NINETEEN

Population and Warfare

A TEST OF THE TURCHIN MODEL IN PUEBLO SOCIETIES

Timothy A. Kohler, Sarah Cole, and Stanca Ciupe

ECOLOGIST PETER Turchin and anthropologist Andrey Korotayev (2006) propose that population size and incidence of internal warfare or sociopolitical instability exhibit a deterministic relationship in prestate societies. Important to their thesis is that both population size and incidence of instability are, and must be treated as, dynamic variables: population growth eventually causes an increase in instability, with a lag, whereas increased instability, also with a lag, eventually leads to decreases in population size.

Because of these lags, they argue that a straightforward attempt to cross-tabulate current incidence of warfare against current population size, as done by Keeley (1996, 117–121, 202), for example, is theoretically indefensible and, practically, likely to lead to spurious results. Indeed, Keeley's tabulation failed to confirm a positive relationship between population size and instability in a series of societies of various scale,[1] although Ember (1982) demonstrated a positive relationship between population density and likelihood of warfare for land in a sample of twenty-six societies, and a positive relationship between the frequency of warfare and the severity of food shortages in an almost nonoverlapping sample of fifteen societies.

In his 2003 book *Historical Dynamics: Why States Rise and Fall,* Turchin has developed the case for fundamentally similar but somewhat more complicated relationships between population and warfare in agrarian states (see also Turchin 2005). His thesis has not been met with unalloyed enthusiasm. Tainter's (2004) review of the book faulted it for reviving a cyclical theory of history, for simplistic analysis, and for naive social theory. We have seen no discussion of Turchin's model for prestate societies, but the analysis deserves attention because of the extreme importance of the universal relationships claimed.

We have a more modest motivation here as well. One of the cases that Turchin cites as supporting his model is a sequence of tree-ring dates published by Varien (1999) from a portion of the prehispanic Mesa Verde region. In this chapter, we will examine the relationship suggested by Turchin and Korotayev with data from a nearby location in the same region, developed in the context of a current National Science

Foundation (NSF) Biocomplexity project (Kohler et al. 2007; Ortman, Varien, and Lee Gripp 2007; Varien et al. 2007). Because of advantages for which we cannot take most of the credit, this seven-hundred-year time series represents one of the most accurate and precise demographic data sets for any prehistoric society in the world.

THE TURCHIN MODELS FOR POPULATION DYNAMICS AND INTERNAL WARFARE IN NONSTATE SOCIETIES

Turchin proposes two related models for the interaction of the variables population density *N* and warfare intensity or frequency *W*. Both assume the same equation for *N*:

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right) - cWN \qquad (1)$$

Except for the c*WN*, this is the familiar function for the logistic growth of human population to some carrying capacity *K*. Turchin defines *W* here as the annual death rate due to warfare.[2] The constant *c* refers to the rate at which the warfare leads to additional death in the population; we added this during fitting, and it is not part of Turchin's published model.

The dynamics of the other state variable, warfare (*W*), might be understood in two slightly different ways. In the first case, Turchin assumes that *W* is directly proportional to the encounter rate among individuals of different groups (e.g., in foraging parties). If two groups send out foraging parties at the same rate, then their total number is proportional to *N*; a single party will encounter parties from the other group at a rate also proportional to *N*; and the total number of encounters will thus be proportional to the product of $N \times N$ or N^2.

The second assumption of the first variant of this model is that warfare declines gradually at the exponential rate *b* in the absence of new hostilities. The prominence of revenge as a motive for warfare in nonstate societies in general (e.g., Chagnon 1988), and quite possibly in the northern U.S. Southwest (Lekson 2002), suggests the utility of this term here. Since *b* and *W* are multiplied in the final term *bW* (which is the rate at which combatants are willing to give up on warfare as a strategy), high values for warfare intensity will lead to more rapid deescalation, presumably as a result of warfare fatigue. In sum, then,

$$\frac{dW}{dt} = aN^2 - bW. \qquad (2)$$

An alternative form for the second equation specifies that the rate at which groups send out war parties is proportional to the product of population density and warfare intensity. This leads to a redefinition of the first term on the right-hand side of (2) as follows:

$$\frac{dW}{dt} = aWN - bW. \qquad (3)$$

The two models (as specified by equations 1 and 2, and by equations 1 and 3) have similar dynamic behaviors, and both achieve a single equilibrium that can be approached in an oscillatory fashion. In figure 19.1, we graph the behavior of the system described by equations 1 and 2 for some arbitrary parameter values, first through time (figure 19.1a), and then in the phase plane relating population size to incidence of warfare (figure 19.1b). From these we can see that (1) high levels of warfare eventually take a toll on population density, (2) decreasing population density eventually causes warfare to subside, and (3) low levels of warfare eventually result in higher rates of population growth. In the absence of changes in *K* (carrying capacity), the two variables eventually find a stable equilibrium after exploring the phase space in a counterclockwise spiral of decreasing amplitude. An important additional point is that if contemporaneous values of *N* and *W* are sampled from the series in figure 19.1a, they will have only a very slight relationship when in fact we can see that increasing incidence of warfare has a deterministic negative impact on the *rate of change* in population growth, and population

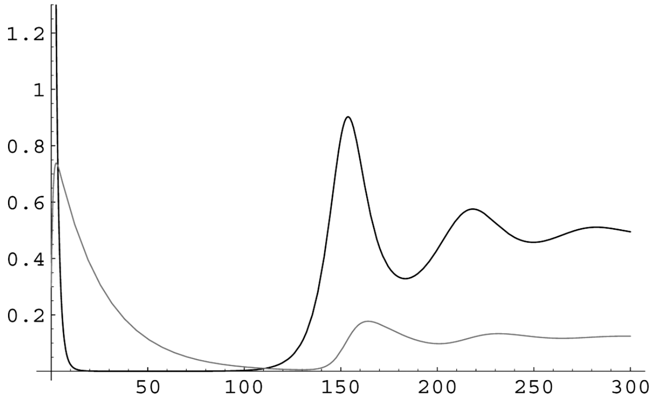

FIGURE 19.1A The relationship of N (black line) and W (red line) through time for the system of equations (1) and (2); values for N and W on the y-axis, time units on the x-axis. Parameter values: $r = .13$, $a = .02$, $b = .04$, $K = 8$; initial conditions $N = 5$, $W = .3$.

