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USING AGENT BASED MODELING TO REPLICATE ORIGINS OF SOCIAL COMPLEXITY: THE CASE OF LIMITED EVIDENCE IN THE LATE LONGSHAN CULTURES AND EARLY ERLITOU CULTURE

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ABSTRACT

Within the archaeological record for Bronze Age Chinese culture, there continues to be a gap in our understanding of the sudden rise of the Erlitou State from the previous late Longshan chiefdoms. In order to examine this period, I develop and use an agent based model (ABM) to explore possible socio-politically relevant hypotheses for the gap between the demise of the late Longshan cultures and rise of the first state level society in East Asia. I test land use strategy making and collective action in response to drought and flooding scenarios, the two plausible environmental hazards at that time. The model results show cases of emergent behavior where an increase in social complexity could have been experienced if a catastrophic event occurred while the population was sufficiently prepared for a different catastrophe, suggesting a plausible lead for future research into determining the life of the time period.

1 INTRODUCTION

Social complexity is largely considered to have originated in a pristine fashion in four locations on the globe: Mesopotamia, the Yellow River basin in China, the Andes of South America, and Mesoamerica (Cioffi-Revilla 2014). Identifying the development of these regions from kinship based societies to chiefdoms and then to states is a topic of great interest among computational social scientists. Computational social science, particularly as it relates to the very origins of human societies, or sociogenesis, is interdisciplinary by nature. It draws from social sciences such as archeology, anthropology, and - where written records exist – historiography. To these fields, the computational social scientist applies computer modeling to shed light on areas that either lack specific evidence or to develop novel hypotheses of political origins.

One area that lacks specific evidence and is in need of new hypotheses of political origins is the seemingly rapid rise to statehood of the Erlitou culture in the middle Yellow River valley of China. Chiefdoms certainly existed in this area prior to Erlitou, but there has been scholarly debate over the genesis of Erlitou and its immediate rise to statehood. Archeologists in China and the West have approached the problem from different perspectives, the former largely informed by historiographic tradition of Chinese state origins and the latter almost exclusive focused on the archeological record.

This problem set has been the subject of study for peleoclimatologists, archeologists, anthropologists, and others. In many cases whether the analysis is conducted with deterministic or stochastic methods, the focus of the research is on the human-environmental interaction. Globally, the transition from the Helocene to the Agricultural revolution of the Neolithic era is the beginning of social complexity that developed into our modern day systems. That this transition occurred was key to enabling the development of human societies as we know them today (Dow et al. 2009). Wirtz and Lemmon (2003) present a compelling mathematical model that projects human-environment interaction from a global

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perspective for the whole of the Neolithic period. While they believe agent based modeling to be a lesser alternative to mathematical models of such global scale, they do acknowledge it to likely be the ideal method for examining such human-environment interactions for smaller spatial scales and shorter time periods. Similarly, Dow et al. explain the transition to the agricultural revolution of the Neolithic period as an endogenous development of population and technology responding to climate change (Dow et al. 2009). Yu et al. (2014) have examined human-environment systems, assuming a limit of flood-bearing capability and mathematically assessing a disaster causing factor against a disaster bearing factor to explore what happens to such a system when extreme flood hits. They use remote sensing as a means to test the existing regional limit of flood-bearing capability.

In addition to this research, there is the contribution of computational social scientists who examine land use and the development and origins of social complexity. Agent based modeling of simple agents making decisions based on fitness level has existed for at least 20 years. One of the first agent based models of human-environment interaction was the Sugarscape model developed by Epstein and Axtell (1996). This model demonstrated the basic movement of a population based solely on the need to maximize their fitness level as a result of a population with heterogeneous metabolism and ability to see a distance toward other food sources. These basic parameters produce complex migration patterns even without any agent to agent interaction modeled. Other related modeling efforts include those examining the simplest formation of polities. These modeling efforts include both general and abstract use of an ABM to simulate increasing complexity of a polity and specific and designed use of an ABM to examine historical human-environment interaction. Simpol presents an abstract spatial-political model of social complexity. The computation requires that "1) the polity must detect and understand situational change, 2) society must mobilize, 3) government must act, and 4) policies must work results in the overall performance of the polity as a whole" (Cioffi-Revilla 2009, p. 36). A similar effort: RebeLand does the same but incorporates an evolutionary algorithm. RebeLand includes a heterogeneous population, natural environment, natural resources, cities, governance structures, and public issues that affect the general population (Cioffi-Revilla et al. 2012).

Archeology has also used agent based models to assist in understanding how specific societies may have changed or disappeared. A key work in this field is that of Axtell et al. (2002) in modeling how the households of the Anasazi may have abandoned the Long House Valley region. This work was highly calibrated based on the household structure, cultural dynamics, land use techniques, climate and archeological data of the time. Based on this human-environment interaction model, the authors were able to replicate the patterns of the disappearance of the Anasazi from the archeological record, to include the pattern of population increase and decrease recorded for the region. Similarly, Kohler et al. (1999) use a highly calibrated model to replicate land use pattern changes between the Pueblo II and Pueblo III population in the ancient Southwestern United States. Whereas in the Anasazi simulation, the interaction between the agents is more specifically designed, the Pueblo model focuses more on the explicitly defined landscape.

