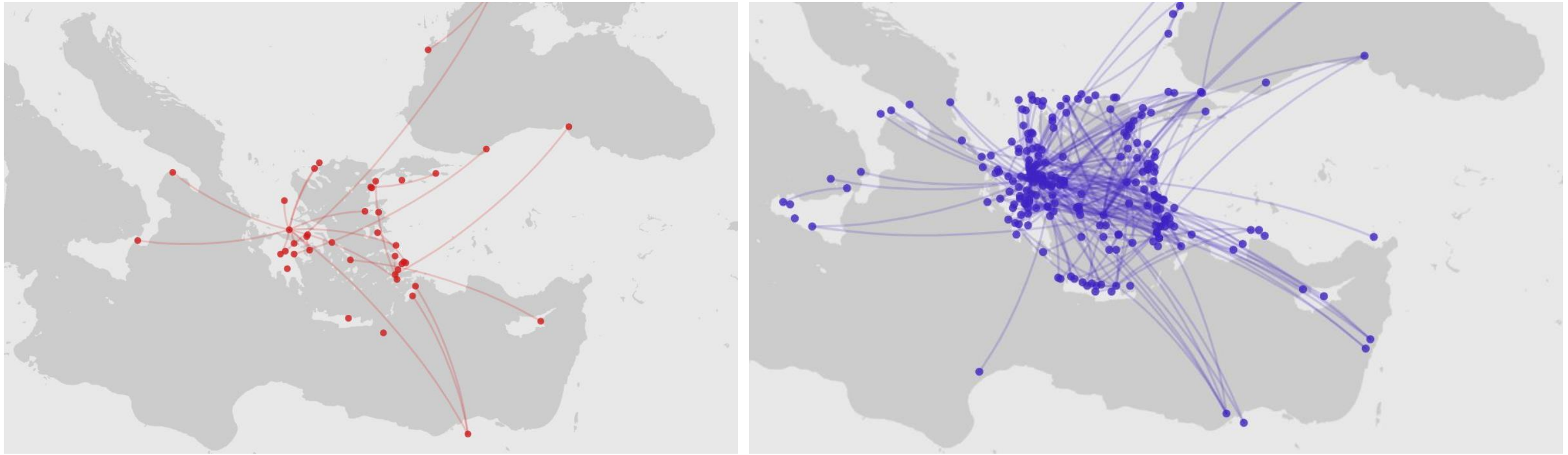
Polis formation in Anatolia

https://sites.google.com/a/umich.edu/imladjov/maps



Willett 2019

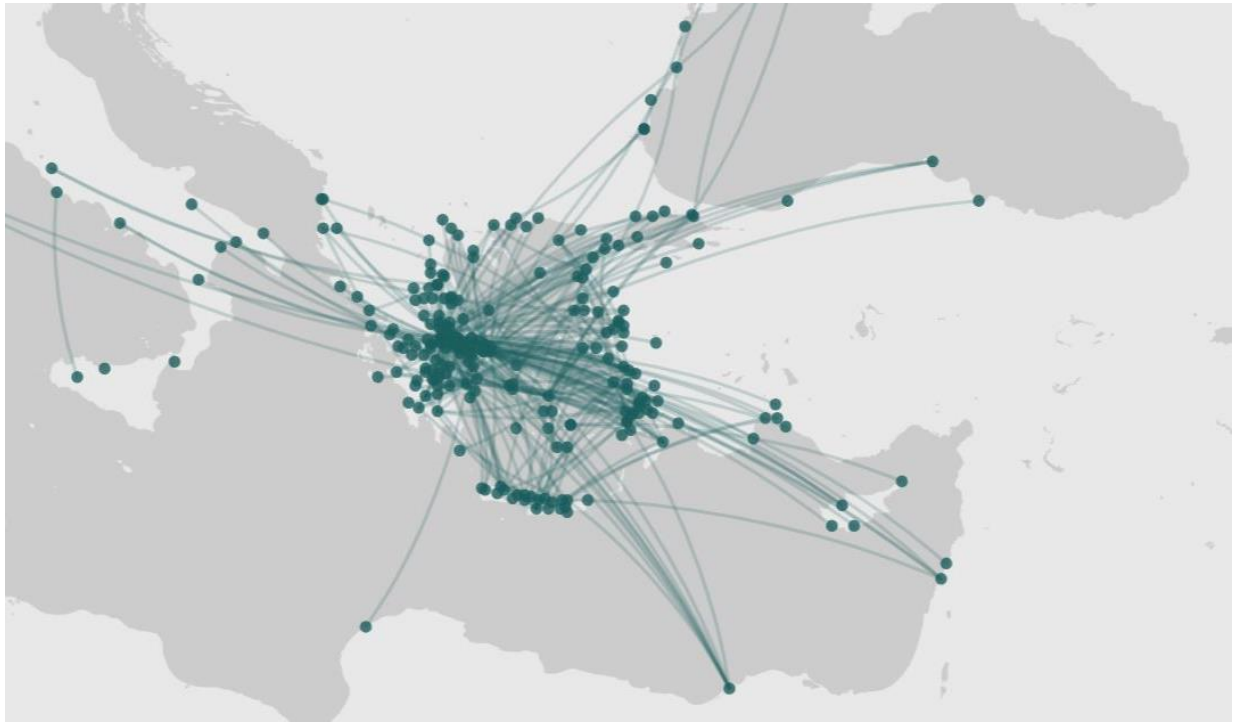
Proxenia networks