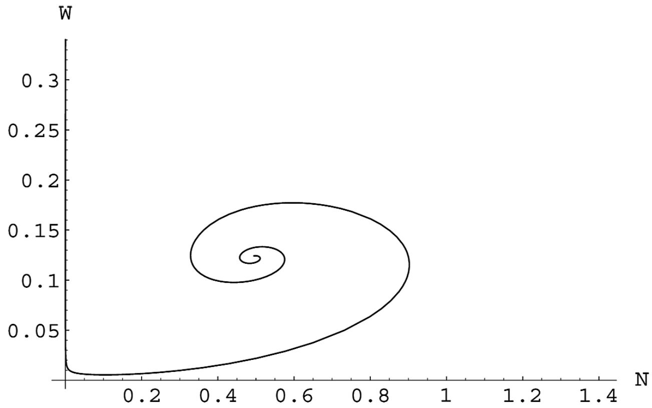

FIGURE 19.1B Relationship of N and W. Time begins at the periphery of the spiral and moves toward the equilibrium point at the center. Parameters and initial conditions are as in figure 19.1a.

growth affects the rate of change in warfare positively (Turchin and Korotayev 2006, 5).

This model, they suggest, will not apply to external warfare. Among relatively complex societies, such warfare may be due to other considerations, notably territorial expansion. Presumably, a related assumption is that the area examined is, or can be treated as, a closed system with no important immigration or emigration. We will attribute poorness of fit of this model in some portions of our sequence to our failure to meet these assumptions.

To examine how well this model fits the prehispanic Pueblo case in our well-studied portion of the northern U.S. Southwest (figure 19.2), we need estimates of N (population density), W (incidence of warfare), K (carrying capacity), the coefficient of instantaneous population growth r, and the proportionality constants a, b, and c. In the following sections we develop each of these in turn.

THE VILLAGE ECODYNAMICS PROJECT

"Village" is an interdisciplinary project to describe and model the dynamics of settlement growth, aggregation, and abandonment in the 1,800-km^2 area of southwest Colorado shown in figure 19.2 between 600 and 1300 CE. It is a joint undertaking of archaeologists at Washington State University and Crow Canyon Archaeological Center, hydrologists at the Colorado School of Mines and BBL, Inc., computer scientists at Wayne State University and the University of Windsor, and several other researchers and disciplines.

BACKGROUND: CULTURE HISTORY

The high, well-watered lands of the northern and eastern portions of the study area, which represent the regional frontier for ancestral Pueblo populations, generally trend down in elevation and become more xeric to the south and

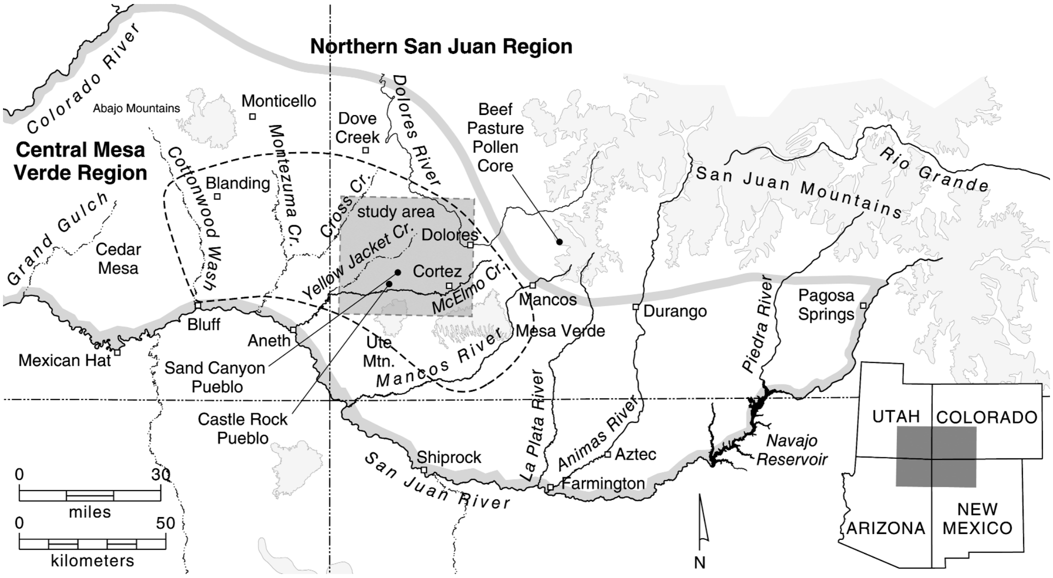

FIGURE 19.2 Location of the Village Ecodynamics project area in southwest Colorado.

east. The high cuesta of Mesa Verde intrudes into our study area from the southeast. Farmers made their way into our region slightly before 600 CE, and this area is rightly famous (e.g., Flannery 2002) for some of the earliest villages in the Southwest, dating to the late 700s and 800s, thoroughly studied by the Dolores Archaeological Project (Breternitz, Robinson, and Gross 1986). The study area was partially depopulated under cold, dry conditions circa 900. A major population influx in the mid- to late 1000s brought with it the earliest structures reminiscent of the great houses of Chaco Canyon and its surrounding area, some 170 kilometers south-southeast of our study area. A few archaeologists (e.g., Wilcox 1999) interpret Chaco's fluorescence following an internal reorganization around 1030 as that of an expansionist, tributary state, though many others are more cautious; see contributions to Lekson (2006) and Kohler and Kramer Turner (2006) for the state of the debate. The polity centered on Chaco Canyon went into decline in the mid-1100s, causing turmoil in our study area, though study area populations continued to grow. In the mid-1200s, many community centers in our area relocated to canyon head locations, and many of these are walled. Local populations began to decline by about 1260, and the area was completely depopulated by farmers sometime in the 1280s. For much more detail on this sequence please, consult Lipe, Varien, and Wilshusen (1999) and Varien and Wilshusen (2002).

