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In the contemporary era of globalization, macro-sociological theory has become more sensitive to the ways in which the embedding of national societies in a larger global system shapes social change (cf. Arrighi 1994; Beck 2005; Go 2008; Turner 2010). And both demographic and environmental factors have once again received serious attention in social theory (York and Mancus 2009). Despite the heightened attention that these phenomena now receive, they are not new. Humans have always been shaped by both interactions with others and with ecological forces. But until the last two centuries, consequential interaction networks were not global in scale. Rather, there were regional world-systems within which human polities cooperated and competed with one another (cf. Abu-Lughod 1989; Chase-Dunn and Hall 1997; Wallerstein 1974). Yet, in many of the classical works in the sociological canon, such as those by Durkheim ([1893] 1984) and Spencer ([1874-96] 2002), human societies are often considered singularly, as if they were driven solely by endogenous factors. If other societies were considered, the mutually-influential interactions among societies were not. Warfare was seen as an exogenous influence on social processes within each society but the interactions of within-society and between-society processes were not analyzed.

We construct and analyze a formal simulation model based on world-systems theory's iteration model (Hall and Chase-Dunn 2006) that illustrates the dynamics of human populations in small-scale (regional) systems of interacting polities; i.e., world-systems.[1] The polities we examine have few members, very limited technology, and little horizontal or vertical differentiation.[2] While quite different from the contemporary global system, these early regional world-systems were the site of many important innovations in human socio-cultural evolution; e.g., sedentism, diversified foraging, simple horticulture. They also are the foundation upon which more complex polities and world-systems evolved.

World-systems theory's iteration model builds upon insights from classical sociology (e.g., Durkheim [1893] 1984; Spencer [1874-96] 2002), anthropology (e.g., Robert Carneiro 1970, 1978; Marvin Harris 1977, 1979), archaeology (e.g., Patrick Kirch 1984, 1991), and systems ecology (e.g., Turchin 2009; York and Mancus 2009). The theory suggests that the population dynamics of a simple, isolated polity are primarily driven by interaction between humans and their resource environment. Availability of resources regulates population by limiting consumption. Consumption constraints increase

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[1] World-systems are defined by Chase-Dunn and Hall (1997) as networks of interaction (trade, warfare and alliances, and information flows) that importantly link human polities with one another.

[2] We prefer the term "polity" to "society." Michael Mann (1986: 1-3) contends that societies cannot be bounded in territorial space because different kinds of important interaction networks have different spatial scales. We agree and so we prefer the term "polity" which generally denotes a spatially-bounded realm of sovereign authority such as a band, tribe, chiefdom, state or empire.

mortality directly through starvation and disease and indirectly by increasing competition and conflict within the polity. Low levels of consumption also drive emigration and it reduces the resource strain.

However, unlike much of the early sociological canon, the iteration model does not assume that all relevant factors occur within a single polity in isolation. Instead, each polity is embedded in a larger regional world-system that is composed of other polities. In addition to the processes occurring within single polities, populations in world-systems are regulated by inter-polity warfare and immigration, two examples of the "system level" variables that emerge when one begins to consider political structures not in isolation, but as part of a larger whole. These system level factors have important consequences on the behavior of the polity, and can regulate the demographics of the polities that comprise the larger system. The iteration model and the simulation derived from the model consider both intra- and inter-polity causes of societal evolution.

This paper begins by first creating a model of a single human polity in isolation -- a polity without differentiated social institutions or a growing stock of production technology. Using this single polity, we reveal the basic dynamics of resource gathering and internal conflict that ruled human social reproduction when polities were small, undifferentiated, and isolated. Our single, simple polity is then integrated into a regional world-system of polities that feed back and influence the growth and behavior of the simple polity through emergent system-level processes (e.g. warfare and immigration), presenting a more realistic model of interpolity interaction and human demographic regulation.

Once the basic dynamics of this interpolity model are established, the impact of environmental variability on the behavior of this interpolity model is explored. Like the early Egyptian societies living on the fluvial plains of the Nile river, some polities face extreme variability in the amount of resources that they have available to them from one year to the next. We explore the impact of such environmental variability in an attempt to highlight the importance of understanding ecological forces in determining the behavior of early sedentary human societies (Diamond 1997).

A number of agent-based spatial models of interpolity competition and conflict between early sedentary societies have been created that highlight the importance of microinteractional factors such as decisions about fertility regulation (Read and LeBlanc 2003), state-formation (Cederman and Girardin 2010), and political succession (Gavrilets, Anderson, and Turchin 2010). These models provide important information and insights about the behavior of such early societies and the microinteractional dynamics that allow for sociocultural, technological, and organizational evolution. However, agent based modeling's focus and reliance upon individual actors to produce outcomes of interest prevents the methodology from being ideal in simulating dynamics at the level of the world system. Our chosen method of system level modeling eschews such a focus on individual actors in favor of macro-societal forces and conforms more closely to the assumptions and intent of world systems theorizing.

However, in order to account for the important insights and findings provided by prior work in agent-based modeling, we test the importance of a parameter not explicitly mentioned in the existing world-systems iteration model that has been shown to be of seminal importance in prior agent-based simulations. The pioneering simulation work of

Dwight Read and his colleagues (Read 2002; Read and Le Blanc 2003), has shown that fertility regulation in early human societies is a crucial factor in explaining population dynamics, especially in regard to the expected amount of conflict within and between societies (a crucial variable in world systems theorizing). To account for this insight, we provide a set of exploratory simulations in which the polities are able to respond to the pressures of their environment by regulating their fertility levels. While fertility regulation is not in the original formulation of the iteration model, our exploratory simulations provide further evidence of its importance in understanding population dynamics even within a world-systemic framework, especially with regard to its ability to bypass many of the negative effects of warfare as a demographic regulator.

THE HUMAN DEMOGRAPHIC REGULATOR

Sedentism and diversified foraging emerged only since the last Ice Age ended about 12,000 years ago.[3] Sedentism, the multi-seasonal occupation of a single geographic locale and the subsequent growth in size and density of settlements, spurred greater socio-cultural complexity and introduced a number of internal and external problems, such as territoriality, the need for protection from enemies, and more efficient production and distribution of resources. These “Spencerian selection pressures” are the exigencies Herbert Spencer identified as forcing polities to adapt or fail, subsequently elaborated upon by Jonathan Turner as the catalysts for institutional development and differentiation (Spencer [1874-96] 2002; Turner 1995, 2003). Similarly, Émile Durkheim’s ([1893] 1984) evolutionary theory hinged upon the competition for resources resulting from increases in the density of a population along with the expansion of the division of labor and proliferation of niches that were integrative adaptations (cf. Colinvaux 1980; Hawley 1986). Indeed, this primary determinant of societal success or disintegration—the provision of food (energy) and other resources in step with population growth and density—forms the basis for many theories of human socio-cultural evolution (cf. Boserup 1965; Cohen 1977; Harris 1977, 1979; Johnson and Earle 2000; Lenski 2005; White 1943, 2007).

Yet, successful adaptation, innovation, population growth, and the emergence of socio-cultural complexity are not inevitable. Some polities reach a relatively stable population equilibrium within their environment, as achieved on the island of Tikopia (Diamond 2005). Others decline and sometimes collapse—such as the polities of Easter Island—experiencing Malthusian corrections of famine, epidemic diseases, and war (cf. Davis 2001; Diamond 2005; Fagan 1999, 2008; Kirch 1991; Tainter 1988; Yoffee and Cowgill 1988). Some polities and regional systems do not stabilize or collapse, but get

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[3] Contrary to common belief sedentism emerged among diversified foragers (hunter-gatherers) well before the emergence of horticulture. Probably the first village-living non-nomadic peoples were those the archaeologists call the Natufian culture who lived in the Levant about 12,000 years ago (Mann 2011). But sedentary diversified foragers continued to live largely undisturbed in California and the Pacific Northwest until the 19th century.

stuck oscillating in a vicious cycle of population growth and conflict (cf. Diamond 2005; Kirch 1991).[4]

Although these studies provide important insights into socio-cultural reproduction and population growth, they suffer from a common shortcoming. They do not incorporate interpolity dynamics into the understanding of the human demographic regulators.

World-Systems

The model presented here differs from other dynamical models in several ways. We employ the comparative world-systems approach developed by Chase-Dunn and Hall (1997; also Hall and Chase-Dunn, 2006) in which human interaction networks define the spatial boundaries of world-systems. The main unit of analysis in our theoretical approach is the world-system (i.e., observing system level dynamics); herein modeled through the interactions between a single local polity and a larger region that contains several other polities. Because the size of a world-system depends mainly on transportation and communication technologies, a single strongly-interlinked global system of states did not emerge until the 19th century. The world-system of early polities discussed in this article is therefore small-scale. However, we note that human polities have almost always interacted in important ways with neighboring polities, and that geopolitics has been an important component of the reproduction and transformation of socio-cultural institutions since even before the emergence of sedentism. For the sake of simplicity, the model we develop in this article presumes that polities are sedentary and territorial and that they compete with each other for access to resources.