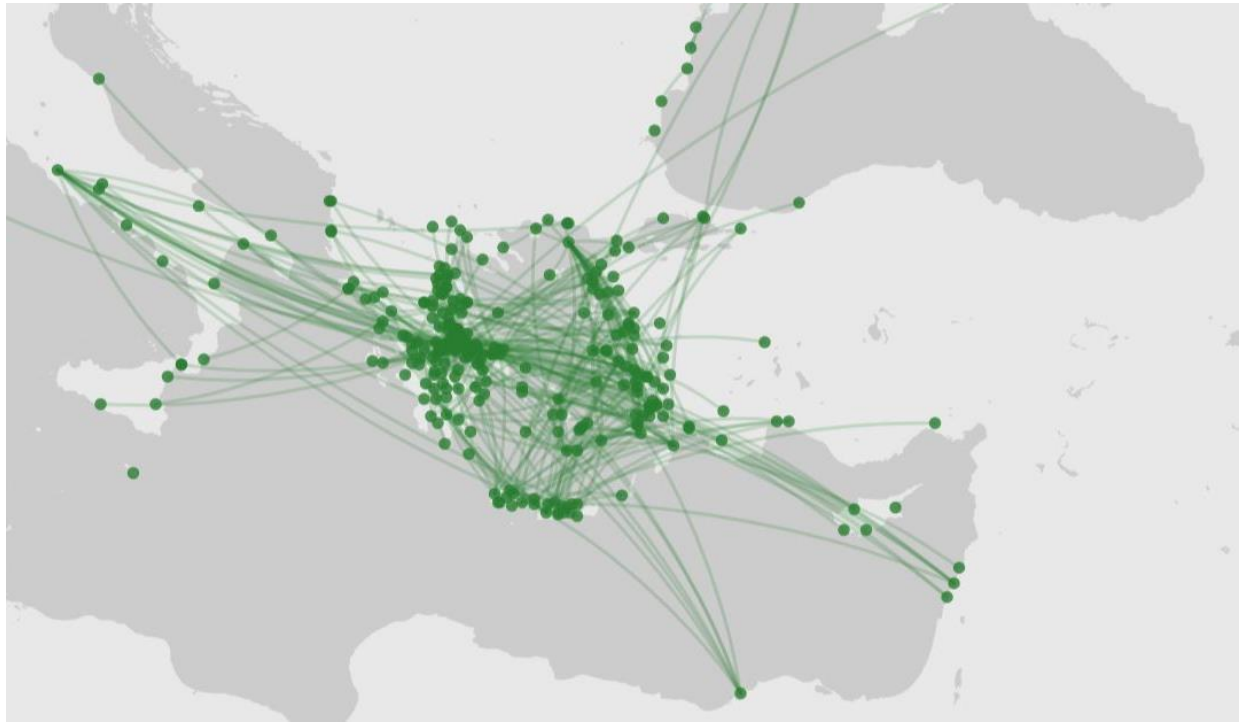


Proxenia networks between *poleis* in 7th to 4th centuries (left) and first half of the 3rd century (right)
Map made with online visualisation tool Palladio (http://hdlab.stanford.edu/palladio/)