There also has been previous work that looks at explicitly defined spatial settings to examine specific social-political hypotheses. Chliaoutakis and Chalkiadakis (2014) use an ABM to examine the early Minoan civilization of Crete during its Bronze Era. Their model focuses on simulating autonomous agents to test different social organization paradigms on land use patterns and population growth. The subject of study for this paper is informed by the aforementioned theoretical efforts. However, it is the first to apply agent based modeling to examine plausible scenarios to account for the lack of evidence for the 100 year period that occurred between the late Longshan culture of Neolithic China and the first state to develop in the middle Yellow River valley. For the remainder of this paper, section 2 will describe the methodology used to test the hypothesis that the demise of late Longshan cultures at the edge of the Loess Plateau and the rise to statehood of Erlitou can be explained by the same social complexity increasing event. Here, I include both a summary of archeological, historiographic, and socio-political underpinnings for the ABM developed to examine this issue and the design of this spatially-explicit ABM. In section 3, I discuss the results from the ABM experiments. In section 4, I summarize the paper and identify areas of further work.

2 METHODOLOGY

In order to examine the topic of this study. I will first establish the evidentiary record for a possible overlap of cultures between the late Longshan of the Neolithic era and the early Erlitou state, both of which existed in the middle Yellow River Valley. While there is inconclusive archeological evidence of the transition period between these two eras to explain the rapid rise to statehood, there is archeological evidence that relates to the time period discussed. I will then simulate social complexity in the middle Yellow River valley, specifically social complexity as a result of hazard response and disaster prevention.

2.1 Archeological Record

Broadly, there are two approaches to examining the archeological record as it relates to the time period in question: the social archeological approach and the archeological approach informed by historiography. The social archeological approach uses anthropological theory and interdisciplinary methods to examine archeological evidence from the standpoint of determining the level of complexity (Liu and Chen 2012). Identified evidence allows for the determination of social complexity based on the levels of hierarchy and the level of organization required for a particular artifact or technology (Marcus and Feinman 1998). The evidentiary data is found in archeological and geographic reports from Chinese academic institutions and archeological compilations from US scholars. It should be noted that US scholars tend to use a social archeological approach to the evidentiary record, while many Chinese scholars (the work of some which was used in this study) are informed by a historiographic approach. This historiographic approach attempts to tie archeological analysis to historiographic records written far after the period described.

Here, it must be noted that two scholars have provided a significant benefit to the cumulative knowledge of this time and area: Li Liu and Xingcan Chen. Their volumes on archeology of this region incorporate all the major details of archeological research in China and bring these findings to the English-speaking reader. To their cumulative work, I draw from individual reports that were written after their latest work was published and details from specific reports they cite but which are not included in their volumes.

Wu et al. conducted geological analysis of the Yellow River Valley and discovered the first samples to show outburst flood sediment dating to the location and time period of the transition from Neolithic to Bronze Erain this region. (Wu et al. 2016) Additionally, Wagner et al. have plotted the existing archeological sites in China and mapped comparisons of different time-slices from the Neolithic to Bronze Era and early Chinese dynasties. The area mapped consists of low-elevated alluvial plains and coastal lowlands and a

chain of mountain ridges and plateaus. (Wagner 2013) The area of study here includes alluvial plains surrounding the middle Yellow River and mountain ridges at the edge of the Loess Plateau and Taihang Mountains. The modeled landscape in this study includes these same features and approximates their location.

The late Longshan cultures of Taosi and Wangchenggang were situated just to the north and to the south of the middle Yellow River. The traditional archeological record places the demise of these cultures at c. 2000 BC (Liu and Chen 2012). However, carbon dating of bone fragments at these sites demonstrates that the Longshan culture, specifically Wangchenggang, may have lingered passed 2000 BC and overlapped with the Xinzhai culture, an early phase of Erlitou culture before what is currently termed Erlitou phase I (Zhang 2007).

The evidence found for Wangchenggang and Taosi cultures denotes at the very least that these societies were advanced chiefdoms in the Middle Yellow River Valley during the late Longshan period (Liu and Chen 2012). The lack of evidence that their political culture did not include a fourth hierarchy indicates they likely weren't yet states. The dating of these cultures places their demise at the end of the third millennium. However, this dating particularly in the region where Wangchenggang existed has been called into question by carbon dating that places the culture as late as 1835 BC (Liu and Chen 2012, Zhang 2007).

Two sets of rammed-earth walls at Wangchenggang do not appear to be associated with each other as part of the same purpose (Zhang and Wang 2014). The latter appears to have been for defense, while the former is unclear, though it may have been used for flood protection (Liu and Chen 2012). The walls at Taosi appear to be for the purpose of protection of the main city as well as flood control (Liu and Chen 2012).