The iteration model of world-system evolution was first presented in Chapter 6 of Chase-Dunn and Hall (1997). It is called an iteration model because its structure is based upon a positive feedback loop that depicts the causes of the growing scale and complexity of human polities since the Stone Age. A somewhat revised version of the iteration model is depicted in Figure 1.

While Figure 1 above is the full causal model of world-systemic evolution, the model presented here is primarily concerned with the negative feedback loop that we call the "nasty bottom." In Figure 1 this negative feedback loop is formed by the negative

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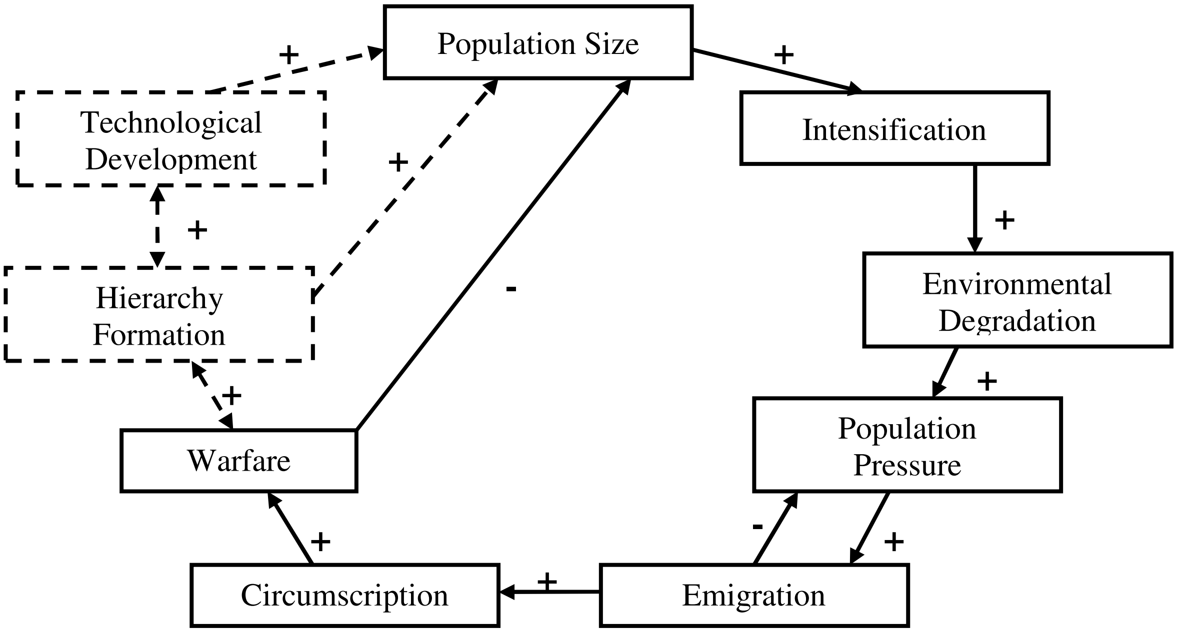
[4] Remarkably, some insect and animal societies exhibit similar dynamics. Wilson (1975), also in Hölldobler and Wilson (2009), argues that both insects and vertebrates modify their behavior in response to relatively short-term changes in the environment. Equally intriguing are Wilson's descriptions of aggression and warfare among animals, especially when read in conjunction with the recent literature on the evolution of human warfare (Gat 2006; Thompson and Levy 2010). As seen in some human societies, the levels of aggression, warfare, and cannibalism in animal populations vary with population density and the availability of food. Intra-specific aggression works to space animals out, and cannibalism and warfare reduce their numbers. In other words, a significant part of the demographic regulator of animals is based on intra-specific competition and conflict, just as in humans. Most species demonstrate more hierarchy, more aggression and more territoriality (and more cannibalism and other "abnormal" behaviors) under conditions of high population density relative to the availability of resources. In short, the geography of both animal and human behavior often exhibits territoriality, and this is related to how much food is available and how many individuals are competing for the food.

arrow from warfare to population size. Following this arrow instead of completing the larger circle essentially bypasses the two boxes with the dashed outlines: hierarchy formation and technological development. This sub-loop depicts the basic human demographic regulator that operated during most of human prehistory when human polities were small and technological change was very slow.

The simulation presented here is of the "vicious cycle" whereby a polity generates population pressure by growing to environmental carrying capacity. This pressure can first be released by the internal mechanisms of starvation, internal conflict or emigration. However, these initial pressure valves are eventually influenced by another set of demographic regulators premised upon the systemic variables arising from interpolity interactions not shown in this diagram. This second set of demographic regulators is a system-level dynamic resulting from circumscription (i.e., the occupation of all viable land) which leads to system-wide population pressures that are released by inter-polity warfare.

Figure 1: Iteration Model of World-System Evolution



As the full iteration model implies, societies can (and often do) break out from this nasty bottom. Some break out of one or both of the nested vicious cycles by developing new technologies that allow more resources to be produced in a given area (e.g., diversified foraging, horticulture, agriculture, industry) and/or by erecting a new organizational hierarchy that regulates access to scarce resources (e.g., chiefdoms, states). The ascension of the human species to dominance in the biosphere is the history of some polities breaking free from the two vicious cycles of the nasty bottom through the implementation of new technologies or new forms of social organization.[5] But in order to understand the simplest polities, the models discussed in this paper assumes that no technological or organizational changes are occurring (i.e. they ensure that societies are mired within the nasty bottom sub-loop of the full iteration model).

MODELING SIMPLE WORLD-SYSTEM DYNAMICS: The Iteration Model[6]

Human populations, like all animals, will tend to increase in size over time in resource-rich environments (Malthus [1798] 2004). Increases in population size necessitate increases in food supplies and other resources. Increased consumption puts pressure on the environment and available resources become depleted.

Population pressure can derive from depletion of natural resources, but also from pollution of the local environment and from anthropogenic climate worsening. This is called "environmental degradation," in Figure 1 and it further reduces the availability of resources from the environment (thereby placing even more strain on the population's resource acquisition habits). Humans react to depletion first by increasing their efforts, a process known as "intensification." Eventually, however, the physical, social, and environmental costs of ever increasing labor effort leads to a search for alternatives, and either some or all of the members of a group are more likely to emigrate to greener pastures when the local pastures have become relatively depleted (Diamond 2005). This archetypal causal flow (i.e. population growth → intensification → environmental degradation → population pressure → emigration) comprises the first demographic regulator in the world-systems' iteration model.

Emigration is only possible, however, when the land surrounding the original settlement is not already densely populated by other humans. If the surrounding land is full, the local polity will experience higher levels of within-polity conflict and between-polity warfare. This concept is central to the evolutionary theory of Carneiro (1970, 1978),

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[5] The iteration model also implies that the organizational and technological solutions are temporary because they have a positive effect on population growth and so the existing solutions eventually fail to keep up with increasing population pressure.

[6] For those interested in more detail of the models and simulations, a web-based Appendix contains the following information: diagrams of the models; the code (containing functional relationships of our models); and tables providing details of the results of the experiments on the SPDR and WSDR models. The Appendix (with live url links) is also available on our website: http://irows.ucr.edu/appendices/st10/st10appendix.htm

who uses the term “circumscription” to refer to barriers to movement (environmental/geographical, social, and political/military).

When circumscription is high, the level of conflict within and between groups increases. Faced with rising population pressure and no means of leaving the home polity, there is an increase in deaths from internal conflict that helps to regulate population growth. Groups are also more likely to encounter one another on hunting or procurement expeditions and are more likely to fight over scarce resources. As pressure in the entire system rises, the frequency and lethality of warfare increases. The resulting deaths reduce both the local and system-wide population, temporarily allowing natural resources to recover. This secondary archetypal process of demographic regulation (i.e. circumscription → warfare) exists at the level of interpolity interactions, and thus is specific to a world-systemic view of early societies. Together with the original regulator, and the iteration model’s nasty bottom provides a view of the mechanisms that kept early sedentary societies small and undifferentiated, but also provides an indication of how such societies succeeded in spreading out across the farthest reaches of the globe.

