Chapter 13
ZambeziLand: A Canonical Theory and Agent-Based Model of Polity Cycling in the Zambezi Plateau, Southern Africa

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13.1 Introduction

The motivation for this model is to explore how the Canonical Theory Cioffi-Revilla (2005), implemented by a computational agent-based model (ABM Cioffi-Revilla 2014, pp. 287–301), generates sociopolitical phase transitions, whereby polities form and dissolve as people migrate to larger, more complex communities. This process of settlement and abandonment exists in the archaeological record of the Zambezi Plateau in present-day Zimbabwe (Fig. 13.1). The process of site abandonment is significant for two reasons: (1) it is key to understanding how the earliest polities in Sub-Saharan Africa originated ("politogenesis") and why they dissolved; and (2) the abandonment and subsequent condition of the Great Zimbabwe polity site is highly significant for ancient and modern Southern African history Fontein (2006, p. 771).

The walled enclosure of Great Zimbabwe supported a capital city for approximately 200 years, from 1275 CE to 1450 CE, based on the presence and absence of imported Chinese ceramics in the archeological record Huffman and Vogel (1991, p. 68). Chinese blue-on-white porcelain, diagnostic of long-distance trade, is not found at Great Zimbabwe after 1450, but it is found at other important centers in Zimbabwe before and after this date. It is important to note that Collett, et al. disagree with Huffman on this point, due to the presence of a large blue-on-white porcelain piece from the Ming Dynasty (1488–1505 CE) that is possibly related to Great Zimbabwe Collett et al. (1992, p. 157). However, Collett, et al. still use the term "abandoned" in reference to Great Zimbabwe Collett et al. (1992, p. 140) (Fig. 13.2).

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Fig. 13.1 Map of Zimbabwe. *Source* http://www.alightforzimbabwe.org

Great Zimbabwe was not the first or only significant polity in the Zambezi Plateau. Pikirayi notes that prior to Great Zimbabwe, Mapungubwe "attained regional prominence during the thirteenth century, managing the resources of a territory that was equivalent to a state in both political and economic terms" Pikirayi (2001, p. 3). Mapungubwe has been proposed as the first state in southern Africa, based on the most current evidence Huffman (2014). After the fall of Great Zimbabwe—"…marked by the presence of massive stone walls built in a variety of architectural styles" (Fig. 13.3)—the so-called Zimbabwe Culture divided into northern and southwestern regions Pikirayi (2001, p. 2–3).

Kim and Kusimba note that the first agrarian communities of the Zambezi plateau (i.e., chiefdoms) date to the first millennium CE, and that "[t]he landscape …was dotted with temporary rockshelter settlements, semi-sedentary camps, villages, and permanent settlements" Kim and Kusimba (2008, p. 137) (Fig. 13.2).

Monumental sites in the Zambezi plateau have been the subject of significant archaeological research since the 1930s, following the pioneering excavations of Gertrude Caton-Thompson. However, the research record has lacked a viable theory explaining the pattern of rise, fall, and abandonment (original polity cycling) that is archaeologically recorded for this area. Great Zimbabwe existed as a capital (central place) for a relatively short time period, and its termination by abandonment correlates with the end of imports from China. In fact, from the arrival of the Portuguese, which begins the written historical record, until the beginning of the