Mack, W., 2015. *Proxeny and Polis: Institutional Networks in the Ancient Greek World*. Oxford

Proxenia networks





Proxenia networks between *poleis* in second half 3rd century (left) and 2nd century (right)
Map made with online visualisation tool Palladio (http://hdlab.stanford.edu/palladio/)

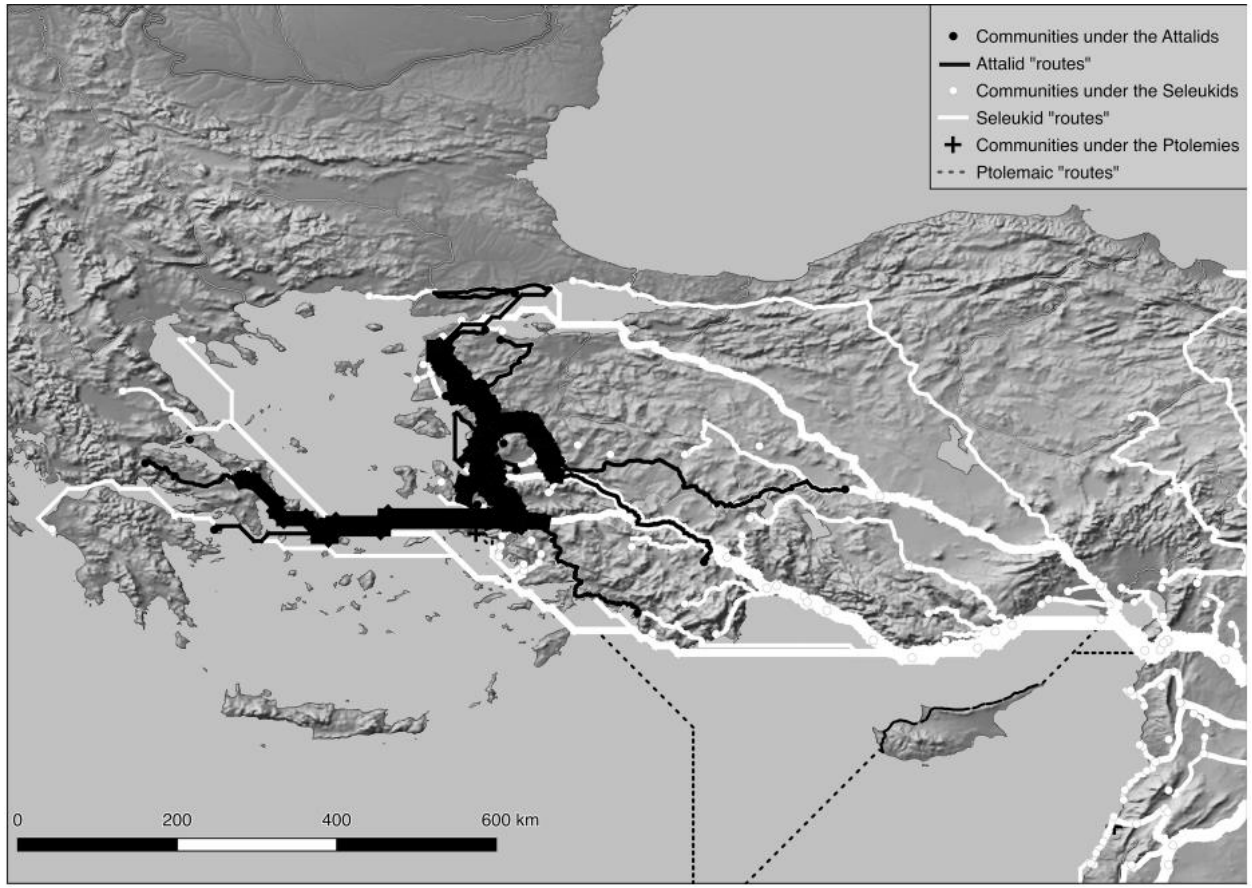
Mack, W., 2015. *Proxeny and Polis: Institutional Networks in the Ancient Greek World*. Oxford