PALEODEMOGRAPHY (*N*)

Scott Ortman, Mark Varien, and others at Crow Canyon Archaeological Center and Washington State University reconstructed the paleodemographic trajectory for our study area beginning from a massive review of all existing site forms along with some new survey. Using a Bayesian framework, Ortman developed a method for combining chronological and demographic information that efficiently exploits the information available from previous excavations, ceramics on site surfaces, tree ring dating, architectural characteristics, site locations, and various measures of site size to arrive at estimates of momentary numbers of households in known habitation sites for each of fourteen periods from 600 to 1300 CE in which our study area was occupied by farming populations (Ortman et al. 2007). Using three slightly different techniques, Varien et al. (2007) extrapolated from these sample numbers to estimate the total

TABLE 19.1. *Summary Data for Chronology, Population, and Carrying Capacity (K)*

VILLAGE MODELING PERIOD	BEGIN (CE)	END (CE)	MIDPOINT (CE)	TRADITIONAL PECOS PERIOD	TOTAL MOMENTARY HOUSEHOLDS[a]	FLUX	CARRYING CAPACITY ESTIMATE (K)
———	600			BMIII	0		———
6	600	725	663	BMIII	304		1,580
7	725	800	763	PI	326		1,580
8	800	840	820	PI	836	180	1,580
9	840	880	860	PI	1,030		1,580
10	880	920	900	PII	370	–477	1,580
11	920	980	950	PII	289		1,515
12	980	1020	1000	PII	653	92	1,345
13	1020	1060	1040	PII	671		1,430
14	1060	1100	1080	PII	1,385	110	1,635
15	1100	1140	1120	PII	1,940		3,234
16	1140	1180	1160	PIII	2,077		3,234
17	1180	1225	1203	PIII	2,326		3,234
18	1225	1260	1243	PIII	3,234		3,234
19	1260	1280	1270	PIII	1,770	–1,430	1,770
———		1300			0		1,400

[a]Using Varien et al.'s (2006) method 3.

NOTE: Study area is colonized by farmers shortly before 600 CE and is completely depopulated by shortly after 1280. Periods 1–5 are reserved for nonfarming groups not discussed here.

population of households in the study area. To keep the following analyses as simple as possible, as our estimate of *N* in the following, we use the estimates for the population of contemporaneous households provided by their "method 3," which they also prefer.[3] Table 19.1 reports these estimates by period.

CARRYING CAPACITY (*K*)

Estimates of carrying capacity for human populations are notoriously difficult to make because humans are so flexible in their behavior. One well-studied class of flexibility is economic (or subsistence) intensification; in the case at hand, we are particularly interested in agricultural intensification, which we define as either working longer or implementing new techniques to derive the same (or more) per capita production from domesticates under population increase or environmentally imposed restrictions on production. Similar processes are described by numerous authors, beginning in anthropology notably with Boserup (1965), but in fact finding intellectual parentage with the British political economist David Ricardo, who recognized that increasing input into production generally succeeds in increasing yield, but only at a decreasing rate. In the case analyzed by Boserup, agricultural intensification provoked by population increase involved both shortening the fallow cycle and introducing the plow; the resultant intensive agricultural system required more hours per person per week. The initial Neolithic domestication of plants and animals is frequently considered an example of subsistence intensification (e.g., Wright 1994). Intensification can involve switching to less desirable animal or plant species if more desirable and easier-to-exploit species become depleted.

Even ignoring the complexities of intensification, it is not clear how to estimate human carrying capacity for a given environment. Five main difficulties stand out. First, humans are flexible in their use of space, and unless prevented by considerations of ownership or distance, they tend to switch patches to maximize return to effort as returns from patches currently exploited decrease to the point where equal or better returns on effort are available elsewhere. Farmers, however, are more territorial than implied by this construction because of their greater investment in land improvements and facilities, and they usually end up distributed across space according to the "ideal despotic distribution" (Sutherland 1996) in which late arrivals are forced into less desirable patches. This is hard to deal with outside of a dynamic spatial model.

Second, humans need to meet their subsistence requirements within the context of also meeting other needs (in our model, they consider water, fuels, protein from hunting, and carbohydrates from agriculture). These constraints may put some areas outside of practical limits for exploitation. Third, all the calories or protein on a landscape are not available to people, whether because of food taboos or because the cost of exploitation is greater than the return, as for low-density or hard-to-process foods. Fourth, especially in the part of the world we are discussing, interannual climatic variability in temperature and precipitation amounts and timing can have significant effects on production, but the magnitude of these effects is hard to estimate. Finally, beyond the consequences of territoriality discussed earlier, human use changes the environment in complicated ways. Some usage (e.g., harvest of woods for fuel and construction and deer hunting) certainly degrades the environment for those purposes at least temporarily, but the cleared land and reduction in agricultural pests might boost production for agriculture.

The agent-based simulations we are developing in the Village project provide at least partial solutions for these problems. (Kohler, Gumerman, and Reynolds [2005] review in a nontechnical way how agent-based modeling is assisting our interpretations of southwestern prehistory.) It is beyond the scope of this chapter to explain in detail how the model works (see Cowan et al. 2006; Johnson, Kohler, and Cowan 2005; Kohler et al. 2007). Most relevant here is that we track caloric production and consumption carefully in the model, "charging" expenses for hunting, gathering of fuel and water, agricultural fieldwork, and basic metabolism, against the production and storage achieved by each household. Production of maize is affected directly by climatic variability, as is growth of woody biomass for fuels; we model densities of the three most important prey species (cottontail, jackrabbit, and mule deer) as a function of the growth of the species they graze or browse (and this vegetation itself is also affected by climatic variability) and the level of human predation. Household efforts to acquire adequate protein and calories may be assisted by processes of generalized exchange (among kin) and balanced reciprocity (among nonkin neighbors).

Base human mortality and fertility parameters are taken from Weiss's (1973, 156) 27.5-55.0 model table; in the simulations used here to develop estimates of *K*, favorable caloric and protein balances increment natality probabilities and decrement mortality rates, by 10 percent relative to that table. On the other hand, an unfavorable protein or caloric balance returns those rates to those in the life table. Inadequate caloric consumption that cannot be immediately offset by new production, existing storage, or exchange causes households to try to move to better areas, but households have no way to exit the study area. When relocating, households choose from among the cells that are favorable for agriculture and are underoccupied, that cell from which it will be least calorically expensive to satisfy their water, fuel, and hunting needs. Households may perish from lack of calories if relocation or buffering techniques are unsuccessful, but in the simulations shown here, inadequate protein consumption by itself never kills a household (though it may increase the likelihood that its individual members may perish).

As a result, the populations achieved by our model households can be regarded as rough estimates of carrying capacity for populations farming maize and hunting deer, rabbit, and hare, under the parameters used in each particular run of the simulation. Our households are capable of limited intensification: they can work harder (e.g., by going farther to hunt or gather fuels as the need arises, or by tending more plots of maize if they have enough workers), and they can switch prey species, among the three that we model, in response to changing local availability.

One important thing that they cannot do in the current simulations, though, is to domesticate and raise turkey. We know that domesticated turkey becomes an increasingly important part of the diet in some sites in the northern Southwest in the 1000s, and then it continues to increase in importance through time in most areas, including our own, replacing declining artiodactyls (chiefly mule deer) (Driver 2002).