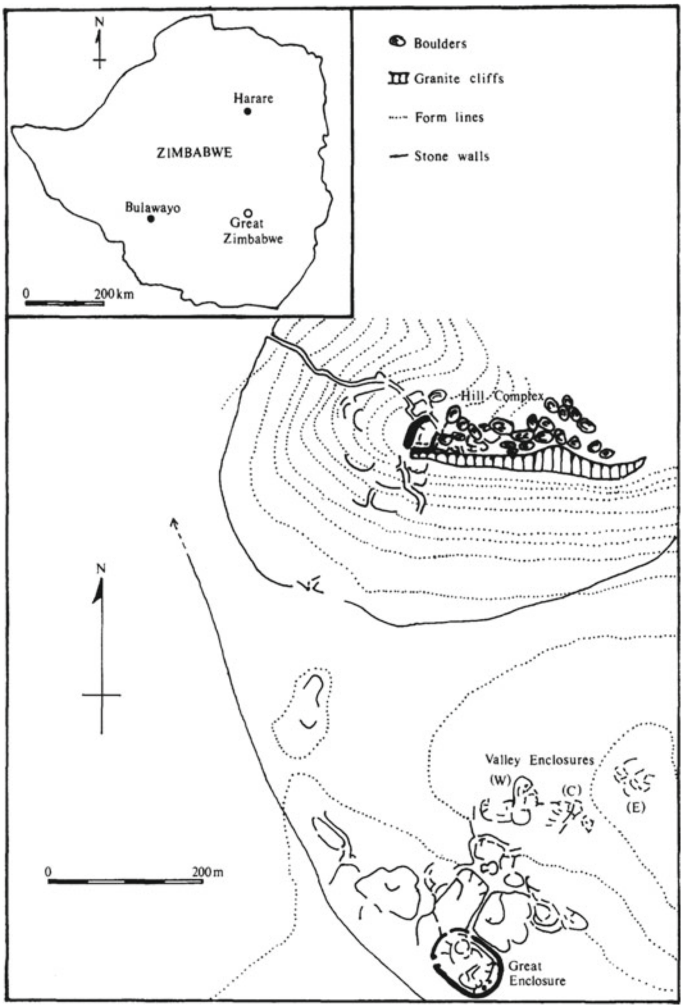

Fig. 13.2 Site map of great Zimbabwe. *Source* Collett et al. (1992, p. 141)

twentieth century, some researchers (notably the archaeologist Randall MacIver in 1906) have questioned whether the site was even created by Africans Collett et al. (1992, p. 140). To this day, the site of Great Zimbabwe is still treated with distant reverence by the local population, as a hallowed but forgotten place Fontein (2006).

This study demonstrates how the Canonical Theory of politogenesis Cioffi-Revilla (2005) provides a viable generative explanation for the process of formation, consolidation, and abandonment of polities in the Zambezi Plateau. The punctuated process of sociopolitical phase transitions, typical of polity cycling (e.g., Marcus 1998, 2012), is explained by modeling the dynamic interplay among leaders and

Fig. 13.3 Great wall enclosure at Great Zimbabwe. *Source* “Zimbabwe wall” by Ulamm. Licensed under public domain via Wikimedia commons

society members (individuals and groups) experiencing fluctuating conditions of leadership and loyalty during recurring times of stress affecting the local community. In this paper, we present an ABM that implements in code the “fast” and “slow” processes of the Canonical Theory to demonstrate how and why a society can evolve from a simple community, such as that which existed in the Zambezi Plateau in the first millennium CE, through the progression of larger and more complex polities shown by archaeology. Larger and more complex polities were generated through a recursive, iterative process of collective action successes and failures by individuals and groups, as explained by the Canonical Theory.

13.2 Methodology

13.2.1 ZambeziLand: An Agent-Based Model (ABM) of Politogenesis by Canonical Processes

The methodology of this study consisted of building and analyzing an organizational agent-based model (ABM) of the region of interest, called ZambeziLand. In particular, ZambeziLand 1.0 implements a causal process for explaining politogenesis (the rise of original social complexity) by applying the Canonical Theory of origins and development of sociopolitical complexity Cioffi-Revilla (2005), Cioffi-Revilla (2014, Chap. 7). The theory uses two time scales. As situational changes recur in a society, a "fast process" punctuated by contingent events begins, including subsequent collective action choices made by society members (leaders and followers). Collective action may succeed or fail, depending on other contingent events. The outcome of each fast process results in the polity generating greater or lesser complexity when examined on a longer time scale Cioffi-Revilla (2005, p. 138) or "slow process." Recursive fast processes Cioffi-Revilla (2005, p. 138) occur relatively quickly as the society succeeds or fails in solving collective action problems that arise in the normal course of its history, with sociopolitical results and effects accumulating over time in the slow process Cioffi-Revilla (2005, p. 138).

The Canonical Theory provides an integrative framework for linking micro-level, short-term political activity by individuals and groups in a given society (fast processes) with macro-level sociopolitical changes experienced over longer periods of time (slow process). All societies experience *numerous* fast processes, each initiated by situational changes, but they realize a *single* slow process resulting from iterations of canonically varying fast processes. The main structure of the fast process is universal and invariant, but the exact branching paths realized vary, depending on contingencies such as a situational change having endogenous or exogenous causes, a society perceiving or not the situational change, collective action occurring or not, success or failure in collective action being realized: hence, the term canonical. The theory explains how and why individual-level choices in the fast process caused by situational changes and associated responses (or lack thereof) can cause the emergent effects evidenced in the archaeological record on the rise and abandonment of sites (slow process) in the Zambezi Plateau.

An ABM was chosen for implementing the Canonical Theory because one of the hallmarks of such formal, computational models is their ability to generate macro-level behaviors caused by micro-level decisions of individual agents characterized by bounded rationality, decision-making autonomy, sociality, and dynamic interactions among them Epstein and Axtell (1996). These are also features assumed in the theory's canonical fast process of situational changes and societal responses that result in the slow process produced by each simulation run.