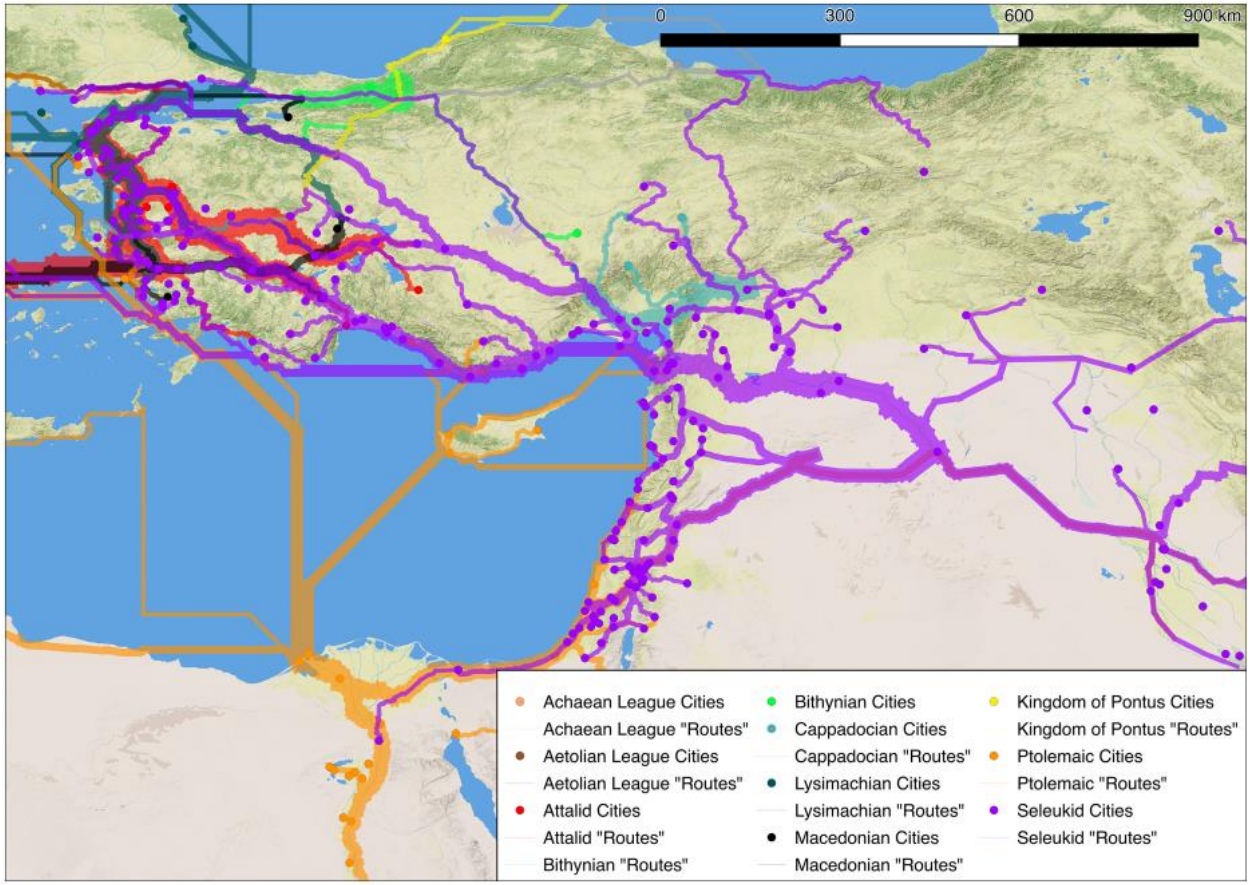
Proxenia networks

Proxenia networks between *poleis* in first half 1st century (left) and second half 1st century (right)
Map made with online visualisation tool Palladio (http://hdlab.stanford.edu/palladio/)

Mack, W., 2015. *Proxeny and Polis: Institutional Networks in the Ancient Greek World*. Oxford

Imperial networks in Hellenistic Anatolia





Horne, R., 2021. Digital Tools and Ancient Empires: Using Network Analysis and Geographic Information Systems to Study Imperial Networks in Hellenistic Anatolia. Journal of World History 32, 321–343.

