MESOLITHIC SETTLEMENT PREDICTION AND EMERGENT MOVEMENT DYNAMICS:
A Predictive Study of Mobility across a Complex Orcadian Landscape

Leo Sucharyna Thomas*1, Alison Heppenstall†1, Caroline Wickham-Jones‡2 and Rachael Oldroyd†1

[1] University of Leeds

[2] University of Aberdeen

March 20, 2018

Summary

A proof-of-concept study integrating Geographic Information Systems and Agent-Based Modelling (ABM) into the study of Mesolithic movement and settlement distribution. Focussing on the development of the physical environment as a resistive force to human mobility. The development of: a static movement resistance surface, settlement prediction model and an ABM approach to pathfinding demonstrates an innovative combination of computation and archaeological study, which serves to provide insight and validation for beliefs held regarding human mobility and settlement patterns in the Mesolithic Period.

KEYWORDS: Agent-Based Modelling (ABM), Mesolithic, Orkney, Landscape, Human Mobility.

Acknowledgements

This research was undertaken as a Masters project at the University of Leeds and the author would like to extend thanks to the institution and primary supervisor Prof. Alison Heppenstall. In addition, great thanks should be extended to Ms. Caroline Wickham-Jones for her expertise and input.
With regard data acquisition Digimap, Marine Scotland and the United Kingdom Hydrographic Office (UKHO) are all due thanks.
Final thanks must be given to Ms. Karolina Werens, for putting up with me and staying by my side throughout the process.

Biography

Leo is an archaeologist with 4+ years in the field, as supervisor, specialist, and teacher, integrating this experience into the GIS Masters, produced this project. Leo is currently a cultural heritage and GIS consultant. Research interests include: prehistory, mobility and site prediction modelling, ABM, (pre-)historic landscape reconstruction, and field archaeology.

1. Research Context

Archaeology is at risk from landscape erosion; major infrastructure projects, policy amendments to development activities, and processes of natural succession threaten the survival of established and as yet undiscovered heritage assets. Heightened landscape realism, understanding settlement affinity and developing accurate movement dynamics, as explored by this project, will allow for the minimisation of loss.

Expediency, skill shortages and financial concerns have long plagued the fields of: archaeology (CBA, 2016), conservation, and heritage, resulting in the need to develop new techniques and approaches that can be used to promote active field-based research, and better inform and direct the actions of the commercial wing. The research presented here specifically targets the highly ephemeral archaeological remains of the Mesolithic period (Darvill, 2010; Wickham-Jones, 2003), within a constricted geographical study area in the western expanse of Mainland Orkney. The Orkney study area provides a well-established and monumental Neolithic presence, with Mesolithic occupation that has long been known about, but rarely identified *in situ* (Engen, UnPub; Wickham-Jones et al., 2017). Sites are limited and predominantly identified haphazardly as a result of agricultural activity (Darvill, 2010; Wickham-Jones, 2003), warping the view of the likely distribution and establishing a need to develop methods to better address the current bias. Orkney may not be considered typical of the broader UK landscape, both in terms of the physical geography and archaeological record. However, the methods employed for this case study have inherent applicability in the wider context of prehistoric settlement and migration studies. In addition, using universal movement resistance inputs and Mesolithic settlement affinities, with the archaeological literature to adjust for variation, the methods may easily scale from a local area of interest to a trans-national study area.

2. Project: Case Study

This study developed a proof-of-concept model that integrated computational techniques into the study of exploratory and migratory movement, and settlement prediction in the Mesolithic period. Development of which allows researchers and curators to possess a deeper understanding of archaeological heritage potential.

For this project the author designed a model-led computational approach to both the pathfinding and settlement activities of Mesolithic hunter-gatherers. The study utilised mainland Orkney as a virgin environment during the period of initial exploration (*c.* 10,000 BC); with an appreciation that simulated agents possess no prior knowledge of the region beyond their field of vision and forged path. This was specifically designed to aid in the location of early migration sites, to potentially address parallels with known established site locations. There is an appreciation that the approach taken here is highly environmentally deterministic, being based on physical aspects of the terrain. This is intentional to highlight the need to have a stoic base for archaeological modelling before complexities of social or economic variability are included.