In the current model (version 1.0), agents represent individual members of society. Each individual can join a group, and each has a level or amount of two attributes: fealty and leadership. Fealty in the ZambeziLand model is a measure of how attached or loyal a person feels towards one's group in general and its leadership in particular. Fealty is a measure of attachment in that if it drops too low for members of a group, they will seek to move to another group with stronger leadership. All members in a group have a leadership score; however, when group decisions or actions need to be made, only the individual with the highest leadership score counts as the group leader.

13.2.2 Model Details

ZambeziLand 1.0 is an ABM consisting of a society comprised of groups of individuals. The model is initialized with 100 groups, each with 50 members, so $N = 5,000$ total population. These features were chosen to represent an egalitarian, undifferentiated society as would have existed prior to the origin of social complexity in the region (i.e., hunter-gatherer tribes). At the start of the simulation, each actor-agent is given an initial value for fealty and leadership. Both are taken from triangular distributions. Fealty randomly is assigned a value between 0 and 100, with a mode of 50. Leadership is assigned a value between 0 and 50 with a mode of 10. Values were chosen to create an initial social situation where strong leadership can exist, but is relatively rare in the population, consistent with social data. Model input parameters set the payoff for an increase or decrease in individual fealty, depending on results from collective action taken by each group.

The model was implemented in Python 2.7.1, which allows for setting fealty and leadership adjustments as input parameters. However, to clarify analysis, all runs are reported here with the same leadership adjustment parameter. Runs of the model were made on a Macbook Pro with four processor cores.

The model takes on average 9 s to run. Four minutes and 30 s were required for executing 30 runs.

13.2.3 Model Action

ZambeziLand 1.0 runs as event loops, where each group of agents has an opportunity to act on one or more of its behaviors at each clock tick. Each event loop starts with a situational change occurring (e.g., drought, attack, or other societal threat or opportunity) and each group deciding if collective action should be undertaken. The situational change is left as generic in the current model version, but can be made specific in subsequent versions. This implements the causal fast process of the Canonical Theory, which links situational changes, societal awareness, collective action, and political results: "[w]hen a society correctly perceives and understands a given situational change, it may or may not be willing and able to undertake collective action …in response to such a change" Cioffi-Revilla (2005, p. 144).

Specifically, a group will undertake collective action if the average fealty score for the group is <50. If the average fealty score is <10, the group will disband and abandon their site, dispersing to eventually form other groups. Collective action is successful with differing probabilities, depending on the quality of the group's leadership: 25 % with good leadership and 10 % with poor leadership. If collective action is successful, each member's fealty is increased by some (differing) amount. If collective action is unsuccessful, fealty for each member is decreased. Furthermore, leadership scores are updated as a result of some (but not all) of the collective action attempts. Importantly, the theory does not assume that collective action will always be undertaken when needed, nor that collective action will always be successful even when undertaken. Therefore, *any emergence of sociopolitical complexity in the resulting long and slow process produced by the model is generative, not deterministically hard-wired or causally pre-determined in any way.*

13.2.4 Model Verification

ZambeziLand 1.0 was verified using four standard model verification procedures: code walk-through, debugging, profiling, and sensitivity analysis Cioffi-Revilla (2014, pp. 235, 297). Although complete sweeps of the entire parameter space were not conducted, numerous parameter settings for initial conditions yielded consistent and replicable results across 30 runs for any given set of initial conditions (parameter settings). All issues encountered were resolved until the model ran as intended.

13.3 Results

The most significant result of the model is the demonstration via computational simulation that an initially egalitarian, homogeneous society can quickly coalesce into a small number of much larger differentiated groups, as shown in Figs. 13.4 and 13.5.

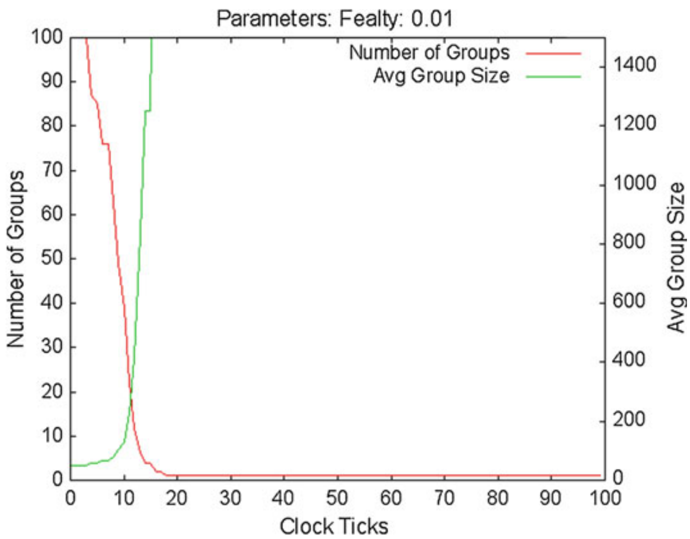

Fig. 13.4 Number of groups (*red*, scaled on the *left*) and mean group size (*green*, scaled on the *right*) for individual fealty payoff = 0.01