Around 2100 BC, the Middle Yellow River region would have suffered decades long periods of flooding according to geographical surveys of the region (Li et al. 2013). The Taosi culture, while it had suffered a period of political turmoil in its late phase, is theorized to have collapsed due to flooding around 2000 BC (Liu and Chen 2012, Zhang 2014). Around 1900 BC, the same region would have experienced drought (Li et al. 2013), however, by this time, the late Longshan cultures would have had significantly more experience handling floods than droughts.

The middle Yellow River valley was regularly prone to flooding, these regular periods would have been met with disaster or luck by the peoples of the region, when no preparation existed. These outcomes would have been consistent with the competitive communities at the chiefdom level of social complexity in the region (Liu and Chen 2012). However, as the late Longshan societies experienced a great period of decades long flooding patterns around the year 2000 (Li et al. 2013) the opportunity for learning from collective action in preparation and response would allow the chiefdoms to become more politically advanced and socially complex. The evidence of Taosi flood control walls and the wall structures at Wangchenggang and Xinzhai that were possibly used for flood control (Liu and Chen 2012, Zhang and Wang 2014), demonstrate some collective action was taken by an advancing society.

As for the specific results of this research, we can shed light on the relationship between the archeological record and the later historiographic record. The origins of statehood in China had long been consumed by the understanding of this period as written in histories from later states. The Shiji (or The Grand Scribe's Records) written around 100 BC by Sima Qian purports to relay the founding of a state (the state of Xia) that matches the late 3rd millennium timeframe and middle Yellow River valley location of the Late Longhsan (Nienhauser 1994). A similar but separate history, the Bamboo Annals, written on bamboo and found in a tomb dating to 480-221 BC also tells the story of the early kings dated to the same late third millennium period (Feng 2013). While most scholars in China have long considered these texts in their archeological approach, Western archeologists and some Chinese archeologists recognize it as a nonstarter to aiding the archeological study (Feng 2013).

2.2 Agent Based Model

Next, I explore this problem set by examining evidence produced by an ABM. In order to facilitate the replication of ABM experiments, Grimm et al. (2010) argue for the use of an Overview, Design Concept, and Details (ODD) protocol to allow for a common language of implementation regardless of computer programing language for the ABM itself. To this end, while I've developed the ABM and conducted the experiments in Netlogo, I use the ODD protocol to explain the ABM so it may be replicated elsewhere in another computing language or platform.

2.2.1 Purpose

The purpose of this ABM is to explore possible socio-politically relevant hypotheses for the approximately 100 year gap between the demise of the late Longshan cultures and rise of the first state level society in East Asia. One hypothesis to be tested, which reflects the archeological debate, on the issue: The demise of late Longshan cultures at the edge of the Loess Plateau and the rise to statehood of Erlitou can be explained by the same social complexity increasing event.

2.2.2 Entities, State Variables, and Scales

The landscape is a 278 X 138 cellular grid representing a region of the Neolithic era middle Yellow River valley (an approximately 200 km X 100 km portion) that is home to the Taosi and Wangchenggang archeological sites. The grid includes cells representing the river, alluvial lands, and mountains. Each cell represents approximately 0.70 ha and holds a maximum capacity of 30 agents. Land suitability and land use is represented by suitability level for the agents and this suitability level increases or decreases based on the number of agents on the patch and the strategy they use to reap the land for their benefit.

Each year of the model (represented by one time step), the land experiences drought or flood based on the percentage for the landscape to do so set by the experimenter. All areas of the landscape have the potential to experience drought. The areas at lower elevations have the potential to experience flood.

Each agent has a fitness status, age, land use strategy, and initial disaster strategy. During the simulation, the agents use the land, age until 31, reproduce, and strategize how to survive floods and droughts. The age of the agents is based on research into average lifespans globally for the Neolithic period. Based on the work of Galor and Moav, life expectancy at birth experienced a decline during the agricultural revolution of the Neolithic period. They find this to be consistent regardless of the time period a region actually entered the Neolithic. While their evidentiary samples are taken from areas that exhibit a Neolithic period far earlier or later than that of East Asia, they do report one sample from Ukraine taken from shortly before the time period of this paper’s study. This sample shows a life expectancy at birth of 25, at 15 of 35, and at 20 of 36. (Galor and Moav 2007) To account for this range, the agents in the model die at the end of their 31st time step, if they do not die of starvation, flooding, or drought during the course of the simulation.

The initial population is set by the experimenter. In terms of calibrating the initial population to the evidentiary record, the late Longshan was the most densely populated period of the Neolithic in this region. The Taosi population being the most densely populated. At its population peak, there were about 13,000 persons. (Liu 2004) For modeling efficiency, the current iteration of the model uses a maximum initial population of 1000 to abstract the real population where 1 agent is equivalent to 10 real persons.

Table 1: Model Attributes.