The range of possible dynamic behaviors, or historical trends, that a theory implies may not be obvious for all but the simplest of systems (Hanneman 1988). In order to convert the theory into a dynamical mathematical model, a number of problems need to be resolved. First, the functional forms of the relationships between elements need to be specified, and some of the variables need to be stripped of their glossy generality and placed into the concrete terms suitable for mathematical modeling. It is also important to include the availability of physical space (land) in the model, as the processes in question are spatial. To accomplish this, we divide the model into two sections (a.k.a. “patches”) that have spatial aspects, a single local polity and the larger regional world-system composed of other polities. We present two main models: 1) the single polity model that focuses on just the local polity and its relationship between population growth and resource use (i.e., the Single Polity Demographic Regulator), and 2) the world-system model that allows outmigration from the local polity to eventually fill up the regional world-system with other territorial polities, generating circumscription and warfare (i.e., the World-Systemic Demographic Regulator). The first model presented isolates only the first half of the nasty bottom, showing how a single polity would behave in isolation, if it didn’t have to worry about the system-level variables of warfare and circumscription. The second model presents the full nasty bottom by including the impact of the system-level variables, and illustrates the importance of looking to a polity “in situ” when attempting to understand macro-level sociological outcomes.

Model 1: The Single Polity Demographic Regulator

The Single Polity Demographic Regulator (SPDR) is a consumer-resource model similar to the logistic models of predator-prey relations used by ecologists. In our model, humans are the predators living in a small polity preying upon the renewable resources of the surrounding area. The polity consists of a population exploiting the resources of a catchment area of fixed size and potential productivity (given fixed, basic technology). The initial population is incremented by births and decremented by deaths and emigration. The number of births occurring in a given iteration (1-year period) is a function of the existing population size, the normal birth rate (that which would occur under no resource constraints), and resource consumption per capita. The normal birth rate is determined probabilistically from iteration to iteration and the values are normally distributed (mean = 0.04, standard deviation = 0.01).[7]

The normal death rate is also stochastic and normally distributed (mean = 0.02, standard deviation = 0.005). When all else is equal, this model makes the Malthusian assumption that births will slightly exceed deaths, but that the realization of these processes are stochastic. Variations from the normal number of deaths are a function of two processes occurring within the local polity: low levels of consumption and internal conflict. Consumption per capita affects the normal death rate directly by modifying it as resources fall below subsistence levels. At subsistence, the normal death rate is realized; as consumption falls to zero, the death rate grows in a rapid linear fashion. Internal conflict also impacts the number of deaths, and is an indirect function of consumption per capita.

The model assumes that internal conflict is normal at subsistence (equal to the deaths of 3% of the population of the local polity) and that death from internal conflict falls gradually to zero as the average standard of living increases. As consumption falls below subsistence, the death rate from internal conflict grows linearly.[8]

Local population dynamics are primarily functions of consumption per capita. Consumption per capita reflects the continuous tension between a polity's energy needs and its ability to extract resources from the environment. In the local catchment area, renewable resources are produced and reproduced by the environment and are extracted and consumed by the human population. In the absence of environmental degradation (discussed later), we suppose that the rate at which resources are renewed is a constant, a necessary simplifying assumption given the significant diversity in resources and environments. The normal resource reproduction rate varies stochastically in a normal fashion (mean = 1.05, standard deviation of 0.05) to mimic changing weather conditions (e.g., periods of wet/dry/cold/heat). The resource reproduction rate asymptotically approaches the carrying capacity, an assumption based on Peter Turchin's "regrowth" function for vegetation and small game resources (Turchin 2003: 177). The local population extracts resources from the environment at a rate which assumes, under normal conditions, that every individual will harvest slightly more resources than those necessary to minimally sustain themselves (constrained by resource availability). The model assumes that all resources which are extracted are consumed; there is no storage since this technology has yet to emerge for our polities. Thus, there is an inherent tendency for per capita consumption to rise, leading to greater population growth and population density.

Increases in population density, in turn, modify the population's effects on the resource environment through the mechanisms of intensification and degradation. Intensification is defined as "the investment of more soil, water, minerals, or energy per

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[7] Our birth and death rates are set to generate a growth rate constant of two percent annually: r = 0.4 - 0.2 = 0.2. This is within the wide range of estimates for similar groups of early sedentary populations (Surovell 2000).

[8] Internal conflict death rates vary across hunter/gatherer and simple horticultural societies (cf. Hewlett 1991; Hill, Hurtado, and Walker 2007); our normal rate is set to allow for fluctuation around typical rates as standards of living change.

unit time or area" (Harris 1977: 5). As the population of a polity increases, and resources become more and more scarce, individuals must increase their resource gathering efforts. Intensification is a positive logistic function of population density. As population density increases, the population increases effort, and the resulting harvest, proportionately. Intensified use of the land, however, leads to environmental degradation. As intensification increases, the rate at which natural resources recover is reduced (due to pollution, soil erosion, etc.). We model environmental degradation as a multiplier in the resource reproduction equation. This multiplier is a negative linear function of intensification. The model also assumes that increasing population densities make for less efficient resource extraction due to decreasing marginal returns for increased labor effort.

The human-resource dynamics of the local polity eventually generate population increases that strain the local resource environment. This leads to waves of emigration from the local polity to the surrounding region, acting as a relief valve—similar to death by starvation or conflict—that reduces population pressure on the local polity. Similar processes occur in animal groups (Raven et al. 2008). Emigration from the local polity is driven by high levels of internal conflict and poor material conditions, both of which are results of low per capita consumption due to high population density and population pressure in the local polity. Emigration occurs by "hiving" or the departure of groups, rather than single individuals. No emigration occurs until a certain percentage of the local population has become mobilized. When emigration does occur, the entire disaffected local population moves out in a single wave.[9]

Classical predator-prey models were based on the assumption that predators simply encountered prey at some random rate and consumed prey whenever possible, making all such models essentially "prey-dependent" whereby predation rates were based on the multiplicative product of predator and prey. However, Solomon (1949) and Holling (1959) contend that due to effects like satiation (whereby predators do not consume prey at every meeting), successful predator-prey models should instead assume that prey death rates are a *nonlinear* function of prey density. As such, their models introduce nonlinear response functions that modify prey death rates and predator growth rates during the process of predator/prey interaction (Berryman 1992). However, Arditi and Ginzburg (1989) point out that these nonlinear response functions act on faster time scales than the rest of the model, necessitating that the predator-prey interaction subsequently be modeled as the *ratio* of predator and prey density (i.e. ratio-dependent models) rather than the product (i.e. prey-dependent models). Following this reasoning, our SPDR uses nonlinear response functions that are ratio-dependent and are therefore consistent with current ecological models.

Germane to results discussed later in this paper, most early logistic predator-prey models displayed a phenomenon known as "the paradox of enrichment" (Rosenzweig 1971). As a certain threshold of prey abundance (i.e. resource availability) was crossed, the predator-prey model solutions were shown to destabilize. Steady state equilibrium solutions transitioned into oscillating boom and bust cycles reminiscent of the behavior displayed by the original Lotka-Volterra exponential models. However, the ratio-

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[9] In the SPDR model, emigration occurs to the "ether;" however, in the WSDR model emigration occurs to a defined region, and can then impact the entire system.

dependence modifications suggested by Arditi and Ginzburg (1989) overcome this tendency, generating exclusively stable steady state solutions. As such, we expected our SPDR model, which adopts the Arditi and Ginzburg ratio dependence modification to the predator-prey model, to display the steady state solutions common to such models, regardless of potential over-enrichment of environmental resources.

The World-Systemic Demographic Regulator

In the SPDR, individuals that emigrated out of the original polity (hereafter the "local polity") left the system entirely. They could no longer influence the operation of the local polity. In the World-Systemic Demographic Regulator (WSDR) model, however, individuals migrate to a region with its own land, resources, and climatic concerns. These individuals set up their own territorial polities, or perhaps join existing polities in the regional interpolity system. In our model, the regional system of polities is the aggregate of these settlements. The same basic population and resource dynamics occur in the regional system as in the local polity. What begins as an open and empty expanse of land eventually fills up with new polities that can feed back on the original local polity. It is from these dynamics that circumscription and warfare arise.

The local polity and its surrounding region of interacting polities are connected by two processes. Excess population from the original local polity migrates to the larger region, relieving population pressure in the local polity (but increasing it in the regional system). Over time, more and more of the available space in the regional system will be taken up and migration out from the local polity will be inhibited by circumscription in the larger region. As the polities in the larger region attain high population densities, the pressure to emigrate from the local polity must become greater and greater for a wave of emigration to occur. At high enough levels of circumscription, emigration from the local polity to the regional system is halted altogether, and population pressure can no longer be reduced through these means. It is at this point that warfare takes over as the dominant demographic regulator in the system, reducing pressure as members from each polity kill one another off.