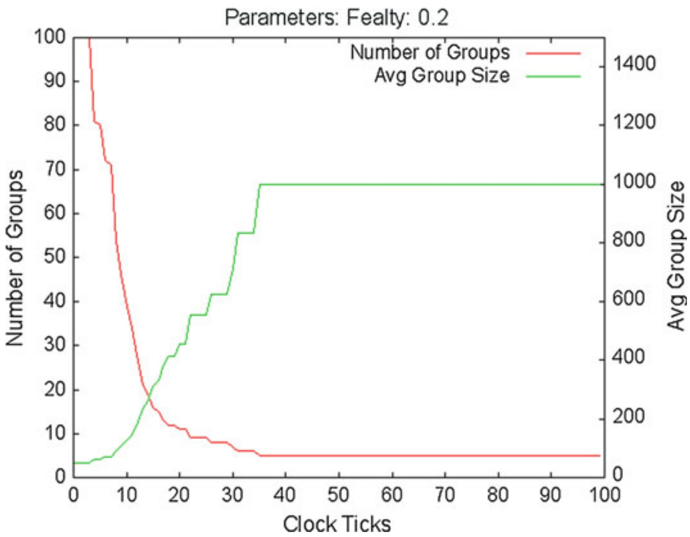

Fig. 13.5 Number of groups (*red*, scaled on the *left*) and mean group size (*green*, scaled on the *right*) for individual fealty payoff = 0.2

Polity emergence (i.e., politogenesis) occurs within the first 18 to 35 clock ticks of a simulation run. After initialization (100 groups, each with 50 members), society rapidly generates between 1 and 13 groups averaging between 384 and 5,000 members. Agents neither die nor are born in this model, so total population remains constant. The speed with which societal change occurs in the model (organizational phase transitions) varies with different input parameters. Interestingly, leadership scores have a positive linear effect on group size, although only the score of the leader is counted; that is, leadership scores are not additive within a group. Also, as the average number of groups increases, average fealty increases for up to between 5 and 6 groups, and average fealty decreases with increasing number of groups.

Additionally, results include a particular qualitative behavior in the trajectory of average fealty levels during model runs. As mentioned earlier, a fealty value is given to each agent at the start of each run, drawn from a triangular distribution between 0 and 100 with a mode of 50. Our results show that fealty quickly drops to relatively low values, becoming unstable, then recovering to a high value that remains stable for the remaining run time. An example of this behavior is shown in Fig. 13.7. This phenomenon occurs under different initial conditions (parameter settings) and occurs at different speeds. But one case behaves differently. Here (see Fig. 13.6), average fealty falls as before, rises to the starting level, but then collapses to a very low value (Table 13.1).

As groups decrease in number, the leadership score of remaining group leaders increases. (Recall that a leadership value is given to each agent at the start of each run, drawn from a triangular distribution between 0 and 100 with a mode of 10.) Few agents begin with high leadership score, by design. However, successful lead-