2.1 Cost Surface

Increasing *in silico* the level of complexity present in the mapping of the physical environment, progresses it from a “passive background” (Wickham-Jones et al., 2016) to a dynamic, realistic surface affecting the movement dynamics and potential settlement activities of prehistoric peoples. This was a primary concern of this project, addressing the practical aspect of human traversal of the physical environment. This is a consideration that is consistently overlooked by studies of movement in the archaeological discipline, often working at a global, continental or national scale. Although cost surface pathway modelling has been used in archaeology, many models have instead focused on methods utilised in prescriptive models such as: site catchment analysis, central place theory or optimal foraging theory (Grøn, 2017; McFayden, 2011), which defines movement within the landscape in regard to social, economic or resource-based drivers (Dean et al., 2000; Grøn, 2017; 2012; Kador, 2007; Lake, 2000; Rouly, 2009; 2015). Frequently, such models impose movement behaviours between these elements using a random-walk principle and the problematic presumption that the agent is cognisant of the route and destination ahead of time (Grøn, 2012).

2.2 Land Cover

The development of a calibrated land-cover allows for a corrected floral coverage across the study area, which represents the Mesolithic landscape rather than the modern. This is generated based on published literature and available palynological records to create a high resolution, faithfully realistic abstraction of the land-cover; given the insufficient pollen cores required for a real-world reconstruction (Davies, 2014; Kohler and van der Leeuw, 2009; Kohler et al., 2009). This calibration is refined by integrating bathymetric data with terrain data, and interpolating the unmapped areas between them. This process does abstract the final landmass, but permits a realistic representation of the submergence resulting from sea-level change since *c*. 10,000 BC, which has seen significant alteration to the shape of Mainland Orkney's landmass (Wickham-Jones et al., 2017).

Integration of a realistic calibration of the Mesolithic land-cover with a movement resistance surface that directly correlates to aspects of the physical environment, builds a comprehensive cost surface that can be interpreted, assessed, and traversed by an agent with the use of computational modelling. Installing a standardised weighting of universal movement resistance input factors (slope, ruggedness, exposure and land-cover) (Carver et al., 2012; Carver and Fritz, 2000; Carver and Müller, 2014), allows for the technique to be relevant beyond the scope of the Orcadian study area, while presenting a basic model that can be adapted for local variation and affinity. Defining the potential movement speed of an agent across a standardised measure of the terrain, allows for the innate complexities of the landscape to be the drivers behind the agent's movement dynamics, in contrast to large-scale biome/resource area classifications.

2.3 Agent-Based Model

Simulating the pathfinding of Mesolithic agents took place in the patch-based Agent-Based Modelling (ABM) environment of NetLogo. Importing the cost surface to equate one raster cell with each patch, while imposing a prescribed, non-random-walk movement dynamic for the agent, established a series of simple, observable behaviours**.** Each of the simulations represents a two-week period of exploration from a specified origin point. The interactions generated between agent and environment was mapped and the pathways overlain atop the complex landscape mapping, which presented emergent behavioural patterns associated with settlement location.

2.4 Settlement Suitability

Development of a 'settlement prediction suitability map' derived from the archaeological literature was key to the validation process for this study. Utilising the Multi Criteria Evaluation (MCE) approach, each 50m^2 cell was attributed a settlement-suitability value based on a weighted combination of relevant Orcadian Mesolithic settlement affinities (drainage, exposure, and distance to potable water and sheltered harbour) (Engen, UnPub; Fischer et al., 2007; Fuglestvedt, 2012; Grøn, 2015; 2012; Spikins and Engen, 2004). This prediction was validated using the locations of known sites and comparing them to the suitability established by the MCE.

3. Conclusion and Future Research

Identifying the pathways and plotting them against the ‘settlement prediction suitability map’ demonstrates and provides insights into the observed behaviours of the agents during multiple simulations, while also internally validating the pathfinding. Furthermore, by interrogating the behavioural patterns, there is potential to identify areas more amenable or likely to possess Mesolithic settlement activity, for example: resource processing and storage sites, hunting camps, or seasonal encampment.