The original population initially occupies a local catchment area, which is assumed to have a somewhat higher carrying capacity (each unit of land in the local system is able to support more people and resources re-grow at a faster rate) than the surrounding region. This bias towards better resource availability and reproduction in the local polity is premised upon the assumption that people will tend to settle in the most resource-rich environments first, and will only move into less desirable lands when pressures drive them to do so. According to Kirch's (1984) studies of the evolution of Polynesian chiefdoms in the Pacific islands, the best land on each formerly unoccupied island was settled first. As individuals migrated from the first settlement, the surrounding less desirable regions became occupied.

In our simulation, circumscription results when the combined processes of natural population growth in the regional system and migration from the local polity create a high population density at the world-system level. As the population densities of the polities in the regional world-system increase beyond carrying-capacity, circumscription increases exponentially. Circumscription halts migration, and causes an increase in interpolity warfare, which causes deaths in both the local polity and the regional system of polities, effectively reducing the population levels and relieving system-wide population pressure.

Warfare events in the world-system occur at a rate that is proportional to the amount of contact among the populations of the local polity, which in turn is based on the product of the population sizes of the local and regional polities. Below a threshold point of circumscription, contact between the two populations does not result in conflict. However, as circumscription grows, populations are increasingly unable to move to alternative locations when confronted with outsiders. The rate of warfare initiation, then, is modified by the level of circumscription. Once initiated, warfare decays exponentially as combatants are exhausted and/or grievances negotiated. Warfare acts as the second major mechanism of demographic regulation. Deaths from warfare in both the local polity and the regional system are directly proportional to the level of conflict and average roughly 20-30% of the populations. This is consistent with warfare death rates of hunter-gatherer polities (Gat 2006:139).

Simulation Methods

To understand the implications of our single-polity and our world-system models, we designed a set of experiments in which key factors that might influence model solutions were varied. The purpose of these analyses was to understand the ways in which varying configurations of basic variables affect the characteristic outcomes and shapes of historical trends implied by the theory across a range of plausible initial conditions.

The factors that we varied were: 1) the size of the spatial areas available to the local and regional polities (land), 2) the enrichment levels of those areas (maximum resource levels; i.e., carrying capacity), and 3) the size of the initial populations. To fully understand the implications of the iteration model, we examine its characteristic behavior across the full range of combinations of these three factors, thereby simulating a wide range of potential early human societies.

For both the SPDR and WSDR models, the initial conditions were varied through a set of “low,” “normal,” and “high” values (relative to the carrying capacity), creating a 3x3x3 factorial experiment. Stella v. 9.0.2 (iseeSystems 2007) was used to simulate the models, with 10 replications in each condition. Replication is necessary because the model contains stochastic variation. Each replication was iterated over 5000 time periods. For all conditions of the experiment, this period of time proved sufficient for the model to reach equilibrium and to display its characteristic qualitative behavior. The regional system in the WSDR was treated as a scaled up version of the single polity so its land and maximum resource values were proportional. The initial population of the regional system was set to zero under all conditions, allowing for the local system to migrate out freely at the beginning of each simulation. No matter where hunter-gatherers settle in a new region, it is assumed that they will migrate out of the initial settlement into surrounding areas only when population pressures get large enough.

RESULTS

Single Polity Demographic Regulator

The majority of logistic predator-prey models that use ratio-dependent nonlinear response functions predict steady state solutions where the predator and prey populations reach stable equilibrium levels under all conditions. In our model, however, we are assuming that our human populations (the "predators") are exploiting largely vegetable resources (the "prey") that reach a maximum density in a given region; a fixed amount of land can only sustain a limited amount of vegetation. Turchin (2003) suggests that vegetable resources recover according to a "re-growth" function that produces linear asymptotic growth rather than logistic growth. Despite this distinct departure from the assumptions of prey growth in logistic models, the solutions to our SPDR model also reach stable equilibrium population levels.

According to Turchin, because humans are territorial mammals, one would expect the results of a simulated model of their resource usage to reflect the effects of fast time scale feedback (Turchin 2009). As the individuals in an animal territory or human polity begin to occupy all the available land, and carrying capacity is breached, surplus individuals with the lowest survival rates and reproductive prospects ("floaters") emerge (Turchin 2009). These individuals do not have the same access to resources as others and die off quickly. Thus, the "population growth rate is reduced to zero without any time lag" (Turchin 2009:2). Therefore, the population should reach a stable equilibrium in a relatively short amount of time.

The solutions to the SPDR model reach this equilibrium state and are consistent not only with Turchin's argument, but with current ecological models of resource acquisition and use. In all conditions of the experiments, the characteristic behavior of the single-polity model is to move to a stable equilibrium, disturbed only by stochastic variation in resource production and short-term adjustments. Recall, however, that this model views only a single polity in isolation whose excess citizens can emigrate "out into the ether" endlessly. While a steady-state solution to the process of demographic regulation may be possible under such idyllic (and unrealistic) circumstances, it begs the question of whether these same results are obtainable when the local polity is considered as part of a larger system.

The initial values for population do not have long-term effects in the single-polity model. If the area is initially settled by more persons than can be sustained by the carrying capacity, the population declines to a stable lower level; if the initial population is below carrying capacity, the population rises to a stable higher level. As expected, solutions are asymptotically stable.

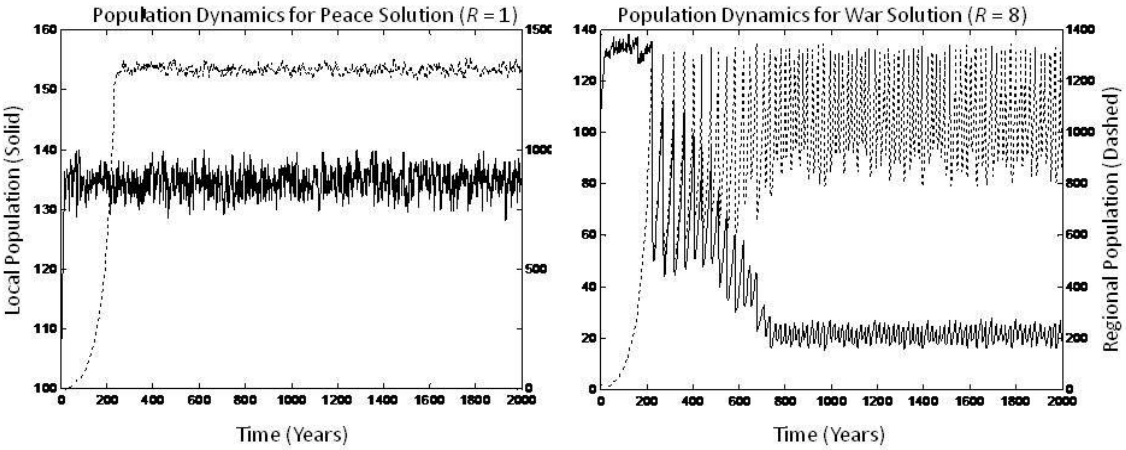
Differences in the amount of land and enrichment levels (as measured by carrying capacity of the resources, or the maximum amount of resources a given area can sustain) do generate noticeable differences in the results. Equilibrium population levels depend more on the amount of land available than on the productivity of the land, until the amount of space reaches high levels. This is as expected: the amount of land determines the population levels that can be supported because of the importance of density (rather than population size) in the theory. The effects of land enrichment levels on population size become strong when the amount of land is high. There is a transition at a given ratio of resources to land. At low values of this ratio (which we will refer to as *R*), the enrichment levels determine the value at which the population will settle. For high values of *R*, the amount of land dominates. Environmental quality and intensification do not move from their baseline when *R* is low because the available land is high and the population density remains low. In the presence of large amounts of land, the limiting forces of pollution and crowding have little effect. In the solutions where land is low, environmental degradation and intensification govern the equilibrium population values.

The single polity model characteristically tends to a single equilibrium value under all conditions. When disturbed, the population asymptotically returns to the equilibrium of the given parameters. As was expected, the paradox of enrichment is not present in SPDR solutions. Instead, the ratio-dependence modification first suggested and implemented by Arditi and Ginzburg (1989) obviated the influence of the paradox of enrichment in the single polity model and allowed for the steady-state solution to remain in effect regardless of resource availability. As such, high resource to land ratio does not produce cyclical solutions. The equilibrium value is determined primarily by this ratio of enrichment levels to the amount of available land. In short, the population dynamics of an isolated simple polity tend to be governed by the richness of the resource environment when population density is low, and by environmental and intensification processes when land area is circumscribed.