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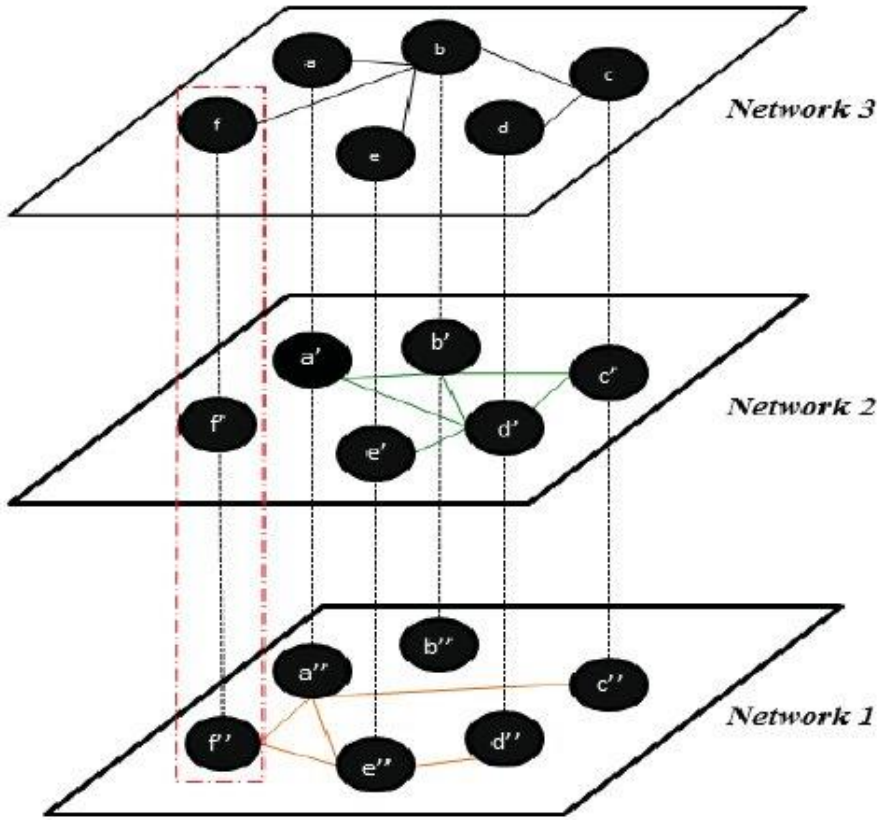
Road forward: Multi-scalar networks in Hellenistic Anatolia

- Complex, multi-level networks
  - Polis formation
  - Community networks
  - Imperial strategies
- Cross-scalar interaction
  - Micro – meso – macro
  - Bottom-up: communities of practice and *koine*
  - Top-down: state formation and governance
- Integrate archaeological and textual data



Bouanan et al. 2015

Bouanan, Y., Ribault, J., Forestier, M., Zacharewicz, G. and Vallespir, B., 2015. Modeling and Simulation of Human Reaction in a Multidimensional Social Network. *IFAC-PapersOnLine*, 48(3), pp.592–597.