Our current simulations show that when human population numbers reach those achieved in our area in the mid-800s, they significantly deplete deer (Cowan et al. 2006). In the absence of turkey domestication or greatly increased long-distance hunting of deer, or other accommodations, the inhabitants of this landscape may well be protein limited at the considerably larger population sizes they achieved in the 1100s and 1200s (table 19.1). Decreasing protein on the landscape (and increasing energy required to hunt for it) contributes to a general decline in agent populations in most simulations. Although agent populations could, most likely, be higher in later periods were our agents able to raise and eat turkey, it is impossible for us to estimate how much higher without completing a detailed analysis of the costs and benefits at the level of the household, and simulating the result.

For the purposes of this chapter, we take, where possible, estimates of *K* from agent-based simulations in which various parameter values are set to maximize the number of households on the landscape (while not exceeding what we view as plausible values for those parameters). Even so, for periods 15–18, our population estimates from the archaeological record are higher than those achieved by our agents, probably due to the intensifications discussed earlier that we don't model. In those cases, we use the highest actual population estimate as the *K*, given abundant evidence (rehearsed in Kohler 2000) that these populations were under considerable stress at those levels. For all of the first five periods (periods 6–10), we assign *K* the highest simulated agent counts achieved in any of these periods, since the agent numbers early in the sequence are limited by the fact that we begin our simulations with two hundred immigrant households in the year 600.

INCIDENCE OF INTERNAL WARFARE (*W*)

In the absence of a written record, archaeologists infer warfare and conflict indirectly from a variety of evidence, including site location and size, frequency of defensive features such as walls, artifacts with potential aggressive or defensive function, and skeletal trauma. Here we develop only one of these lines of evidence, skeletal trauma.[4] To make the database as large as possible, we extended the collection of these data beyond the boundaries of the study area to include the area just south of Ute Mountain, all of Mesa Verde National Park, and on south to the Colorado–New Mexico border, and into southeastern-most Utah, as far south as the San Juan River. We believe that cultural processes were similar enough across this somewhat larger region that this should not distort our findings.

The kinds of trauma used to identify violence consisted of fractures (healed or not) to the ulna and/or radius, which most likely resulted from a blow to the arm raised in defense. We also considered perimortem and antemortem cranial fractures as warfare-related trauma. However, not all cranial fractures are likely to result from such circumstances. Accidental falls are the most common source of cranial trauma among children and the elderly (Hussain et al. 1994), and facial fractures to the nasal bone or occipital region are more likely to occur during spontaneous interpersonal violence (Walker 1997). Thus, such fractures were not included in this analysis. Finally, we included the cultural modification and disarticulation of human remains (as might result from cannibalism) encountered at sites such as the well-known Cowboy Wash (Billman, Lambert, and Leonard 2000) and Aztec Wash sites (Dice 1993), Mancos 5MTUMR-2346 (White 1992), and Castle Rock Pueblo

TABLE 19.2. *Raw Data and Calculation of Instability Index W*

PERIOD	MIDPOINT	X	N	X/N	A	B	μ	RAW INSTABILITY INDEX	W (FINAL VERSION)
6	663	2	11	0.1818	–0.12119	–0.4058	0.1794	0.1038	0.1038
7	763	1	10	0.1000	–0.12119	–0.4058	0.0928	–0.0162	0.0000
8	820	0	6	0.0000	–0.12119	–0.4058	–0.0222	–0.3231	0.0000
9	860	3	55	0.0545	–0.12119	–0.4058	0.0529	0.0358	0.0358
10	900	6	18	0.3333	–0.12119	–0.4058	0.3365	0.3154	0.3154
11	950	0	13	0.0000	–0.12119	–0.4058	–0.0097	–0.1071	0.0000
12	1000	5	20	0.2500	–0.12119	–0.4058	0.2506	0.2220	0.2220
13	1040	17	70	0.2429	–0.12119	–0.4058	0.2430	0.2353	0.2353
14	1080	24	45	0.5333	–0.12119	–0.4058	0.5370	0.5387	0.5387
15	1120	44	108	0.4074	–0.12119	–0.4058	0.4083	0.4065	0.4065
16	1160	30	35	0.8571	–0.12119	–0.4058	0.8668	0.8894	0.8894
17	1203	4	34	0.1176	–0.12119	–0.4058	0.1159	0.0915	0.0915
18	1243	6	75	0.0800	–0.12119	–0.4058	0.0789	0.0673	0.0673
19	1270	51	121	0.4215	–0.12119	–0.4058	0.4223	0.4210	0.4210

NOTE: *x* is the count of skeletal remains (per individual) with warfare-related trauma, and *n* is the number of individuals. We used Bayes's theorem to generate an improved estimate of π from the observed sample proportion *p* (where $p = x/n$, as explained in Cole 2006). See also Robertson (1999) for discussion of this method.

(Kuckelman 2002b). We did not count other types of fractures to other parts of the body (the most common being rib fractures) because we could not confidently determine that these were not accidental in origin.

Cole (2006) collected these data from the literature and not via direct examination of the materials (some of which have been reburied). The kinds of sources used largely consisted of site reports and "gray" literature. She could usually determine the age and sex from these reports; they also usually included a detailed description of any skeletal trauma and pathological conditions, and the position and location of interment. Thus, she was able to decide which kinds of trauma to attribute to violence—and her determination did not necessarily agree with that of the original author. She used Turner and Turner's (1999) *Man Corn* as a secondary source when considering the cultural modification and disarticulation of human remains. Large-scale excavation projects such as the Dolores Archaeological Program, the Towaoc Canal (Reach III), the Ute Mountain Piedmont project, and the Sand Canyon Archaeological Project provided most of the data.

Table 19.2 shows the *n* of individuals for each period, the number of those with skeletal trauma suggestive of warfare (*x*), and the resultant estimate of *W* (slightly refined using Bayesian techniques and converting negative values to zero; see Robertson 1999, including the formula in his note 2] for a discussion of the method used here).

Turchin and Korotayev considered *W* to be warfare intensity or frequency, so the death rate to warfare *cWN* (in equation 1) is assumed to be directly proportional to its intensity. In the same way, we consider our estimate of *W* to measure intensity of conflict, and we therefore must make the same assumption—that this intensity will be directly proportional to a death rate from warfare.