World-System Demographic Regulator

Under certain conditions in the WSDR model, migration from the local to the regional system occurs and warfare arises as the entire system becomes circumscribed. Placing the local polity in the context of a regional system of polities fundamentally modifies the population dynamics. Like the SPDR, the central factor determining the values of solutions is the ratio of enrichment levels (the carrying capacity of the resources) to available land, *R*. Unlike in the SPDR, however, *R* not only determines the equilibrium values, but the qualitative form of the solutions as well. In the SPDR, the form of every solution is identical. Stable equilibrium is always reached. In the WSDR, there are two unique types of qualitative solutions that are contingent on *R*. One type is stable steady state solutions like those found in the SPDR, and the other type is stable cyclical solutions. This variability in the qualitative solutions obtainable through the WSDR model highlights the importance of system-level variables in understanding the behavior of polities.

Figure 2: Two Qualitative Solutions of the World-Systemic Demographic Regulator



In Figure 2, the two qualitative solutions are displayed. The graph on the left demonstrates a typical solution where both the local (the darker line) and regional (the lighter line) polities reach stable equilibrium. In these types of solutions, there is no warfare. The large amounts of available land lead to low population densities and the amount of resources limits population growth. These solutions have been termed the "peace solutions."

The graph on the right displays a typical solution where both the local and regional polities reach asymptotically stable oscillations. After any perturbation disturbing the populations from their cycles, they will decay back to the original cycles. In these types of solutions, warfare is frequent. There are enough resources in these models to allow overcrowding and high levels of circumscription. This leads to cycles of warfare with a war event every human generation or so (~20 years). These types of solutions are "war solutions."

As the level of enrichment in the system grows, and the value of R crosses a critical value, R_c, a phase transition occurs whereby solutions suddenly shift from steady state peace solutions to cyclical war solutions. In mathematical theory (specifically, nonlinear dynamics), this phase transition is called a bifurcation. Mathematicians have observed bifurcations similar to the one present in our model where solutions with stable equilibriums become solutions with unstable equilibriums surrounded by stable limit cycles. These phenomena are known as supercritical Hopf bifurcations (Strogatz 1994). They commonly occur in many chemical reactions when a key control parameter (in our model, the level of enrichment) crosses a certain threshold value. In our model the threshold is roughly $R_c = 4$ (i.e. the ratio of resources to land is 4, implying resources are highly abundant given the amount of land). R_c is not constant however and varies as a function of the carrying capacity of the resources (enrichment) and amount of land. When levels of enrichment rise above the threshold, destabilization of the system is inevitable.

When enrichment levels are low, individuals starve while competing for resources and reproductive rates are generally low. Individuals that can barely feed themselves cannot support offspring. Population levels hover around an equilibrium value where individuals are consuming just enough to survive. When enrichment levels are high, humans tend to consume more than the minimum levels of consumption necessary for survival, and reproduction rates soar. Overshoot is a common feature of resource rich environments where populations reproduce at rapid rates (Catton 1980). As population density increases and migration no longer becomes a viable release for population pressure, circumscription and warfare emerge. As conditions become volatile, with land and resources rapidly becoming scarce, intense wars over territory reduce population levels and the environment is allowed to recover. Interpolity conflict becomes the primary demographic regulator.

As warfare, migration, and circumscription are introduced in the WSDR model, we see some of the results predicted by Malthus, Spencer, and others. Environments with normal or high levels of resources but with normal or low amounts of land result in dynamics where migration ceases relatively quickly and regular warfare prevents population growth from exceeding a low level in the local polity (exponential growth implies small recovery rates in small populations). Warfare as a function of density regulates population levels. In *worse* environments, with low enrichment levels, there are regular migrations and no warfare. Though this appears to be counterintuitive, it is consistent with Rosenzweig's (1971) paradox of enrichment that predicts a transition to stable equilibriums when enrichment levels are low, and is consistent with recent agent-based simulations of early human societies that conform reasonably well to empirical evidence (Read 2010). The ecological factors of degradation, intensification, internal conflict, and starvation determine the dynamics and regulate population levels on a fast time scale. This phase transition, brought about by the enrichment levels in a given human environment, determines whether ecological factors (as in the SPDR) or sociological factors (as in the WSDR) govern the population dynamics of polities.

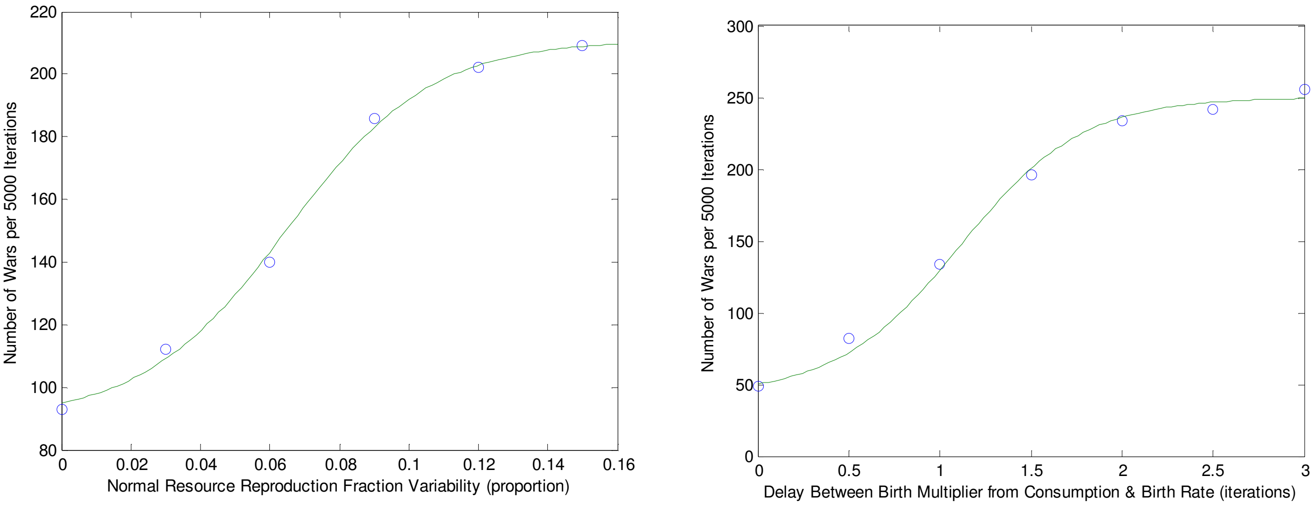
Exploratory Application: Environmental Variability

When settlements are located in marginal environments they may be particularly sensitive to variation in resource availability. Severe droughts or floods or unusually cold or hot weather, can inflict great burdens on human populations operating near the margin. Oscillations between years of excess and scarcity can exacerbate overshoot leading to frequent wars. More advanced technologies of production, storage, distribution, and trade might emerge from selection pressures of climatic variation. In our model, no such technological innovation is possible, so populations facing extreme climate variation adapt through migration and warfare.

An experiment was performed by incrementally modifying the variation in the rate at which resources re-grow after being used. The regrowth rates vary normally around a mean of five percent. This means that from year to year, different amounts of resources are produced in an unpredictable manner; the higher the standard deviation of the regrowth rate, the more drastic the yearly changes. The standard deviation values used to stochastically generate regrowth rates from iteration to iteration were varied without modifying the average speed of regrowth. As variation in resource reproduction rates increased, the number of wars grew logistically (Figure 3, Left). That is, increases in variability at very low or very high levels of variability increase warfare slowly, while increasing variation at intermediate levels generates rapid increases in warfare.

As the level of resources becomes highly variable there is a greater probability that during any given year, polities are suffering from a shortage of resources or from overcrowding due to excess resources. For those polities with a paucity of resources, the ecological factors of starvation and internal conflict will rectify the problem by quickly reducing the population. However, those polities that overshoot due to abnormal excess will experience abnormal levels of circumscription, and more frequent warfare. Though it is only suggestive for our model of stateless systems, such a pattern is known in the early state-based system in China around the turn of the first millennium BCE. The Chinese states at that time (Zhou, Xia, and Qin) were plagued with "constant warfare" (Fagan 2008). Fagan argues that underlying the political and military upheavals was a highly unstable subsistence agricultural economy. It is likely that highly variable conditions of subsistence in stateless world-systems were similarly vulnerable to disruption.

Figure 3: Interpolity Warfare as a Function of Environmental Variability (Left) and Delays in Fertility Regulation (Right)



Exploratory Application: Fertility Regulation

The model we have been examining supposes that resource privation sets off a number of processes within a settlement. In times of shortage some emigrate, others are killed by starvation and related frailty, others die as a consequence of increased conflict. York and Mancus (2009) argue that fertility regulation is an important sociological phenomenon undermining Malthus's narrow view of mortality as the only human demographic regulator. Read and LeBlanc (2003) also suggest that populations under resource strain are able to regulate fertility to some degree. Their model incorporates a culturally-embedded decision making process. In this model, the fertility rate is suppressed by people's cost-benefit analysis based on family units, which is assessed in relation to resource availability and population density. Read and LeBlanc also incorporate multi-agent modeling which includes resource density and population mobility, as well as the emergence of social complexity among settlements.