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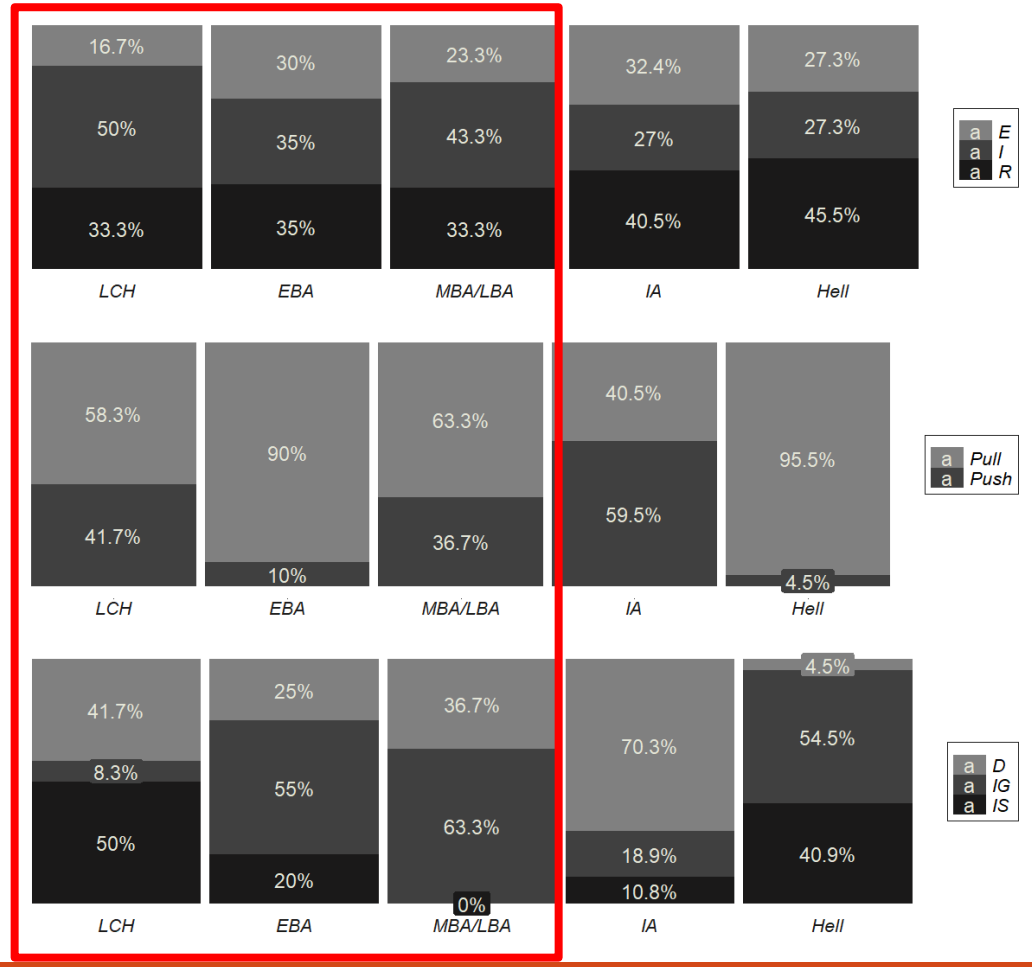
Conclusions: Social complexity trajectories in Anatolia

- Late Chalcolithic (LCH: 4000 – 3100 BCE)
  - Small-scale communities of few hundred people
  - Polity growth capped by limits to information processing in face-to-face communities
- Early Bronze Age (EBA: 3100 – 2000 BCE)
  - Development of additional structures of social organization allows polity growth
  - Strong shift towards integration as pulling force for network formation inducing stronger complexity formation
- Middle and Late Bronze Age (MBA/LBA: 2000 – 1200 BCE)
  - Continuation of EBA patterns
  - Increased intra-system diversification resulting in social inequality and stratification



Daems, D., 2021. *Social Complexity and Complex Systems in Archaeology.* Routledge.