COEFFICIENTS *r*, *a*, *b*, AND *c*

The instantaneous coefficient of population growth (Odum and Barrett 2005, 239) is the growth rate achievable in the absence of limiting factors. We calculate a minimum estimate for *r* by finding the value required for 304 colonizing households present in our study area by about 663 CE to increase to 1,030 households

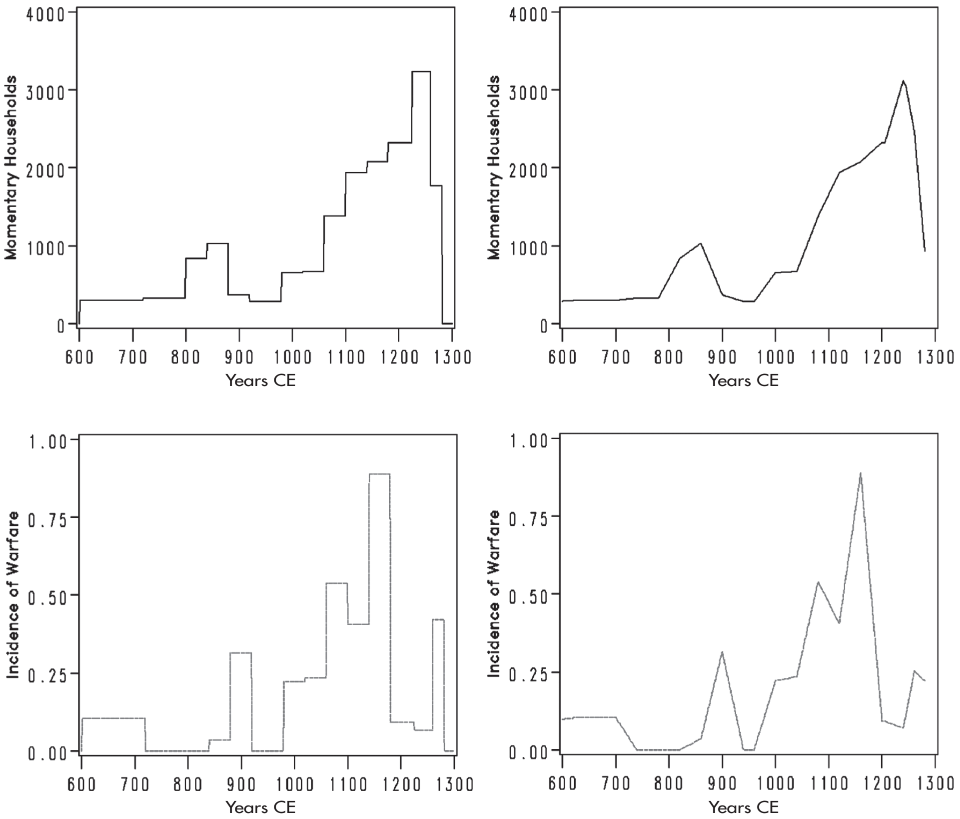

FIGURE 19.3 Unsmoothed (left column) and smoothed (right column) versions of *N* and *W*.

by about 860 CE (table 19.1), leading to an estimate of 0.006 (annual) for *r*. In our attempts to fit Turchin's model to our data, we used values for *r* ranging from 0.007 to 0.014 in recognition of the fact that the maximum attainable *r* for human populations is higher than 0.006, perhaps as high as 0.02 (Ehrlich and Ehrlich 1970). We also added fluxes to the model at various points where we identify growth in excess of that achievable through in-place processes or emigration (see table 19.1; Varien et al. 2007). We estimate best-fit values for the proportionality constants *a*, *b*, and *c* in the context of fitting the models to both the population and the warfare intensity data.

EVALUATING THE MODEL

There are several ways to determine how well Turchin and Korotayev's models fit these data from southwest Colorado. First, we can inspect the time series of *N* and *W* (figure 19.3) to see if they bear any resemblance to the relationships claimed in the models (figure 19.1a). These two series are graphed to a common scale in figure 19.4, after smoothing using forty-year running means, following Turchin's procedure. Discounting the slightly higher-than-expected *W* in our earliest period, we see that in the first cycle of this historical sequence, *N* peaks before *W*, just as expected, and then falls in the context of high *W*, as expected, and then *W* falls, too, just as *N* begins to rise again. This is all as it should be. But between about 1000 and 1200, increases in *W* lead increases in *N*, very much contrary to the model.

Another way to evaluate the models is to inspect the phase plot of *N* against *W* (once again after smoothing), keeping in mind the shape proposed by the model (figure 19.1b). The plot generated from our data (figure 19.5) shows the expected relationships from the 600s through

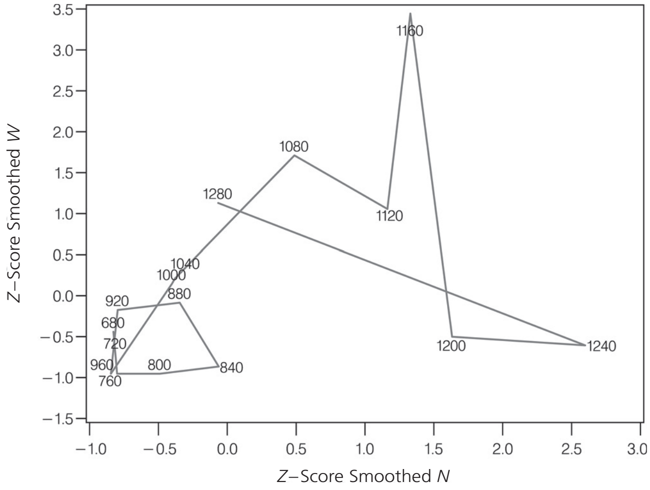

FIGURE 19.4 Graph of standardized, smoothed population (*N*, black) superimposed on standardized, smoothed warfare frequency (*W*, red).

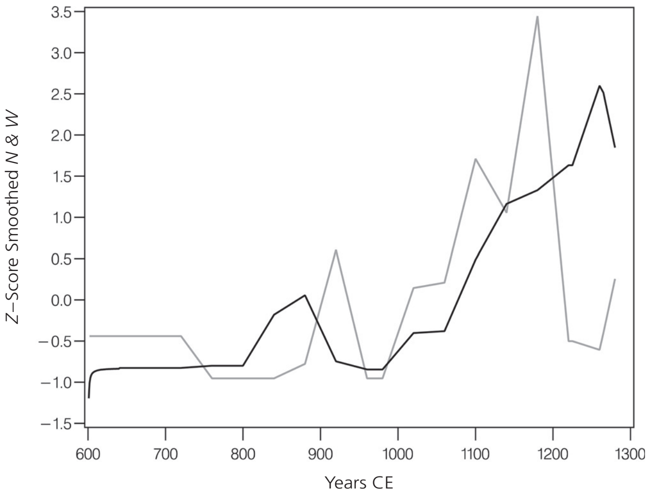

FIGURE 19.5 Phase plot of *N* and *W* (after smoothing and standardization) using data from southwest Colorado.

the mid-900s, with mild reversals not far outside of the expected pattern through 1040. There is a strong reversal of the expected pattern for the next three data points (1080–1160) with a return to the expected pattern in the 1200s, albeit in a different region of the phase space.