The project has successfully proven the methodology, and as a proof-of-concept the model has immense scalability. This analysis has demonstrated that established claims within the archaeological literature concerning settlement affinity appear to be valid, with scope for amendments based on the study area. Potential for further study lies in regard to the development beyond bounded study areas and the increased levels of layered complexity in the environment, as well as the agent behaviours (Davies, 2014; Ch’ng, 2013; Gammack, 2015; Kohler and van der Leeuw, 2009; Willensky and Rand, 2015).

References

Carver, S., Comber, A., McMorran, R., Nutter, S., 2012. A GIS model for mapping spatial patterns and distribution of wild land in Scotland. *Landscape Urban Planning*. **104**, (3-4), 395-409. DOI: 10.1016/j.landurbplan.2011.11.016.

Carver, S., Fritz, S. 2000. Munro-bagging with a computer...? : Naismith's rule and the long walk in. *Scottish Mountaineering Club, The Scottish mountaineering club journal*. **191**, 317-322. Edinburgh: Scottish Mountaineering Club.

Carver, S., Müller, C. 2014. *Wildness Study in Wales*. [Online]. Wildland Research Institute. [Accessed 21 March 2017]. Available from: http://www.wildlandresearch.org/media/uploads/Report_WildMappingWales-v.2-Feb-2015.pdf.

(CBA) Council for British Archaeology. 2016. *CBA response to new Neighbourhood Planning and Infrastructure Bill announcement*. [Online]. [Accessed 26 August 2017]. Available from: http://new.archaeologyuk.org/cba-response-to-new-neighbourhood-planning-and-infrastructure-bill-announcement.

Ch'ng, E. 2013. Model resolution in complex systems simulation: Agent preferences, behaviour dynamics and n-tiered networks. *Simulation*. **89** (5), 635-659. DOI: 10.1177/0037549712470582.
Darvill, T. 2010. *Prehistoric Britain*. New York: Routledge.

Davies B.J. 2014. *Turtles in space! Integrating GIS and NetLogo*. [Online]. [Accessed 26 August 2017]. Available from: https://simulatingcomplexity.wordpress.com/2014/08/20/turtles-in-space-integrating-gis-and-netlogo/.

Dean, J.S., Gumerman, G.J., Epstein, J.M., Axtell, R.L., Swedlund, A.C., Parker, M.T., McCarroll S. 2000. Understanding Anasazi culture change through agent-based modeling. In: Kohler T.A., Gummerman G.J. Eds. *Dynamics in human and primate societies*. Oxford: Oxford University Press. 179-205.

Engen, M. [No Date]. *Locating Mesolithic coastal sites in northern Europe: The Norwegian method adjusted for GIS and tested in Scotland*. Unpublished.

Fischer, A., Richards, M., Olsen, J., Robinson, D.E., Bennike, P., Kubiak-Martens, L., Heinemeier, J. 2007. The composition of Mesolithic food. Evidence from the submerged settlement on the Argus Bank, Denmark. *Acta Archaologica*. **78** (2), 163-178. DOI: 10.1111/j.1600-0390.2007.00104.x.

Fuglestvedt, I. 2012. The pioneer condition on the Scandinavian Peninsula: the last frontier of a 'Palaeolithic way' in Europe. *Norwegian Archaeological Review*. **45** (1), 1-29. DOI: 10.1080/00293652.2012.669998.

Gammack, D. 2015. Using NetLogo as a Tool to Encourage Scientific Thinking Across Disciplines. *Journal of Teaching and Learning with Technology*. **4** (1), 22-39. DOI: 10.14434/jotlt.v4n1.12946.
Grøn, O. 2017. Optimal foraging or not? An Evenk example of resource exploitation. *Stratum Plus*. **1**, 319-328.