Feature	**Design**	**Calibration**
Region specific landscpape	278 X 138 cell grid, approximately 200km X 100km (each cell ~ 0.70 hectare)	Liu and Chen 2012
Taosi and Wangchenggang setup	agents randomly set within the approximate location of these sites	Liu and Chen 2012
Drought	cell attribute changes based on expermenter's set probability abstractly modeled throughout landscape	Li et al. (2013) states that the region did experience long periods of drought at the end of the Neolithic in this region
Flooding	cell attribute changes based on expermineter's set probability abstractly modeled throughout floodplain	Li et al. (2013) states that the region did experience long periods of flood at the end of the Neolithic in this region
Landscape fitness	fitness level of individual cells	*future iterations of the model will explicitly define the fitness levels based the evidentiary record, current version assumes uniform initial fitness levels*

Maximum cell capacity	30 agents	Liu (2004) states a range of 32-63 persons per ha for late Longshan cultures, each cell in the model is approx. 0.70 ha
Agent's max age	31	approximation based on Galor and Moav (2007) analysis of Neolithic life spans globally
Agent reproduction	10 years of reproductive period, minimum fitness level required	*reproductive patterns of the late Longshan cultures currently unknown*
Leader selection	one leader per cell, stochastically derived	*abstraction based on assumption that selecting a leader requires locational proximity*
agent disaster strategy	0 or 1 where 0 is the optimal strategy to survive drought and 1 is the optimal strategy to survive flooding	*assumption of mutually exclusive strategies to allow for experimentation that accounts limited preparation resources*
agent land strategy	0 or 1 where 1 is the optimal land strategy	*abstraction of land use that allows for simple variation*

2.2.3 Process, Overview, and Scheduling

Each time step represents one year and begins with the agents aging one year at the same time their fitness score diminishes.

The fitness of the land responds to the agent's land use strategy and the number of agents on the land. With each time step, land with more than one agent using it degrades. Where there is only one individual using a piece of land and the suboptimal land use strategy, the fitness of the land neither improves nor degrades. Where there is at least one agent using the optimal land use strategy on a piece of land, the fitness of the land increases enough to bring the land back to its default fitness level after the annual degradation of it at the time step.

Once the agents have used the land, they decide whether to remain in their location or move to better land. The agents assess their plot of land against that of nearby land. Here, "nearby" is defined as the eight surrounding cells in the Moore neighborhood.

At each time step, the land experiences disaster as set by the experimenter. The two possible disasters are flood and drought. All of the cells on the landscape may experience drought. For example, if the simulation is run with a 50% chance of drought, about 50% of the cells in the simulation will experience drought. Only the cells located in the valley or the flood plain may experience flooding, termed the flood zone. Each cell in the flood zone has a probability of flooding based on the probability set for the run. For example, if there is 50% probability of flooding. About 50% of the cells in the flood plain will flood.

Where there is flood or drought, the agents are still able to use the land, but at a different rate. Where agents have a suboptimal strategy for flood, and the land they are on floods, they die. Where they have an optimal strategy they do not lose any fitness, but they do not gain any fitness from the land. Here, they are able to maintain. Where the agents have suboptimal strategy for drought, and the land they are on droughts, they die. Where they have the optimal strategy for drought they similarly maintain.

Agents on land that has not experienced flood or drought increase their fitness based on their land use strategy. If there is more than one agent on a parcel of land (a cell), the agents select a leader randomly and adopt the strategy of that leader. This will be the strategy they use on the next time step. The remaining agents who have a score of at least 10 and an age of at least 20 seeks other agents on their same area of land. The agents meeting that criteria then reproduce at a rate of one new agent for every two on that cell.