A third way to evaluate the models is to realize that, if the lag suggested by the models in the effect of increasing *N* on *W* in the actual record is about forty years in length, then we ought to be able to see a strong positive relationship between *N*, lagged forty years, and *W*. Here, once again, we replace the observed values for *N* and *W* with forty-year running means for both, sampled at forty-year intervals. Figure 19.6 shows that there is indeed a positive relationship, but not a significant one, at least when all periods are included. The data points for the late 1000s and mid-1100s are particularly strong outliers. Once again, the 1200s appear to represent a consistent regime, but one that is very different from the regime in place from the 600s to 900s.

Finally, and most rigorously, we can fit values of *a*, *b*, and *c* for the models, using the time series of our empirically known *N* and *W* (table 19.1), and then assess the goodness of fit obtained using the parameters so derived. Here we consider the model proposed by equations 1 and 3 only, since initial exploration showed that we obtained better fits with this model than the one in equations 1 and 2. We start by assuming that initially, at year 600, the population size is

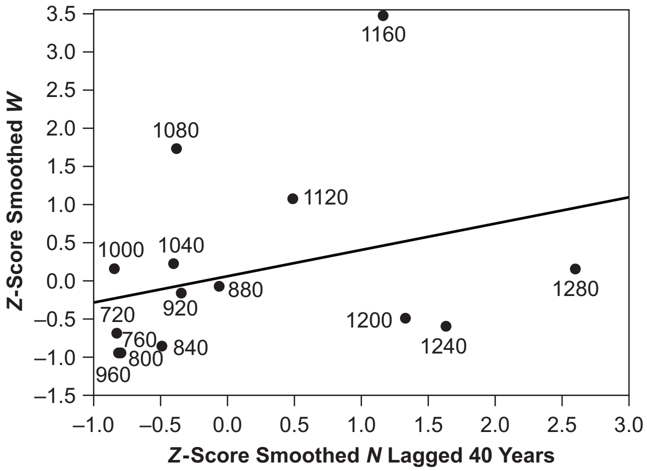

FIGURE 19.6 Regression of $W[t]$ on $N[t-1]$: $r^2 = .09$, $p > F = 0.27$.

$N_0 = 152$ households, and the intensity of warfare is, as given in table 19.2, $W_0 = 0.0519$. With this assumption and known values for r and K, we estimate the remaining parameters a, b, and c using the weighted least-square regression. Let us define the functional

$$J(a,b,c) = \sum_{i=1}^{n} \omega_N (\log(N_i) - \log(N_{data_i}))^2 + \sum_{i=1}^{n} \omega_W (W_i - W_{data_i})^2,$$

where n represents the number of data points (in our case, the seventeen time periods) indexed by i, N_i, and W_i are the population size and war intensity at times t_i predicted by the solution of equations 1 and 3, N_{data_i} and W_{data_i}, represent the data values for the populations and for warfare at times t_i, ω_N and ω_W, are additional weights that ensure that we give equal influence to both the population, N, and the war intensity, W, observations. They are given by

$$\omega_N = \frac{1}{\sigma_N^2} = \frac{1}{\dfrac{\sum_{i=1}^{n}(N_{data_i} - \overline{N_{data}})^2}{n-1}},$$

and

$$\omega_W = \frac{1}{\sigma_W^2} = \frac{1}{\dfrac{\sum_{i=1}^{n}(W_{data_i} - \overline{W_{data}})^2}{n-1}},$$

where $\overline{N_{data}}$, $\overline{W_{data}}$ are the average values of the measured data, N and W. Differences in logarithms for the population, N, rather than differences in numbers were used to accommodate the changes in size (large population sizes from 1080 to 1280, vs. small populations in the 640–880 period). We gave equal weight to the warfare intensity data and to the population data in the minimization algorithm. The optimization analysis was performed using the Nelder-Mead nonlinear iterative routine (fminsearch) and an ordinary differential equation solver (ODE45) in Matlab.[5] The resultant values for a, b, and c are shown in the captions of figure 19.7.

Of interest here is that the fitted values for W far exceed those observed in the 1200s and even exceed the possible values for this parameter, which are from 0 to 1. The model cannot accommodate both the very high W and moderately high N values seen in the 1000s and 1100s with the very high N and moderate or low W values experienced in the 1200s. This emphasizes both of these departures as things that need to be explained.

DISCUSSION

We find relatively strong support for the version of the Turchin-Korotayev model represented by equations 1 and 3 during the first population cycle, when exogenous factors appear to have