In our model, the extent to which the "normal" birth rate is achieved depends on the level of consumption per capita earlier in time (decisions about births occur three-quarters of an iteration [i.e., 9 months] before births, and decisions about births depend on the state of consumption per capita in the previous iteration). This is in accordance with Read and LeBlanc who provide evidence that polities pattern their birthing behavior on the "glut" or "dearth" of their resource environment (Read and LeBlanc 2003). When consumption levels are at subsistence, the normal birth rate is realized; as consumption per capita falls to zero, the birth rate falls linearly to zero. When consumption levels rise above subsistence the birth rate increases linearly. Prior to the formation of complex subsistence technologies, organizational hierarchies, and the eventual demographic transition in modern societies, this basic model suffices as a general model of birth regulation in the foundational iteration model.

However, as pioneering work by scientists like Read and colleagues have shown, more complex and intricate types of fertility regulation can and do occur, and have important effects on macro-sociological behavior. For example, a polity could develop stronger and more rapid fertility-restricting responses to resource shortages. Mating may be delayed or sexual practices modified. Since lactation lowers fertility, longer periods of nursing of infants increases birth intervals. Delayed responses to increased resource availability have the effect of slowing the growth of population pressures, and hence migration, conflict, and warfare. While such explicit influences on fertility regulation are outside the purview of the original iteration model, we feel that the evidence exists that such a factor is important, and would have effects on the overall operation of our basic simulation.

To test this hypothesis, we simulated fertility restriction. The birth rate in our basic model is multiplied by a variable that is dependent on the consumption level of the polity. As consumption levels rise, so does the value of the multiplier and the birth rate steadily grows. However, a delay is present in the model whereby the number of births for a given iteration (year) are dependent on the consumption levels of the previous iteration (year). The length of the delay corresponds to the amount of time it takes for the polity to regulate its fertility rate based on their levels of consumption. We varied the length of this delay from zero to three iterations, and the frequency of warfare was greatly affected. As the delay increased, the number of wars per unit time grew logistically (Figure 3, Right). Polities with a slower reaction time that cannot reflexively adjust their fertility rates to reflect current consumption crises are more likely to suffer population overshoot, resulting in resource shortages, emigration, domestic conflict and, indirectly, inter-polity warfare. Polities that are more responsive in regulating fertility are less dependent on warfare as a regulatory mechanism.

DISCUSSION

In this article we have presented the first phase of a bottom-up approach to modeling a theory of human socio-cultural evolution. We begin with a single, simple polity in isolation, where demographics are governed primarily by ecological factors. We then add an aggregate of a set of polities and model the interaction between the local and regional polities, finding that the emergence of warfare (unified, focused interpolity conflict) also regulates population levels. Taken together, our mathematical simulation of Chase-Dunn and Hall's iteration model of the evolution of polities in world-systems embraces the "ecological embeddedness of human societies" called for by York and Mancus (2009:122) and illustrates that the expected population dynamics for a sedentary human polity vary widely dependent upon whether one assumes that polity to exist in isolation, or to be embedded in a larger interpolity system. If one eschews the world-systemic view of these early human settlements, one would expect each such settlement to achieve a stable population equilibrium. On the other hand, if one takes into account the interpolitical interactions each settlement has with its regional world system, then a much wider and more nuanced range of potential population dynamics are possible. We suggest that the world-systemic view of early human settlements proposed by Chase-Dunn and Hall's iteration model, and simulated here, provides a more robust and complete picture of early human sedentism.

The theoretical model developed in this paper builds on a well-developed tradition of modeling demographic regulation dynamics—mostly in non-human contexts—through consumer-resource (predator-prey) interaction. Like other theories of this type, we find path dependence with multiple outcomes depending on initial conditions. The solutions to our SPDR model are consistent with current ecological models that have stable equilibrium solutions (due to the form of our response function that determines the process of consumer/resource interaction). But our theoretical model also goes beyond standard ecological models in several important ways. Perhaps most importantly, space and geography matter greatly. We argue that, in addition to the effects of carrying capacity, the level of population density is critical to emerging interpolity conflict. Following Durkheim, and later theorists of the impacts of population density, we argue that it is not only the balance between human populations and resources, but the distribution of those populations and resources in space that matters. The primary human demographic regulator (increased deaths and decreased births resulting from resource constraints) is based upon the interaction of humans with their natural environment. The secondary regulators of internal conflict -- migratory movements and inter-polity warfare -- are driven by population density. In our world-system model, spatial circumscription and interpolity warfare operate as a demographic regulator and produce cycles of population growth and decline when enrichment levels cross a given threshold.

Discussions of the long-term dynamics of many state-based world-systems (e.g., the Maya and early China mentioned above) point to the importance of environmental variability. Peter Turchin (2009b) connects many important dynamics to the interactions along meta-ethnic boundaries between sedentary and nomadic populations. His "desert pump" idea suggests that long droughts in regions that have marginal productivity led to incursions and warfare among sedentary and nomadic polities. Similarly, in our model, short-term climatic variation can have a major impact under certain circumstances. In the case of population collapses driven by over-exploitation of resources, a closed system does not recover and remains trapped at low population levels unless there is variation in the climate that allows for a transitory surplus that can be exploited to restart the process of population growth. This process can be seen in the SPDR. Moreover, when we introduce higher levels of random variability in the resource recovery rates of the local polity and the larger system of polities in the WSDR—with all other values held at baseline levels—we observe much more frequent warfare and boom and bust cycles. This is consistent with theories and historical evidence concerning population and warfare dynamics in marginal, unstable environments.

We find that patterns of warfare are extremely sensitive to variations in the size of the land areas and their resource capacities. Where very large amounts of land are available and maximum resource levels are low, populations—and population pressure—remain low and conflict is largely avoided. However, as a region becomes more and more settled, and there is no longer an excess amount of land available, population pressure grows with circumscription and warfare becomes the primary force driving demographic regulation. Our findings illustrate that the often discussed "paradox of enrichment" may behave as a supercritical Hopf bifurcation in early sedentary societies. Vastly divergent population dynamics may be observable in such societies depending on the ratio of resource enrichment to land availability, a finding unique to these simulations.

Fertility controls and differences in delays in the effects of resource shortages on reduction in fertility have been shown to be important in numerous prior simulations, and we have explored the consequences of adding these considerations to the world-systems iteration model. We compare models with different delays in the effect of changes in consumption per capita on birth rates. The first model assumes the minimal biological delay of nine months only, corresponding to no real fertility control. The second model assumes a delay of one year; the third model assumes a delay of two years. We show that increased delay in fertility due to extended lactation, voluntary birth spacing, or other norms that may reduce fertility have dramatic stabilizing effects on overall dynamics—often leading to the elimination of overshoot and collapse, and producing longer periods of peace.

This finding is important, as the level and amount of conflict predicted by the world system iteration model is moderated by an unincluded microinteractional variable: fertility regulation. However, one must be cautious in assuming that fertility regulation is always and everywhere a panacea for interpolity conflict. As Hardin (1968) points out, free riding is a common problem when individuals are asked to make personal sacrifices for the preservation of communal resources and the furtherance of the common good. While history is rife with examples of societies that were able to regulate their fertility in order to escape the nasty bottom of interpolity warfare, starvation, and overcrowding, history is also full of examples of societies that failed to achieve such regulation and became mired in the nasty bottom (Diamond 2005). While fertility regulation is an important variable that must be considered in conjunction with the insights from world systems theorizing regarding the importance, prevalence, and consequences of warfare in early human societies, one must not assume that the dynamics of the nasty bottom will always be overcome.

Variation in the frequency and intensity of warfare among polities at the hunter/gatherer level, according to our model of a relatively simple world-system—and to Durkheim and Carneiro—are driven by circumscription. Interpolity warfare may exert very powerful effects on the emergence of new material, cultural, and organizational technologies. We have held technology constant and have not allowed cooperative interpolity interaction (e.g., trade) in order to construct the basic demographic and resource competition dynamics. Further simulation should be developed that use the same demographic and resource dynamics presented above, but also allowing polities to develop new techniques of production, social organization and exchange, thereby completing the process of simulating the full world-systems iteration model.