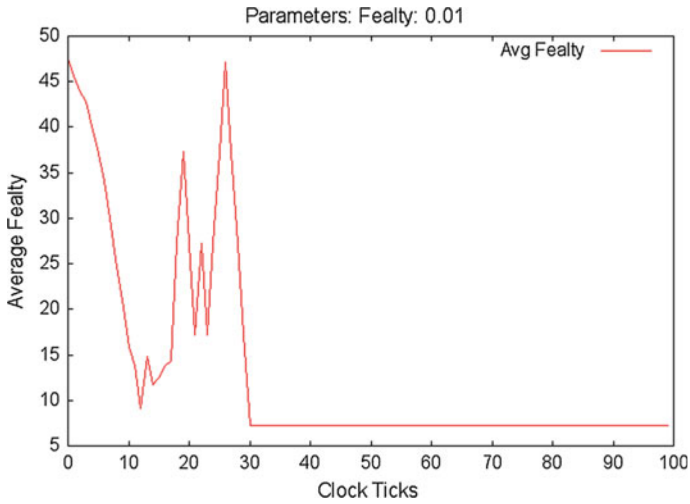

Fig. 13.6 Average group fealty for individual fealty payoff = 0.01

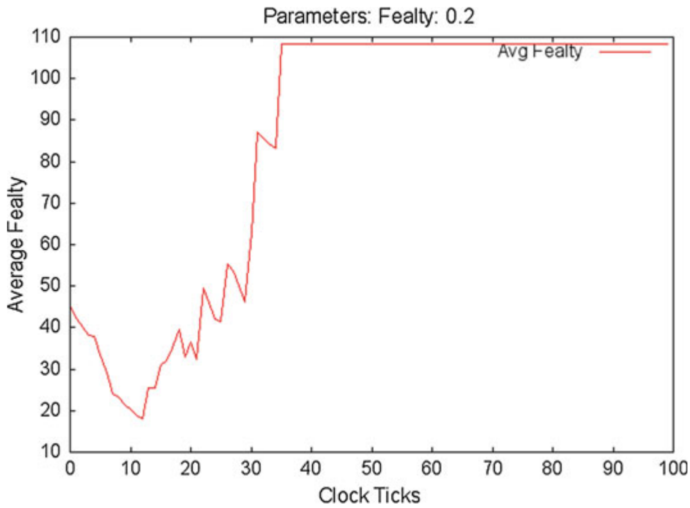

Fig. 13.7 Average group fealty for individual fealty payoff = 0.2

ers end model runs with leadership scores orders of magnitude higher than what they started with, as shown in Figs. 13.8 and 13.9. This result is illustrated by representative graphs of the evolution of leadership in two groups, a successful one (Fig. 13.11) and one that disbanded quickly (Fig. 13.10). These two groups also provide representative examples of change in membership (Figs. 13.12 and 13.13) and group fealty levels (Figs. 13.14 and 13.15).

Table 13.1 Table of model results for representative levels of individual fealty Payoff

Fealty Payoff	Tick	Numb of groups	Avg size	Avg fealty	Leadership score
0.01	18	1	5000	27.285	5079.352
0.1	31	4	1250	77.730	1281.403
0.2	35	5	1000	108.317	1011.797
0.25	33	13	384	64.488	396.870
0.3	32	12	416	78.023	426.149

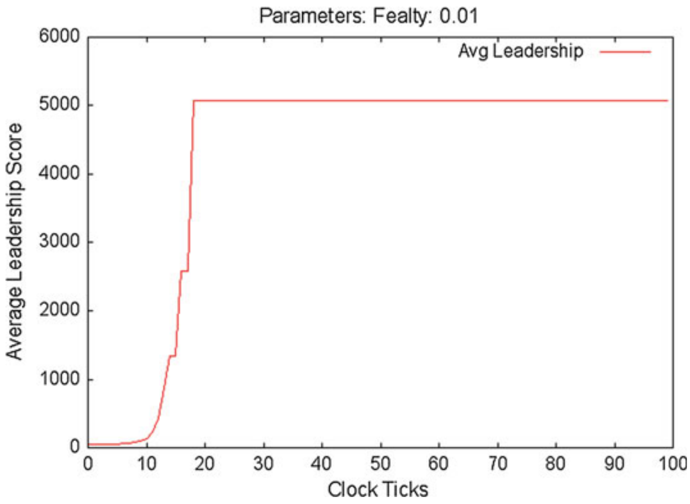

Fig. 13.8 Average leadership score for individual fealty payoff = 0.01

13.4 Discussion

13.4.1 Interpretation of Main Results

ZambeziLand demonstrates how a society of initially small and egalitarian groups could evolve into a complex society with a few large groups in response to changes in how individual members perceive their group and the state of extant leadership. The key in the model's political process—important in societies such as those known to have existed in the Zambezi Plateau—is taking a particular kind of collective action during the fast process: in this case, to abandon a group that is perceived to be unsuccessful and join another, more successful group. Figures 13.4, 13.5, 13.6, 13.7, 13.8, 13.9, 13.11, 13.12, 13.13, and 13.15 show instances of emergent slow processes generated by numerous fast processes iterating by canonical variations during 100 branching processes of collective action attempts in response to situational changes.