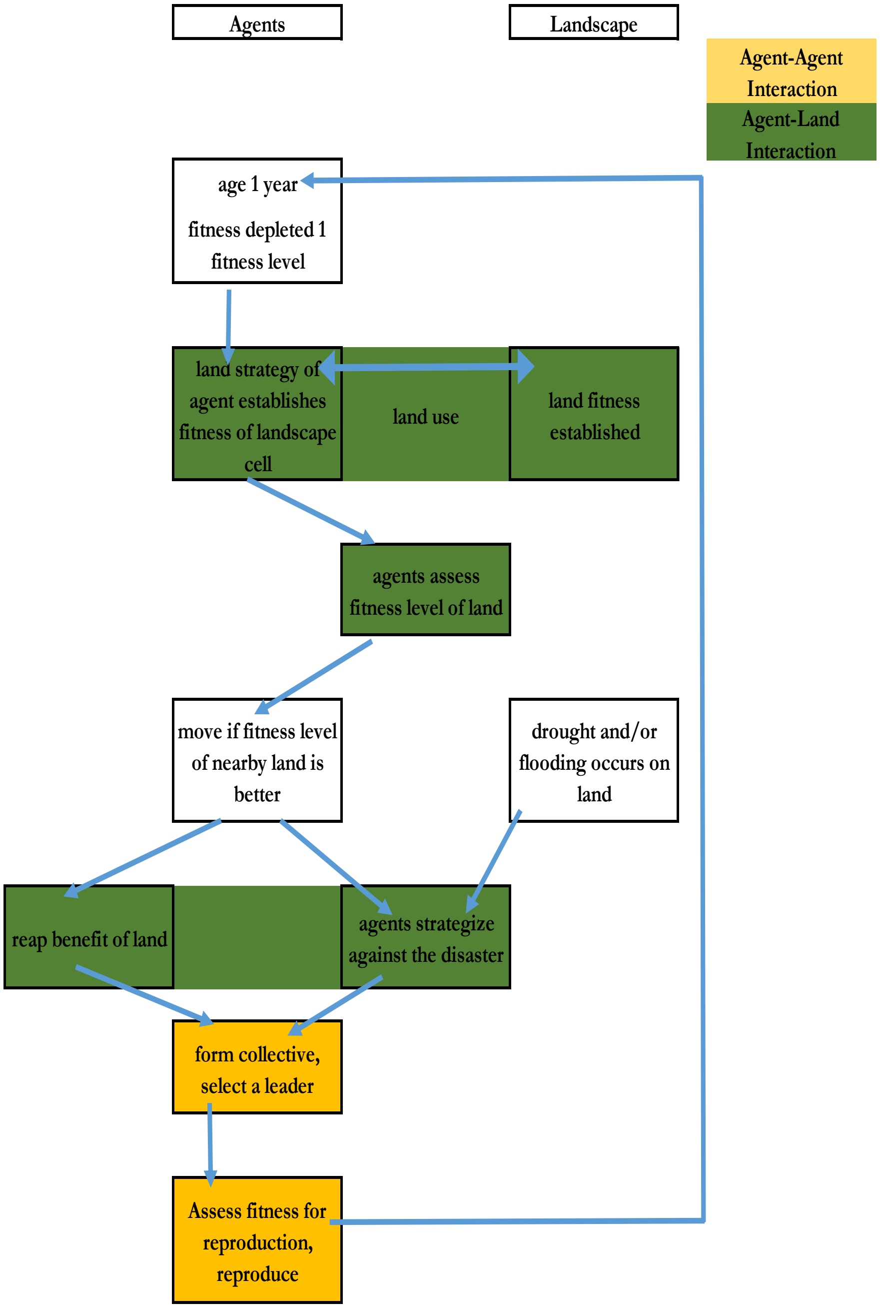

Figure 1: Activation Schedule.

2.2.4 Design Concepts

The underlying socio-political theory guiding this ABM and which the resulting collective agent behavior should be modeled against is the canonical theory of the origins of social complexity. The canonical theory is predicated on the probabilities that any one possible societal action is one of a set of several other actions, set forth in a chain of causal events each with their own probability (Cioffi-Revilla 2005; Cioffi-Revilla 1998). The accumulation of experience with collective perception and collective action is a response or lack of a response that culminates in a level of disaster for the society or a compounding of social complexity with a successful disaster response experience.

This theory allows examination of both a “Fast Process” and a “Slow Process.” The fast process allows examination of a single type of series of events and the resulting development or degradation that results. The slow process occurs over a much longer time scale and culminates in the beginning of something new and lasting.

2.3 Verification and Sensitivity Analysis

Model verification can be done iteratively in the development of a model and also via parameter sweeps. When done iteratively, this is referred to as progressive debugging. A method of parameter sweeps that can be used includes extreme combination tests. (An et al. 2005) In order to verify the model, I used a progressive debugging method to ensure a feature worked properly before adding the next feature. Additionally, I conducted parameter sweeps to both test the sensitivity of the parameters and to examine the operation of the model when extreme parameters were used in combination.