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Appendix to

"DEMOGRAPHIC REGULATORS IN SMALL-SCALE WORLD-SYSTEMS"

(http://irows.ucr.edu/appendices/st10/st10appendix.htm)

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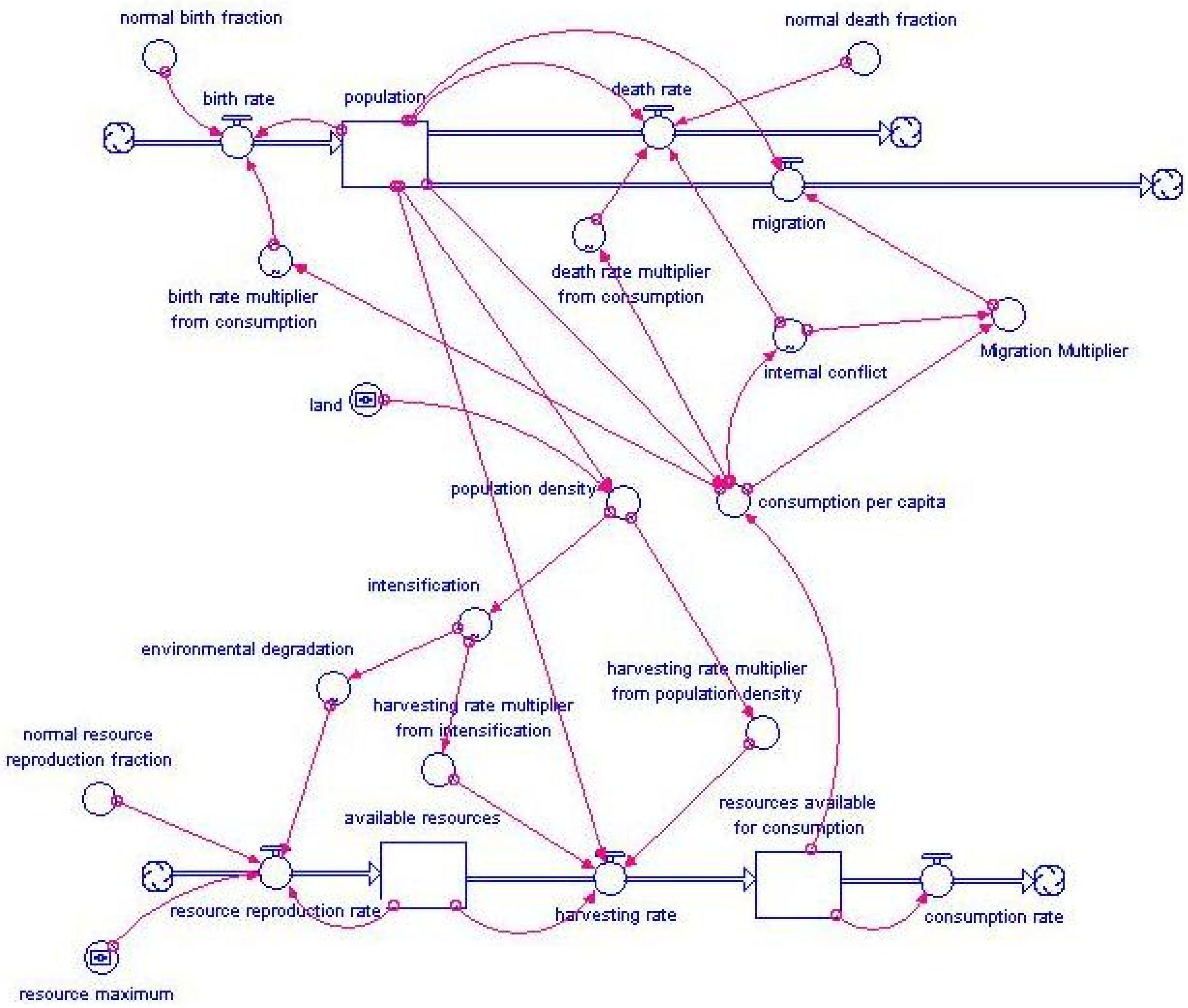
Section A: Stella Diagram of the Single-Polity Model (SPDR)



Section B: Model Code for the Single Polity Demographic Regulator (SPDR)

To examine our SPDR model you will need to download and install the iSee Player:

http://www.iseesystems.com/softwares/player/iseeplayer.aspx

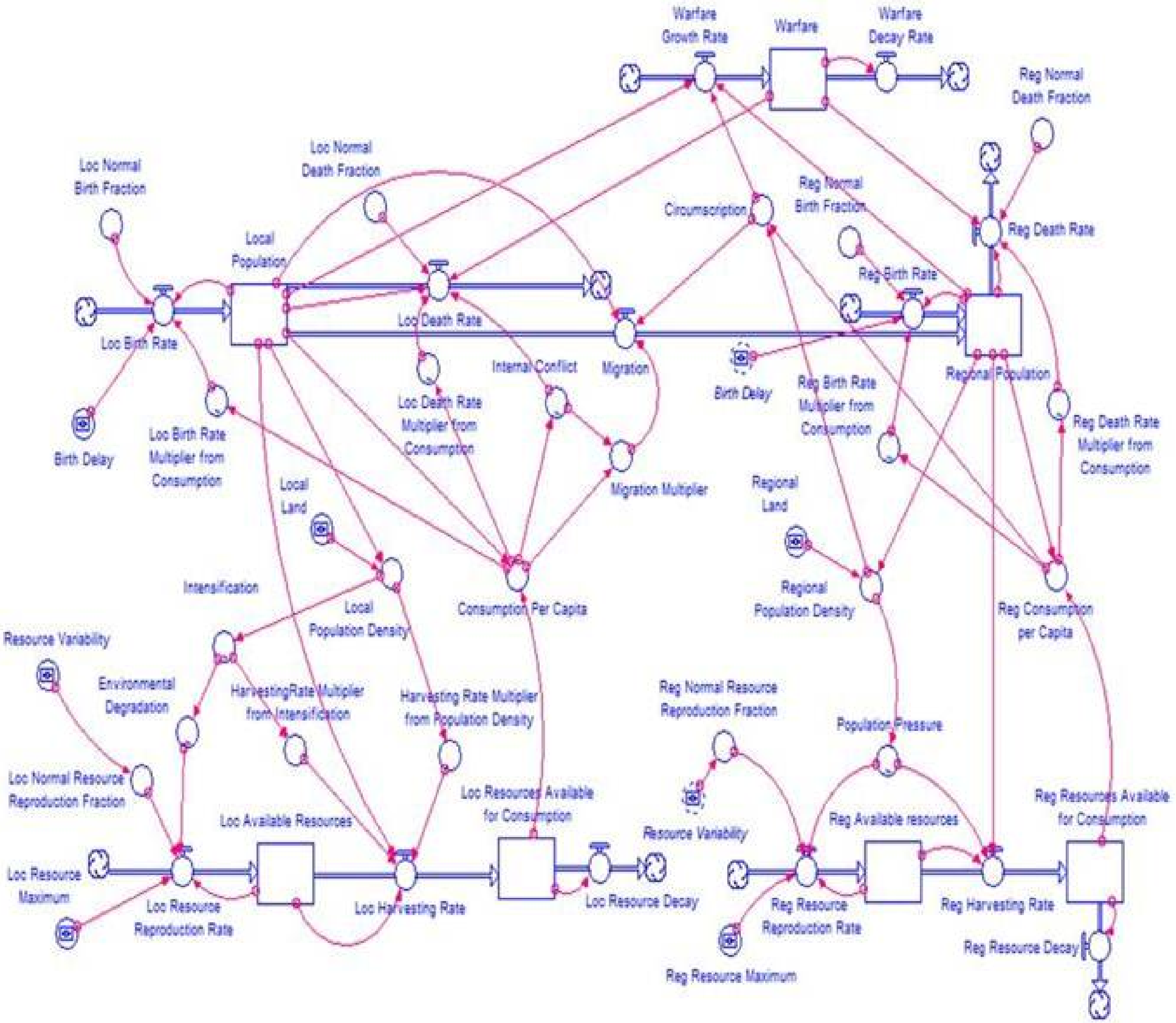
The SPDR model is at:

http://irows.ucr.edu/appendices/st10/SPDR.STM

Section C: Experimental Results for the Single-Polity Model

Factors			Population		Consumption		Environment		Intensification	
Land	CC	IPop	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
-1	1	1	120	4.1	0.91	0.023	0.76	0.004	1.48	0.010
-1	1	0	120	1.6	0.91	0.010	0.76	0.008	1.48	0.016
-1	1	-1	120	3.0	0.91	0.020	0.76	0.017	1.48	0.033
-1	0	1	120	4.0	0.91	0.023	0.76	0.004	1.48	0.010
-1	0	0	120	1.6	0.91	0.010	0.76	0.009	1.48	0.017
-1	0	-1	120	3.1	0.91	0.020	0.76	0.017	1.47	0.034
-1	-1	1	120	4.0	0.91	0.023	0.76	0.004	1.48	0.010
-1	-1	0	120	1.6	0.91	0.010	0.76	0.008	1.48	0.016
-1	-1	-1	120	3.1	0.91	0.020	0.76	0.017	1.48	0.034
0	1	1	141	3.7	0.91	0.020	0.76	0.005	1.48	0.010
0	1	0	141	2.4	0.91	0.010	0.76	0.013	1.48	0.026
0	1	-1	141	4.5	0.91	0.020	0.76	0.019	1.47	0.038
0	0	1	141	3.7	0.91	0.020	0.76	0.005	1.48	0.010
0	0	0	141	2.4	0.91	0.010	0.76	0.013	1.48	0.026
0	0	-1	141	4.4	0.91	0.020	0.76	0.019	1.47	0.038
0	-1	1	134	3.8	0.91	0.024	0.80	0.011	1.40	0.020
0	-1	0	134	1.9	0.91	0.016	0.80	0.014	1.40	0.028
0	-1	-1	134	3.9	0.91	0.024	0.80	0.019	1.40	0.037
1	1	1	216	3.1	0.91	0.017	1.00	0.000	1.00	0.000
1	1	0	215	6.9	0.91	0.017	1.00	0.000	1.00	0.000
1	1	-1	215	10.6	0.91	0.024	1.00	0.000	1.00	0.000
1	0	1	177	3.4	0.91	0.018	1.00	0.000	1.00	0.000
1	0	0	177	4.2	0.91	0.016	1.00	0.000	1.00	0.000
1	0	-1	177	7.2	0.91	0.023	1.00	0.000	1.00	0.000
1	-1	1	156	3.8	0.91	0.018	1.00	0.000	1.00	0.000
1	-1	0	156	2.9	0.91	0.015	1.00	0.000	1.00	0.000
1	-1	-1	156	5.7	0.91	0.023	1.00	0.000	1.00	0.000

Section D: Model of the World-Systemic Demographic Regulator (WSDR)



Section E: Model Code for the World-System Model (WSDR)

To examine our WSDR model you will need to download and install the iSee Player:

http://www.iseesystems.com/softwares/player/iseeplayer/aspx

The WSDR model is at:
http://irows.ucr.edu/appendices/st10/WSDR.STM

Section F: Experimental Results for the World-System Model

Factors			Local Population		Local Consumption		Local Environment		Local Intensification	
Land	CC	Ipop	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
-1	1	1	20	13.2	1.05	0.047	1.00	0.022	1.01	0.043
-1	1	0	23	19.4	1.05	0.048	0.99	0.037	1.01	0.073
-1	1	-1	23	20.0	1.05	0.051	0.99	0.038	1.02	0.075
-1	0	1	25	14.5	1.05	0.031	1.00	0.021	1.01	0.042
-1	0	0	27	19.9	1.05	0.034	0.99	0.037	1.02	0.074
-1	0	-1	28	20.3	1.05	0.037	0.99	0.038	1.02	0.075
-1	-1	1	107	10.4	0.96	0.040	0.87	0.084	1.26	0.167
-1	-1	0	107	10.1	0.96	0.038	0.87	0.083	1.26	0.167
-1	-1	-1	107	10.3	0.96	0.041	0.87	0.084	1.27	0.167
0	1	1	24	17.2	1.05	0.060	1.00	0.023	1.01	0.046
0	1	0	27	23.9	1.05	0.061	0.99	0.037	1.02	0.074
0	1	-1	27	23.9	1.05	0.062	0.99	0.037	1.02	0.074
0	0	1	113	19.7	0.99	0.058	0.91	0.093	1.17	0.185
0	0	0	114	19.3	0.99	0.057	0.91	0.093	1.18	0.185
0	0	-1	115	19.7	0.99	0.059	0.91	0.094	1.19	0.187
0	-1	1	131	3.2	0.94	0.016	0.82	0.019	1.36	0.037
0	-1	0	131	2.3	0.94	0.014	0.82	0.020	1.36	0.038
0	-1	-1	131	4.3	0.94	0.021	0.82	0.023	1.36	0.045
1	1	1	208	3.9	0.94	0.019	1.00	0.000	1.00	0.000
1	1	0	208	6.6	0.94	0.017	1.00	0.000	1.00	0.000
1	1	-1	207	10.8	0.94	0.024	1.00	0.000	1.00	0.000
1	0	1	171	3.2	0.94	0.018	1.00	0.000	1.00	0.000

1	*0*	*0*	171	4.2	0.94	0.017	1.00	0.000	1.00	0.000
1	*0*	*-1*	170	7.3	0.94	0.023	1.00	0.000	1.00	0.000
1	*-1*	*1*	151	3.1	0.94	0.017	1.00	0.000	1.00	0.000
1	*-1*	*0*	150	3.1	0.94	0.016	1.00	0.000	1.00	0.000
1	*-1*	*-1*	150	5.7	0.94	0.023	1.00	0.000	1.00	0.000

Local Internal Conflict		**World-system Population**		**World-system Consumption**		**War Deaths**			**Number of Wars**
Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**Median**	**S.D.**	**Mean**
0.029	0.012	998	102.6	1.151	0.125	0.053	0.040	0.045	3138
0.031	0.011	997	102.5	1.148	0.126	0.053	0.040	0.044	3063
0.031	0.011	997	102.8	1.143	0.138	0.053	0.040	0.045	3049
0.030	0.012	990	59.5	1.066	0.102	0.037	0.030	0.031	3114
0.032	0.010	990	59.1	1.065	0.102	0.037	0.030	0.031	3051
0.032	0.010	990	59.0	1.060	0.117	0.037	0.030	0.031	3034
0.069	0.024	973	59.2	0.951	0.078	0.046	0.030	0.042	706
0.069	0.022	972	60.9	0.953	0.080	0.046	0.030	0.042	748
0.069	0.022	973	60.2	0.949	0.099	0.046	0.030	0.042	695
0.029	0.012	1044	162.5	1.113	0.103	0.073	0.050	0.068	2033
0.031	0.011	1044	162.5	1.109	0.110	0.073	0.050	0.068	1982
0.031	0.011	1045	162.8	1.105	0.128	0.073	0.050	0.068	1971
0.055	0.028	1088	113.3	0.991	0.093	0.058	0.033	0.057	1043
0.055	0.026	1088	112.7	0.990	0.098	0.058	0.031	0.056	1017
0.057	0.026	1093	112.6	0.982	0.110	0.058	0.031	0.057	1038
0.082	0.014	1091	10.8	0.909	0.021	0.000	0.000	0.000	0
0.082	0.012	1091	10.6	0.910	0.034	0.000	0.000	0.000	0
0.082	0.012	1091	10.6	0.906	0.069	0.000	0.000	0.000	0
0.079	0.016	1894	22.9	0.909	0.020	0.000	0.000	0.000	0
0.078	0.014	1894	23.4	0.906	0.062	0.000	0.000	0.000	0
0.078	0.015	1894	23.4	0.902	0.085	0.000	0.000	0.000	0
0.079	0.016	1479	17.4	0.909	0.019	0.000	0.000	0.000	0
0.079	0.014	1479	17.1	0.908	0.047	0.000	0.000	0.000	0
0.078	0.014	1479	17.4	0.904	0.074	0.000	0.000	0.000	0
0.079	0.015	1235	14.2	0.908	0.018	0.000	0.000	0.000	0
0.079	0.013	1235	14.4	0.908	0.040	0.000	0.000	0.000	0
0.078	0.014	1234	14.2	0.905	0.068	0.000	0.000	0.000	0

Migration Periods		Migrants per Period	
Mean	S.D.	Mean	S.D.
0.0	0.00	0	0.0
0.1	0.23	0	0.0
0.0	0.06	0	0.0
0.0	0.06	0	0.0
0.0	0.00	0	0.0
0.0	0.00	0	0.0
14.2	4.14	13	1.3
13.3	4.12	13	1.3
15.3	4.54	13	1.0
0.0	0.06	0	0.0
0.0	0.06	0	0.0
0.0	0.06	0	0.0
9.0	4.40	15	1.5
9.6	3.70	15	1.4
10.3	5.61	15	1.3
33.2	3.96	15	1.6
33.1	5.10	15	1.5
33.8	4.74	15	1.5
43.3	4.37	24	2.3
44.9	5.91	24	2.3
44.2	4.99	24	2.3
45.2	3.64	19	1.8
43.9	4.61	19	1.8
43.6	6.43	19	1.8
43.4	5.80	17	1.6
43.5	6.58	17	1.5
41.3	4.93	17	1.6