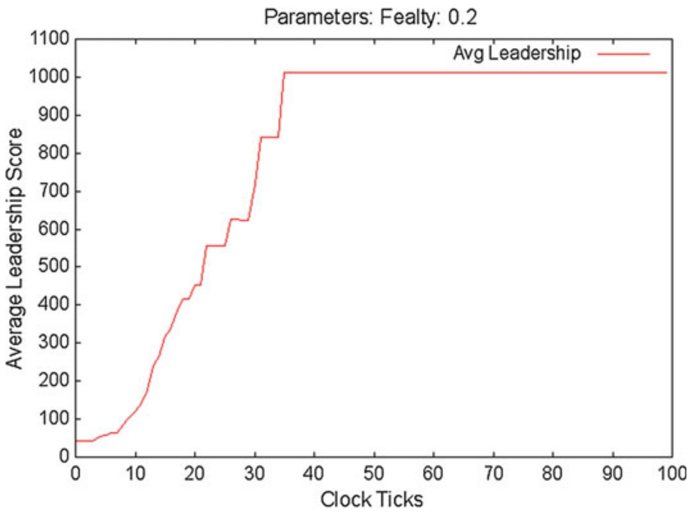

Fig. 13.9 Average leadership score for individual fealty payoff = 0.2

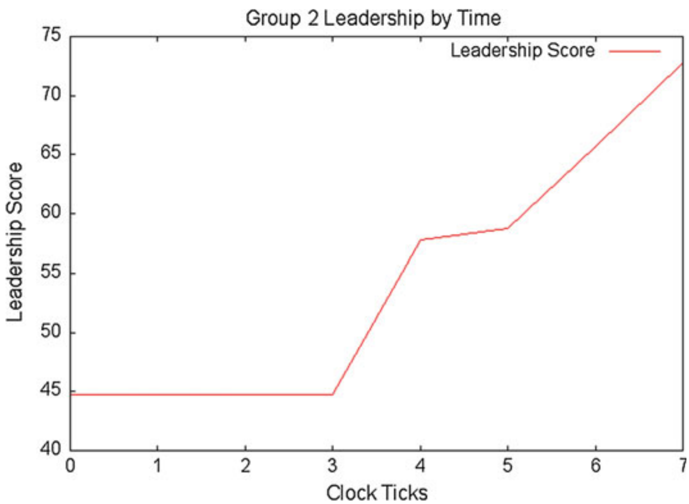

Fig. 13.10 Group 2 leadership score for individual fealty payoff = 0.25

Model runs (i.e., slow processes, in terms of the Canonical Theory) end with a few large groups, in spite of groups and group leadership having more than one chance to improve overall feeling of loyalty to the leadership. Groups must, at each clock tick (fast process), re-assess their need for collective action, and this assessment is largely independent of the group's past history during previous ticks (fast processes). Although this simplifying assumption is more forgiving than the real world, it is still sufficient to cause failure of some groups and the rise of large groups in the slow

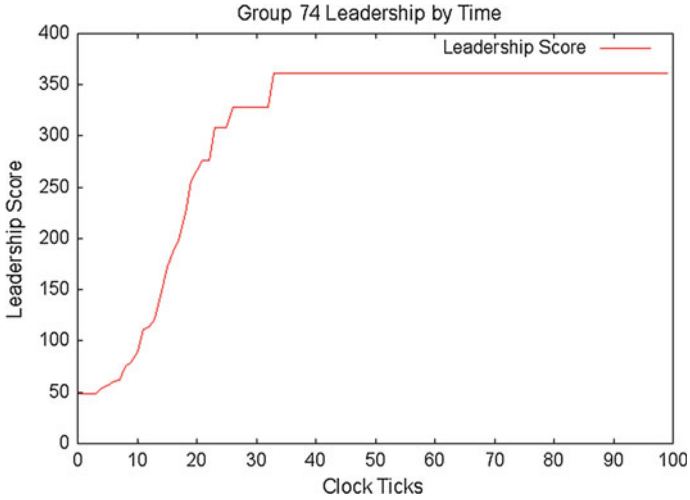

Fig. 13.11 Group 74 leadership score for individual fealty payoff = 0.25

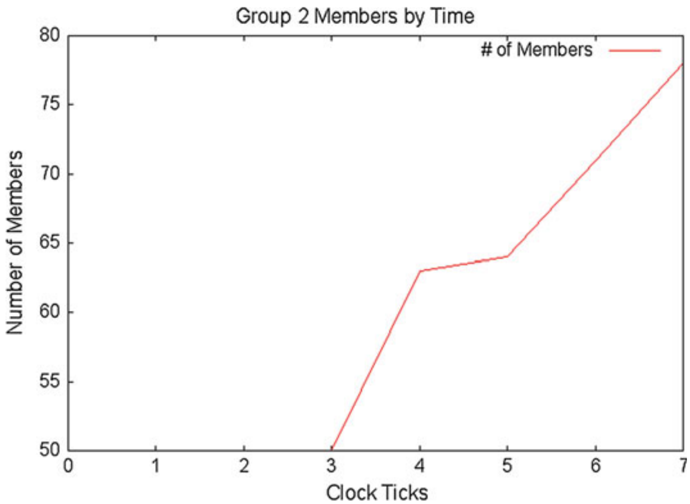

Fig. 13.12 Group 2 membership for individual fealty payoff = 0.25

process. Comparing Fig. 13.14 with Fig. 13.15 results show that one group suffered a significant fall in average feelings of loyalty, but then recovered, due to successful collective actions and addition of members from failed groups.