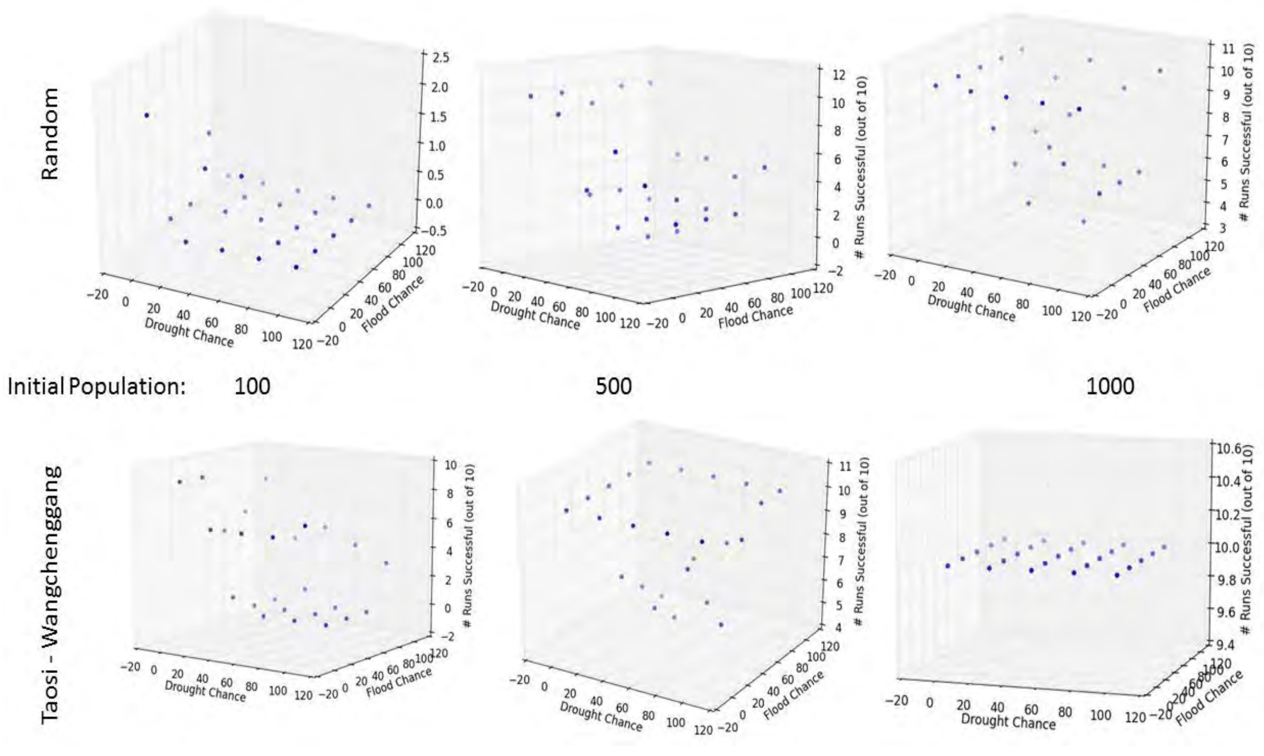

Figure 2: Instances of Population Survival During Sensitivity Analysis.

For the sensitivity analysis, I used Behavior Space within NetLogo to conduct 1500 simulations. The simulation runs ended once the population reached over 2000 at the start of a run. This decision was due to the apparent survival of the population writ large once the population reached 2000. These simulations included 10 simulations each of the following combinations for each of the parameters:

- Initial Location: Random, Taosi-Wangchenggang
- Population sizes: 100, 500, 1000
- Drought probability – 0, 25, 50, 75, 100 percent
- Flood probability – 0, 25, 50, 75, 100 percent

Within the model, collective action against disaster increases with population density. As such, the model survival rate was highly sensitive to initial location of the agent population. Agents in the model managed to survive in 43% of the instances where agents where initialized in random locations on the landscape and 72% of the instances where agents originated in the approximate locations of Taosi and Wangchenggang centers. This setting initializes with a locally dense population in two regions. (Figure 2)

3 RESULTS

The demonstrated sensitivity of the model to initial population location corresponds with what we would expect from path dependent behavior per the canonical theory – where the prior established proximity increases the probability that collective action will occur. As such to examine our findings I analyze the 750 runs that occurred in the setting with the population initially located at in the Taosi and Wangchenggang areas.

First, I examined the land strategies used. With regard to use of the land, in no instances did the population survive where all the agents remaining used the worse of the two land strategies. In almost all instances the surviving population used a mix of the optimal and sub-optimal strategy. In five of the 750 runs, the surviving population of just over 2000 agents used the optimal strategy exclusively. Because the land strategy for each agent remains the same throughout the simulation, it is unclear if this is due to a coincidence within the realm of randomness or if only those with the optimal strategy were able to survive.

Next, I examined the disaster strategies used by the agents. The disaster strategy that the agents used in most cases corresponded with the optimal strategy for the given disaster. When there was a greater chance of drought in the region, the surviving population exclusively used the strategy optimal in drought conditions. Of the 210 instances where the population survived (out of 300), all 210 simulations consisted of agents using only the drought optimal strategy.

As can be seen from Figure 2, the population had a greater chance of survival overall for a given run, when the chance of one disaster over another was greater. This result is expected. As the local leader selection process is stochastic, the surviving populations have a greater chance of being those where the chosen leader selected the optimal strategy to defend against the hazard experienced locally. In 150 simulations that exhibited an equal probability of flood and drought, the population survived in 103 instances. An exclusively drought optimal strategy was used in 49% of the simulations, exclusively flood optimal strategy in 10%, and some mixture of the two in 41% of the runs.

When there was a greater chance of flood in the region, there were 230 simulations where the population survived. Of those 230 simulations, 23% used exclusively the flood optimal strategy and 54% used a mix of the two strategies. Additionally, 23% used exclusively the strategy that was only optimal for drought. In one of the simulations where the agents exclusively used the strategy optimal for drought rather than flood, the probability for flood was 100% with no chance of drought.. This use of the suboptimal strategy, translates to collective action preparing for a drought, when in fact no drought arrived, suggesting in this run and possibly in the other 23% of runs, a third strategy emerged (not endogenous to the agents themselves) whereby they were clustered outside of the flood zone and sufficiently prepared for the arrival of a drought. The instance where the suboptimal strategy was exclusively used was with an initial population of 100, and of the 2161 agents at the simulation's end, 77% used the optimal land strategy.