Grøn, O. 2015. *The 'fishing-site model' – a method for locating Stone Age settlements under water, or the opposite?* [Online]. [Accessed 26 August 2017]. Available from: https://www.researchgate.net/publication/283210389_The_%27fishing-site_model%27_-_a_method_for_locating_Stone_Age_settlements_under_water_or_the_opposite.

Grøn, O. 2012. Our grandfather sent the elk – some problems for hunter-gatherer predictive model. *Quartär*. **59**, 1-14. DOI: 10.7485/QU59_8.

Kador, T. 2007. Where are we going? Movement and Mobility in Mesolithic research. *Internet Archaeology.* **22**. DOI: 10.11141/ia.22.2.

Kohler, T.A. 2000. Putting social sciences together again: An introduction to the Volume. In: Kohler T.A., Gummerman G.J. Eds. *Dynamics in human and primate societies*. Oxford: Oxford University Press. 1-19.

Kohler, T.A., van der Leeuw, S.E. 2009. Introduction: historical socionatural systems and models. In: Kohler, T.A., van der Leeuw, S.E. Eds. *The model-based archaeology of socionatural systems.* Canada: School for Advanced Research. 1-12.

Kohler, T.A., Johnson, D., Varien, M., Ortman, S., Reynolds, R., Kobti, Z., Cowan, J., Kolm, K., Smith, S., Yap, L. 2009. Settlement ecodynamics in prehispanic Central Mesa Verde region. In: Kohler, T.A., van der Leeuw, S.E. Eds. *The model-based archaeology of socionatural systems.* Canada: School for Advanced Research. 61-104.

Lake, M.W. 2000. MAGICAL Computer simulation of Mesolithic foraging. In: Kohler T.A., Gummerman G.J. Eds. *Dynamics in human and primate societies*. Oxford: Oxford University Press. 107-144.

McFayden, L. 2011. Temporary spaces in the Mesolithic and Neolithic: Understanding landscapes. In: Pollard, J. *Prehistoric Britain*. Oxford: Blackwell Publishing. 121-134.

Rouly, O. (2015). At the root of sociality: Working towards emergent, permanent, social affines. In: Andrews, P., Caves, L., Doursat, R., Hickinbotham, S., Polack, F., Stepney, S., Taylor, T., Timmis, J. Eds. *Proceedings of the European Conference on Artificial Life 2015*. 82-89. MIT Press.

Rouly, O. 2009. *In Search of the Roots of Social Complexity.* Unpublished. George Mason University, Fairfax, Virginia.

Spikins, P., Engen, M. 2004. *Putting Predictive Models Underwater, Challenges New Perspectives and Potential of GIS Based Predictive Models in Submerged Areas*. [Online]. [Accessed 25 August 2017]. Available from: http://proceedings.caaconference.org/files/2004/51_Spikins_Engen_CAA_2004.pdf.

Wickham-Jones, C. 2003. *Searching for the First Settlers of Orkney*. [Online]. [Accessed 25 August 2017]. Available from: http://www.orkneyjar.com/archaeology/dhl/papers/cwj/index.html.

Wickham-Jones, C. 2003. *Searching for the First Settlers of Orkney*. [Online]. [Accessed 25 August 2017]. Available from: http://www.orkneyjar.com/archaeology/dhl/papers/cwj/index.html.

Wickham-Jones, C., Bates, C.R., Bates, M., Dawson, S. 2017. The Changing Landscape of Prehistoric Orkney. In: *The Ecology of Early Settlement in Northern Europe - Conditions for Subsistence and Survival* - Per Persson. **1**. DOI: 10.1558/equinox.30926.

Wickham-Jones, C., Bates, M., Bates, R., Dawson, S., Kavanagh, E. 2016. People and Landscape at the heart of Neolithic Orkney. In: Ostericher, I. *Archaeological Review from Cambridge: Volume 31.2. Landscapes.* Cambridge: Victoire Press Ltd. 26-47.

Wilensky, U., Rand, W. 2015. *An introduction to Agent-Based Modeling: Modeling natural, social, and engineered complex systems with NetLogo*. Massachusetts: MIT Press.