Some results were expected, given the importance of membership in groups with strong leaders. However, it is surprising how few groups remain in the stable system, and the speed at which the system coalesces is also surprising. This dynamic phenomenon merits further investigation. It may be due to the fact that the model does

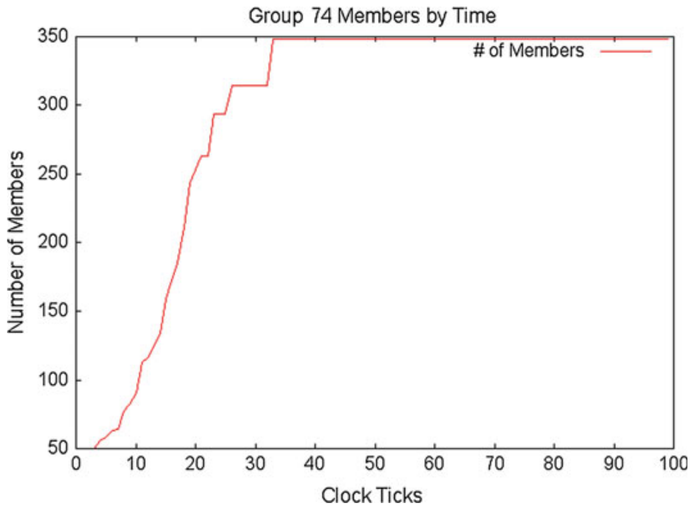

Fig. 13.13 Group 74 membership for individual fealty payoff = 0.25

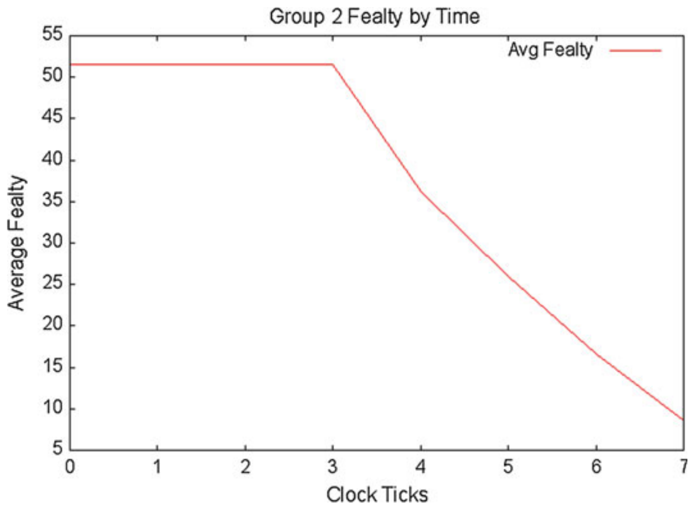

Fig. 13.14 Group 2 average fealty for individual fealty payoff = 0.25

not include dampening effects in regard to communications among group members and among groups. Archaeological and historical records show that long-distance communications take time. Moreover, the model can be extended to add activation and decay effects in the individual decision-making and behavior of agents, an embellishment totally compatible with the Canonical Theory, arguably making the slow process more realistically slow.

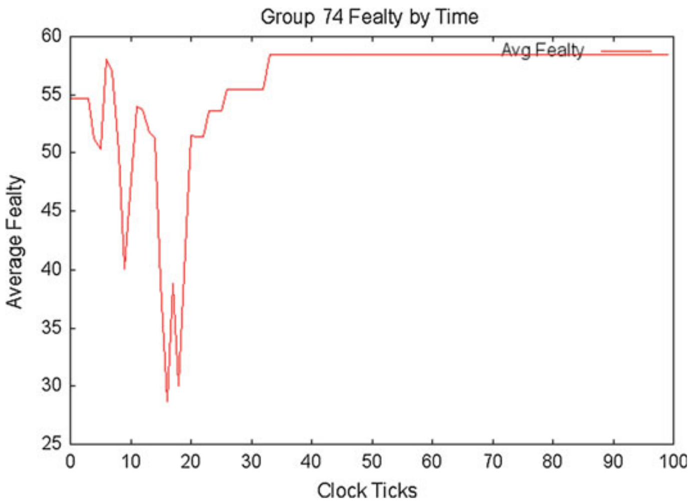

Fig. 13.15 Group 74 average fealty for individual fealty payoff = 0.25

Results also show that leadership is positively and strongly related to group size, but not to average fealty within a group. Preferred group size, by average fealty, is around 1,000 individuals, while average fealty is quite low when everyone is in one large group. Leadership scores continue to rise as groups become larger. This is counterintuitive. Leadership is expected to vary in the same way as average fealty, given the link between leadership and positive group feelings. This is another area that would need to be explored as the model is extended. It may also highlight the possibility of collective action failure, even when leadership seems adequate.