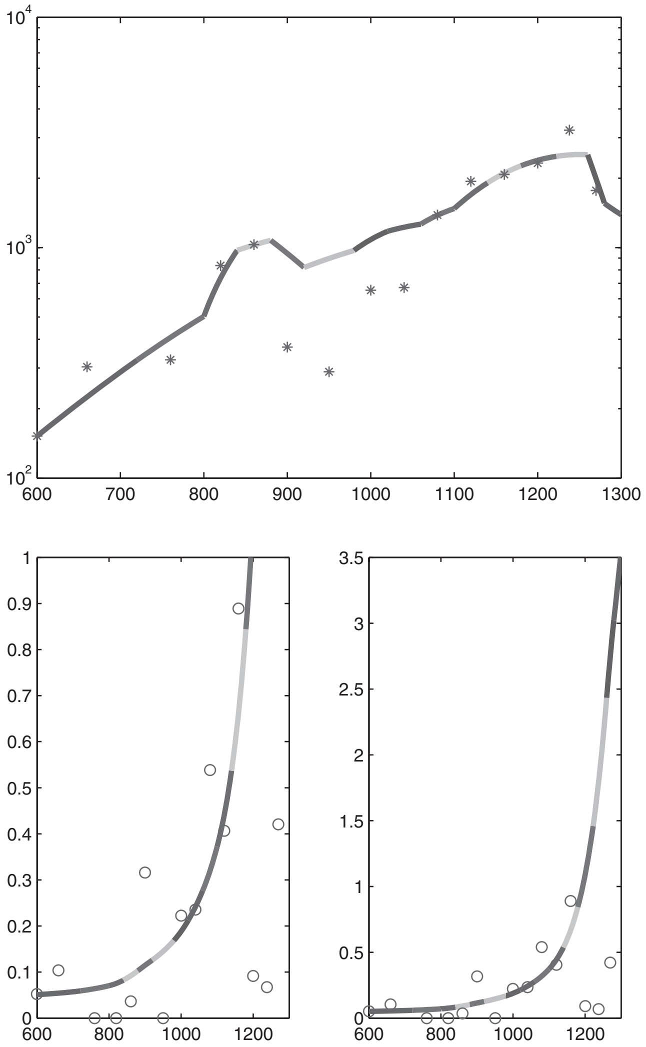

FIGURE 19.7 Top: *N* (note log scale) from data (blue asterisks) against best-fit model for equations 1 and 3 (colored line). Bottom: *W* from data (blue circles) against best-fit model for equations 1 and 3 (colored lines). (below) On the left we graph *W* in its possible range, from 0 to 1.0. On the right we graph the actual estimated values, which exceed 1 in the 1200s. Using *r* between .007 and 0.014, best-fit values for the unknown parameters *a*, *b*, and *c* are $a = 0.00011$, $b = 0.003$, $c = 0.006$, and the goodness of fit as measured by the residual $(ESS_{\log(N)} + ESS_W)$ is 2.98.

been weak. The rise and fall of population and frequency of warfare in this first cycle do not require any explanation beyond that provided by the model, although we must still elucidate the mechanisms underlying this relationship. The apparent failures of the model during the second population cycle may be due to the relative strength of exogenous factors in our area, discussed later.

Why are population size and warfare linked in the manner proposed by the model, and seen in our area from 600 through the 900s? Explaining why increased warfare might eventually cause decline in population is relatively easy. First, there are of course some direct deaths due to warfare that affect present and future population size. Second, Divale and Harris (1976) suggested that protracted warfare may lead to female infanticide, as parents attempt to raise more boys to become warriors. Such female infanticide, if present, can perhaps be identified in young adult sex ratios if we look carefully, and it would, of course, depress current and future population size. Third, to the extent that warfare stimulates aggregation, and aggregation promotes disease, warfare may depress populations through a back channel. Fourth, it is possible that prolonged conflict, by stimulating aggregation, leads to population distributions with respect to resources that are so inefficient that they may even suppress reproduction slightly. We are currently examining this possibility by comparing agent distributions from our simulations, which are efficient in their use of space and resources, to the actual household distributions from the archaeological record (Kohler et al. 2007). Finally, we know from much sad contemporary experience that people will leave war-torn areas if they are able to do so. Therefore, population decline in periods of violence may be due in part to flight from danger to safety.

In the absence of these conditions, on the other hand, populations increase given appropriate levels of production.

It is only slightly more difficult to detail the mechanisms by which more people on a landscape eventually cause more warfare. Obviously, absent innovations to increase production (technical in nature, or sociopolitical, having to do with the organization of production or distribution, or the means for conflict resolution), more people will lead to more conflicts over (fixed) resources. But more subtle mechanisms may also be at work. More people increase the relative importance of the social milieu, and warfare is a time-honored path for achieving social status and wealth, either through reputation for bravery in battle that becomes generalized to other social domains or through land or chattel acquired in victory.

IMPLICATIONS FOR LOCAL CULTURE HISTORY

This analysis suggests some novel explanations for various aspects of the prehistory of this area, including the following:

- The onset of aggregation in this area in the Pueblo I period in the late 700s and the mid-800s apparently takes place in a climate of little violence, which weakens warfare as a general explanation for early aggregation in the Southwest.
- The depopulation of this area at the end of the Pueblo I period may be as closely related to a rising incidence of warfare, and inhabitants' desires to leave those conditions behind, as it was to unfavorable climatic conditions.
- The first increases in violence that are unanticipated by the model occur in the late 900s and early 1000s, well before the earliest structures in our area that look "Chacoan" (Lipe and Varien 1999, 272). This anomaly pointed up by the model suggests that we need to look for external influences before they become obvious as Chacoan-style architecture. Perhaps sites like the Dobbins stockade (Kuckelman 1988), the Dripping Springs stockade (Harriman and Morris 1991), the stockaded Ewing Site (Hill 1985), and Two Raven House (Hayes 1998)—all dating to the early 1000s—represent resistance (ultimately unsuccessful) to Chacoan expansion.
- The circa 1080s immigration (spanning the period from 1060 to 1100) represents the first successful Chacoan intrusion into this area—quite possibly achieved via violence given contemporaneous values for *W*—followed by a second wave of consolidation in the early 1100s. Several stockaded settlements have also been documented for the mid–to late eleventh century (Mustoe Site [Gould 1982], Yellow Jacket [Lange et al. 1986], Casa Bisecada [Morris 1988], and Roundtree Pueblo [Morris 1991]). The slight decrease in violence in the early 1100s, if real, represents as close to a "Pax Chacoensis" as our area ever experiences.
- The collapse of the Chacoan system in the mid-1100s brought violence to unprecedented levels in our area, perhaps in the form of score settling as old (but apparently resented) power structures fell apart. Chaco's decline or demise was accompanied by population decline in the Chacoan heartland of the Central San Juan Basin, which is hit hard by a long mid-1100s drought, though not in our area, where climatic conditions were slightly more favorable for maize production (Kohler et al. 2007).
- The surprising and sudden reappearance of much less violent conditions circa 1200 returns our area to a regime in which

population and warfare were again related as proposed by the model, except that warfare incidence was much lower than would be anticipated by the model, given its relationship to population in the first population cycle. Although this appears to be in sharp contrast to what others have suggested for the level of warfare in the 1200s Southwest, this is not necessarily the case. The example of direct evidence most often used to infer violent conditions consists of the village-wide massacre at Castle Rock Pueblo that occurred in the late 1200s. Indirect evidence often cited for high levels of conflict in the 1200s also includes movement to inaccessible/defensive locations at canyon rims or in alcoves and near water supplies, which was largely a mid-1200s phenomenon. Evidence for violence in the early 1200s, then, is rather limited. This is all the more surprising because the early 1200s were cold, and maize farming must have been uncertain in many upland and northern areas; poor and uncertain production have been used as predictors for warfare in this area or its surrounding region by Lekson (2002), Kantner (1999), Kuckelman (2002b), and LeBlanc (1999, 34–35). Perhaps a new political model emerged out of the chaos of the mid- to late 1100s that was able to restore more peaceful conditions. Given the effects expected by scalar stress theory on political organization in these populations, which were constantly increasing in size from the mid-1000s through the mid-1200s (Johnson 1982), it seems likely that this marked decline in violence is due to the local emergence of structures—such as alliances or confederacies among communities—that had wider spatial, demographic, and political scope than the community-level organizations that probably dominated the first population cycle. These structures were by inference able to quell violence within their scopes of control—at least until the late 1200s.