This one outlier run, demonstrates the emergence of a third possible strategy against the abstracted environment of this model: a small population that is able to extract itself from the flood zone based on the luck of the cells it's chosen to move to, while maintaining a strategy that would be certain death if luck struck their cell with flood. However, the preparations represented by the strategy chosen would be ideal to withstand the other disaster, drought. This type of strategy would not only be emergent (i.e. not predicated on the programming of the agent behavior itself, but rather a separate product of specific local interactions), but would also represent a possible strategy of resilience. This type of resilience would also indicate a type of event that would allow the social remnants of a complex society to live on in a smaller population only to emerge successful against a separate societal threat that increases its social complexity.

As such I test the hypothesis: “The demise of late Longshan cultures at the edge of the Loess Plateau and the rise to statehood of Erlitou can be explained by the same social complexity increasing event” using the parameters that produced the above outlier run. I used 100 simulation runs of an initial population of 100 and a flood chance of 100%. The population survived in 72% of the runs. In 69% of the runs, the population survived using the optimal strategy. The population survived using the suboptimal strategy in 3% of the 100 runs. As such, in three percent of the cases the location of the population protected them from the immediate threat and the population was also prepared for potential threat from drought.

Using the optimal strategy in a situation, where planning resources are scarce and cannot be aimed at all possible hazard scenarios, would leave a population vulnerable to those other hazards. A population which survives a hazard, while preparation resources are aimed at a separate hazard is stronger. While this experiment is merely an abstraction, it does serve to demonstrate a possible scenario, where an apparent demise of a population, poised the survivors of a disaster to replicate the same level of social complexity with the potential for a leap to higher levels in quick succession.

3.1 Validation

As previously stated, the marker for whether the model is simulating the appropriate social-political behavior is whether it produces collective action that responds to success or failure in a probabilistic fashion. Because the agents in runs that result in population survival predominantly follow the optimal strategy for the given disaster, we can say the model exhibits this behavior. Such a qualitative goodness-of-fit test is reasonable for a model meant to exhibit historical exploration. (Axtell and Epstein 1994, Parker et al. 2001)

4 CONCLUSION AND FUTURE WORK

The transition from Neolithic chiefdoms to the first Bronze Age state in the Yellow River Valley lacks sufficient explanation. Here, I used an ABM to explore possible hypotheses in support of location specific socially complex issues in archeology, anthropology, and history. By testing the result of local behavior of heterogeneous agents on a spatially specific grid, one can examine macro behavior that relates to specific archeological problem sets. In the case of the lack of evidence for a direct line between the social complexity of the late Longshan cultures and the rapid rise of statehood of the first Bronze Age culture in the middle Yellow river valley, an ABM enabled hypothesis development and testing.

Future work on this problem set would do well to include an agent memory, an evolutionary algorithm (EA), explicit land fitness levels, and draw from evacuation models, such as that of Song et al. Memory or EA could be used to replicate the process of oral history and tradition building, further exploring how levels of social complexity could possibly be maintained for short periods by smaller populations than generally regarded as necessary for maintaining the same level for longer periods. Explicit land fitness levels, based on evidence for land cover and suitability from the time, would enable a more realistic model of land use.

REFERENCES

An, L., M. Linderman, J. Qi, A. Shortridge, and J. Liu. 2005. “Exploring Complexity In A Human–Environment System: An Agent-Based Spatial Model For Multidisciplinary And Multiscale Integration,” *Annals Of The Association Of American Geographers*, 95(1): 54-79.

Axtell, R and J. Epstein. 1994. “Agent-Based Modeling: Understanding Our Creations.” *The Bulletin Of The Santa Fe Institute*, Winter 1994: 28-32.

Axtell, R., J. Epstein, J. Deand, G. Gumermane, A. Swedlund, J. Harburger, S. Charkravartya, R. Hammond, J. Parker, and M. Parker. 2002. "Population Growth And Collapse In A Multiagent Model Of The Kayenta Anasazi In Long House Valley," *PNAS*, 99(3): 7275–7279.

Berger, T., and Parker D. 2001. "Agent-Based Models Of Land-Use And Land-Cover Change In *Proceedings Of An International Workshop,* edited by D. Parker, T. Berger, and S. Manson, http://earth.clarku.edu/lcluc/pubs/Modeling/II-3_Parker_et%20al_2002.pdf.

Chliaoutakis, A., and G. Chalkiadakis. 2014. "Utilizing Agent-Based Modeling To Gain New Insights Into The Ancient Minoan Civilization," In *Proceedings of the 2014 International Conference on Autonomous Agents and Multi-Agent Systems*, edited by A. Lomuscio, P. Scerri, A. Bazzan, and M. Huhns, 1371-1372, Paris: International Foundation for Autonomous Agents and Multiagent Systems.

Cioffi-Revilla, C. 2005. "A Canonical Theory Of Origins And Development Of Social Complexity." *The Journal Of Mathematical Sociology*, 29:2, 133-153.