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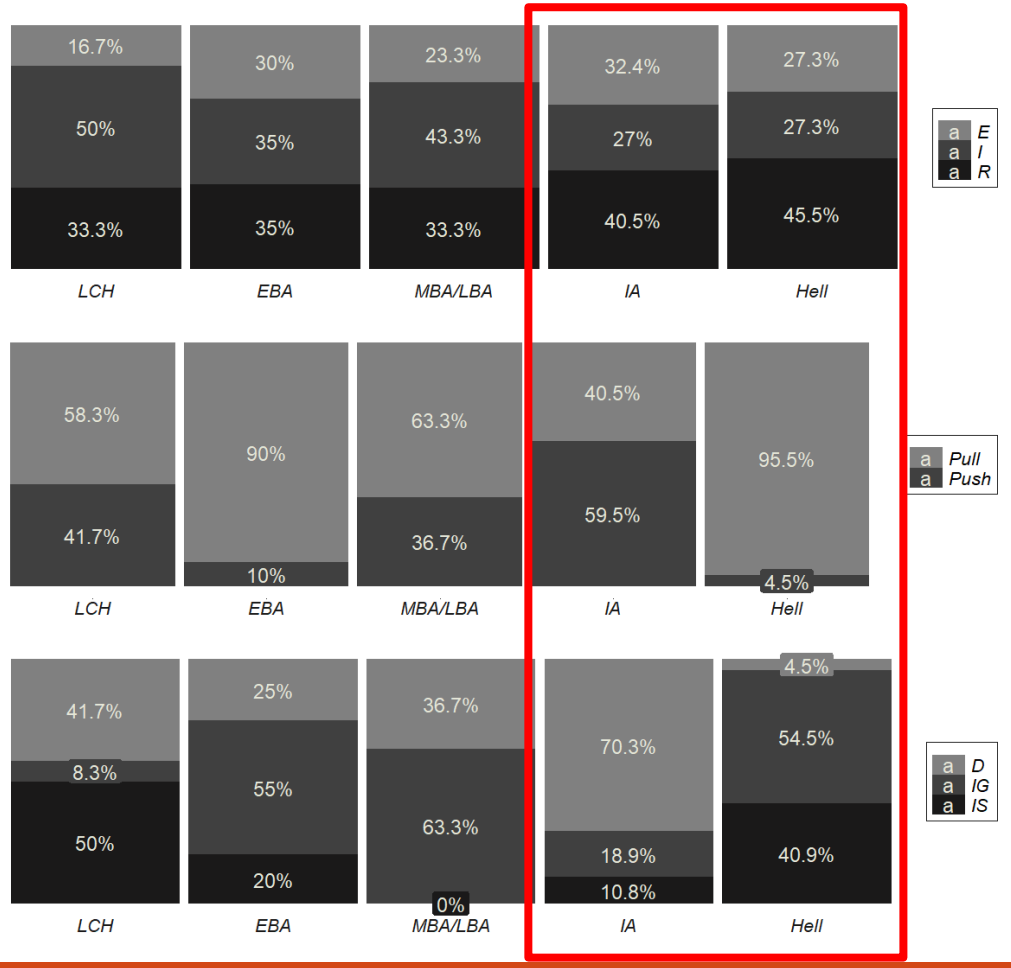
Conclusions:
Social complexity trajectories in Anatolia

- Iron Age (1200 – 334 BCE)
  - Breakdown of social complexity trajectories
  - Reorganisation through shift towards inter-system diversification as main pushing force
  - Niche diversification and landscape-filling
- Hellenistic period (334 – 100 BCE)
  - System overhaul with focus on integration and intensification as major pulling force
  - Larger polity sizes and central place formation
  - Widespread urbanization and market integration



Daems, D., 2021. *Social Complexity and Complex Systems in Archaeology.* Routledge.

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Conclusions: Archaeological networks

Formal approach to connectivity, interaction and relationality

Challenges

- Deep understanding vs. ‘push the button’ approach to network science
- Dealing with fragmentation and coarse resolution of archaeological data

Contributions of archaeology to broader network science

- Understanding change in social systems though long-term perspectives
- How to study complex patterns of interaction through indirect and fragmented sources

Establishing common ground in archaeological and historical network analysis

- Similar methodological challenges
- Similar research questions
- Similar goals

Slides available here: https://github.com/driesdaems10/ANEE

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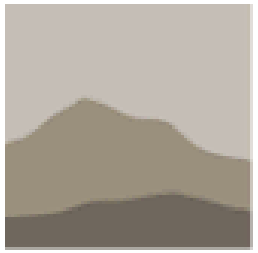

SAGALASSOS
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