It is interesting that in most model runs, average fealty declines at the beginning of the model run, only to (sometimes) recover and rise. This is due to the fact that collective action succeeds only 25 % of the time with good leadership, and only 10 % of the time with poor leadership. This means that most individual agents and groups will experience failed collective action more often that successful collective action. As groups begin to disband to join stronger groups, group leader scores increase, in turn increasing the overall chance of experiencing successful collective actions.

13.4.2 Further Model Development

ZambeziLand could be developed further to extend the range of research questions and empirical features of the region. In the current version 1.0, the role of environmental factors is not taken into account, although the Canonical Theory includes detailed causal processes explaining how and why exogenous and endogenous types of situational change are generated in each society and environment. These can be

(1) exogenous factors external to and beyond societal control (e.g., attacks by neighbors or natural hazards such as flooding, drought, or epidemics, among others), (2) endogenous factors internal to society (e.g., aggressive individuals, technological failures, miscalculation), or (3) a combination of both. Further, and independent of the type of situational change affecting a society (exogenous, endogenous, or combined), the environment may affect different groups in different ways, consistent with the Canonical Theory. The model can be spatially developed and extended by placing groups that are relatively homogeneous in size in locally distinct environments. This is supported by work by Sinclair and Lundmark on the clustering of farming community sites in the Zimbabwean plateau. As they have noted: "[t]here remains a strong impression that environmental factors of topography, soils, and rainfall play an important role in the localization of southern clusters as a whole, but it seems clear that cluster spacing and internal organization within clusters are much more the result of social and political factors" Sinclair et al. (1993, p. 709). In terms of the Canonical Theory, this is a direct reference to causal anthropogenic triggers of situational change, which can be exogenous or endogenous. ZambeziLand 1.0 is more akin to a dynamic organizational network model, without geographic implementation on a biophysical landscape. However, as is true everywhere, geography plays a significant role in the prehistory of the Zambezi Plateau.

ZambeziLand is an ABM that can be modified and applied to other pleogenic regions—such as Mesoamerica, the American Southwest, Andean Peru, and the Near East, among others—where polity cycling has been established Marcus 1998; 2012, Cioffi-Revilla (2014, Chap. 5). The Canonical Theory also applies to other regions and cases of politogenesis, given appropriate and sufficiently valid and reliable data for individual cultural attributes and features of commonly recurrent local fast processes.

13.5 Summary

The Zambezi Plateau region in Southern Africa experienced the formation and fall of archaeologically visible polities with different levels of sociopolitical complexity during many centuries, before the arrival of Europeans and the beginning of the region's written history. Much archaeological work has been done to recover this past (i.e., the slow process record, in terms of the Canonical Theory), but one of the most important persistent questions has been a theoretically effective explanation for the rise, fall, and abandonment of large polities centered around monumental structures with massive stone walls called *zimbabwes*. Several of these survive to the present day, the largest of which is called Great Zimbabwe, located near present-day Masvingo, Zimbabwe. The Great Zimbabwe period, lasting only 200 years, was preceded by Mapungubwe and succeeded by *zimbabwes* built to the north and southwest of the Great Zimbabwe site. Given the success of these polities, what caused them to decline in such a way that the sites are considered to have experienced not only decline but abandonment?

The agent-based model presented here, called ZambeziLand 1.0, provides support for a theoretically grounded explanation of settlement and abandonment based on the Canonical Theory. In this theory, a succession of opportunities to engage in collective action by individuals and groups in society (iterative fast processes with canonical variations) strengthens or weakens the complexity of their respective polity (the singular slow process of each society). Iterations of this so-called “fast process” over time generate broader institutional changes whereby the effects of collective action within each fast process accumulate through a “slow process” resulting in a polity with variable and seemingly idiosyncratic but explainable levels of complexity over time. These processes exhibit the same cross-cultural universal pattern. This is a novel contribution that advances our understanding of polity cycling in the Zambezi Plateau, arguably extending to other regional applications elsewhere (e.g., as originally observed by Steward and developed more recently by Marcus Marcus 1998, 2012, among others).

The ZambeziLand model provides an explanation of how a society can change its complexity over time through decisions made by group members in fast processes. In the model, groups rose, declined, and disbanded as leadership and feelings of loyalty and group attachment rose and fell. Such feelings were affected by successes and failures in collective action, and the probability of success was dependent in part on the strength of group leaders. Comparable dynamics occur today in all societies.

The main finding presented here is that group dynamics, centered on collective feelings of loyalty to a group, can generate the macro-level behavior observed in the archaeological record of Southern Africa. This computational finding has implications for further investigation into the role of ideologies and imagery, especially on views of group leadership and loyalty among the people that built the monumental *zimbabwes* of Southern Africa.

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