Cioffi-Revilla, C. 2009. "Simplicity And Reality In Computational Modeling Of Politics," *Computational Mathematics And Organizational Theory*, 15: 26-46

Cioffi-Revilla, C. 2014. *Introduction To Computational Social Science*. London: Springer.

Cioffi-Revilla, C. 1998. *Politics And Uncertainty*. New York: Cambridge University Press.

Cioffi-Revilla, C., K. De Jong, and J. Bassett. 2012. "Evolutionary Computation And Agent-Based Modeling: Biologically-Inspired Approaches For Understanding Complex Social Systems." *Computational Mathematics Organizational Theory* 18:356–373

Dow, G., C. Reed, and N. Olewiler. 2009. "Climate Reversals And The Transition To Agriculture," *Journal Of Economic Growth*, 14:27–53.

Epstein, J., and R. Axtell. 1996. *Growing Artificial Societies: Social Science From The Bottom Up.* Washington, D.C.: Brookings Institution Press.

Feinman, G., and J. Marcus. 1998. *Archaic States.* Santa Fe, NM: School Of American Research Press.

Feng, L. 2013. *Early China: A Social And Cultural History*. New York: Cambridge University Press.

Galor, O., Omar, M. 2007. "The Neolithic Revolution And Contemporary Variations In Life Expectancy," Brown University, Department Of Economics, Working Papers 2007-14.

Grimm, V., U. Berger, D. Deangelis, J. Polhill, J. Giske, and S. Railsback. 2010. "The ODD Protocol: A Review And First Update." *Ecological Modelling,* 221(23), 2760-2768.

Kohler, T., J. Kresl, C. Van West, E. Carr, and R. Wilshusen. 1999. "Be There Then – A Modeling Approach To Settlement Determinants And Spatial Efficiency Among Late Ancestral Pueblo Populations Of The Mesa Verde Region U.S. Southwest," *Dynamics In Human And Primate Societies*, edited by T. Kohler and G. Gumerman, Oxford University Press.

Li Z., C. Zhu, G. Wu, C. Zheng, S. Shao, F. Feng, and N. Wang. 2013. "Hénán Shěng Shǐqián Rénlèi Yízhǐ De Shíkōng Fēnbù Jí Qí Qūdòng Yīnzǐ." *Acta Geographica Sinica*. 68:11.

Liu, L., and X. Chen, (2012). *The Archeology Of China: From The Peleolithic To The Early Bronze Age*. New York: Cambridge University Press.

Liu, L. (2004). *The Chinese Neolithic : Trajectories To Early States*. Cambridge: Cambridge University Press.

Qian S. 1994. *The Grand Scribe's Records – Volume I.* edited by W. Nienhauser. Bloomington, IN: Indiana University Press.

Song, X., L. Ma, Y. Ma, C. Yang, and H. Ji. (2016). "Selfishness- and Selflessness-based models of pedestrian room evacuation." *Physica A: Statistical Mechanics and Its Applications*, 447: 455-466.

Wagner, M., P. Tarasov, D. Hosner, A. Fleck, R. Ehrich, X. Chen. 2013. "Mapping Of The Spatial And Temporal Distribution Of Archaeological Sites Of Northern China During The Neolithic And Bronze Age," *Quaternary International*, 290-291:344-357

Wirtz, K., C. Lemmon. 2003. "A Global Dynamic Model For The Neolithic Transition, Mathematical Modeling Institute For The Marine Environment," *Climatic Change*, 59(3):333-367.

Yu, G., S. Wang, Q. Yu, L. Wu, Y. Fan, X. He, X. Zhou, H. Jia, S. Zhang, and X. Tian. 2014. “The Regional Limit Of Flood-Bearing Capability: A Theoretical Model And Approaches,” *Water Resource Management,* 28:1921–1936

Wu, Q., Z. Zhao, L. Liu, D. Granger, H. Wang, D. Cohen, X. Wu, M. Ye, O. Bar-Yosef, B. Lu, J. Zhang, J. Zhang, P. Zhang, D. Yuan, W. Qi, L. Cai, and S. Bai. 2016. “Outburst Flood At 1920 BCE Supports Historicity Of China’s Great Flood And The Xia Dynasty,” *Science,* 353(6299): 579-582.

Zhang, G., and Q. Wang. 2014. “Shǐqián Xià Shāngchéng Chéngguō Zhī Zhì Fēnxī.” *Central Plains Heritage 2014* Article 6. Zhengzhou University.

Zhang, Q. 2014. “Dà Yǔ Zhìshuǐ Yǔ “Jiǔzhōu” Hé “Shí'èr Zhōu” Xíngchéng Kǎo Lùn.” *Journal Of North China University Of Water Resources And Electric Power (Social Science Edition)*. 30:3 Jun 2014.

Zhang, X., S. Chou, L. Cai, G. Bao, and J. Wang. 2007 “Xīn Bì Yī'èr Lǐtou Yī'èr Lǐ Gāng Wénhuà Kǎogǔ Niándài Xùliè De Jiànlì Yǔ Wánshàn,” *Archeology And Science*, Section 8.

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