- Finally, recurring violence in the late 1200s is predicted by the model to contribute to the depopulation that terminates occupation of this area by Pueblo peoples.

It has been a puzzle to explain the history of aggregation in our area. It is clearly connected with population size, but people continued to live in aggregated settings circa 900 and 1270, even as populations were decreasing. The lagged effect of population size on prevalence of violence assumed by the model and visible in our data suggests that aggregation for protection would continue to be important after population peaks. On the other hand, initial aggregation (e.g., in the late 700s and mid-800s, and perhaps again in the mid-1200s, though this case is much more problematic) appears to take place in an atmosphere in which warfare-related trauma was unusual. We suggest that initial phases of aggregation were often connected with economic and political factors scaling with population size, whereas retention in aggregates at and after population peaks was due, at least in part, to considerations of safety.

IMPLICATIONS FOR EVOLUTIONARY ANALYSIS

Since the Turchin model posits a close association between warfare and population size, it is inescapably relevant to evolutionary concerns with population-size effects on cultural transmission (e.g., Henrich 2004; Shennan 2000).

More fundamentally, warfare can be an important mechanism for cultural group selection (which need not involve extinction of demes). If the cycles identified by Turchin take place repetitively over evolutionary time scales in patchy environments among competing groups with differential group success, and if these processes are typically linked with migration to new patches by some groups as they are in the record discussed here, we have the key ingredients required to make cultural group selection a strong force in human cultural evolution. Such conditions can promote the evolution of altruistic behaviors such as bravery in warfare that may be deleterious to the individual but benefit the group and contribute to its success relative to its competitors. Moreover, the prosocial but individually costly behaviors, norms, and values that can become part of cultural practice via this mechanism need not be related to warfare (Boyd and Richerson 1985).

CONCLUSIONS

Like any model that works reasonably well, the Turchin model has two main strengths. First, for those regions of the problem where it fits, it tells us that no additional causal processes are needed to explain the phenomena of interest, so long as we can identify satisfactory mechanisms for the processes invoked and can with reasonable certainty eliminate equifinality (the possibility that *other* models might explain the phenomena equally well). We also learn from those circumstances where the model fails, since those regions of the problem require additional or different causal processes.

For the cultural-historical case discussed here, the relative success of the model suggests that absence of warfare enhances population growth but that high population sizes tend to entrain violence, and once violence becomes prevalent, it tends to decay slowly because of revenge effects. In the record discussed here, warfare may be a significant factor in the cessation of population growth in the mid-late 800s, and its prevalence may contribute to declines in population, including emigration, around 900 and in the late 1200s. Except when considering its possible effects on settlement location, southwestern archaeologists tend to think about warfare as a dependent variable. This analysis strongly suggests that it has other independent effects as well.

On the other hand, we also see that these tendencies can be overridden (climate permitting) by strong sociopolitical factors that can result in population growth even amid violence, as experienced from the late 900s through the mid-1100s in the area discussed here. The fact that our model does not explain the relationship between population and warfare during this period, and that the Ember and Ember model (1992) used by Lekson (2002) to explain warfare in the Southwest fails in this same area for the early 1200s, demonstrates that, as Keeley (1996, 17) suggested, "no complex phenomenon [such as war] can have a single cause."

The poor fit of the model during the periods of Chaco expansion, control, and collapse is not unanticipated, however, given that the model is not designed to apply to external warfare motivated by desire for territorial expansion—as might have been the case for Chaco. Minimally, the disjunction between the predictions of the model and the record has the virtue of throwing into relief the drastic change in the relationship between warfare and population caused by Chacoan influence, *whatever* that was. Secondarily, the 1200s return to a relationship between violence and population more in line with that predicted by the model, but with less violence than we would have expected given the relationship between violence and population in the first cycle, makes it possible for us to suggest the probable form of the local political regime in our area during the final century of its Pueblo occupation. In sum, the Turchin model identifies a simple set of relationships that has explanatory power when the conditions required by the model are met. Perhaps equally gratifying—and demonstrative of the potential of model-based archaeology as defined by Kohler and van der Leeuw (2007)—the model is almost as helpful even when it does not fit.

On the somewhat less positive side, we suspect that the situations where this model works well may be few and temporary; at least in the post-Neolithic world, we cannot often find places and times where exogenous factors are of little import for long periods. Specifically, as in the case reviewed here, the relationships within the model are subject to being upset, or at least complicated, by the increases in geographic scope and sociopolitical scale typical of post-Pleistocene societies when viewed over long enough periods. Perhaps the conditions required by the model would be more frequent in the pre-Neolithic world.

Acknowledgments. We thank Bill Lipe for comments on the prehistory of Mesa Verde region; Scott Ortman for his help with Bayesian estimates; Crow Canyon Archaeological Center for the use of its library to compile the statistics on warfare; Doyne Farmer of the Santa Fe Institute for his helpful discussion of assessing the fit of the Turchin-Korotayev models; the Santa Fe Institute (SFI) for its congenial atmosphere; NSF SBE 0119981, which helped fund the development of the agent-based model discussed here and provided funding to build and organize the database of archaeological sites with which we compare the model; WSU for sabbatical support for Kohler; and audiences at Crow Canyon, SFI, the University of Calgary's Chacmool conference, University College London's CEACB conference, UBC, and Yale, who heard trial versions of various portions of these materials. Finally, we are grateful to Stephen Shennan for his invitation to participate in the very interesting CEACB meeting and in this volume.

NOTES

1. Keeley (1996) cannot accurately correct for varying carrying capacities in these estimates in such a way that he could convert equivalent population densities into possibly very different "population pressures." In those limited cases where such corrections were possible, he considers the data to show either a complex, or weak, relationship between population "pressure" and intensity of conflict (119).
2. This equation by itself can be considered a model for harvesting; in that case, the WN term represents how many people can be "harvested" by war. This model has the interesting property, illustrated by Mooney and Swift (1999, 274–277), that increasing values for W increase the total numbers of casualties up to a point, but when values of N become sufficiently depressed, then further increases in W cause the total number of casualties to decrease (since the achieved population growth will be small because of the small N).
3. In method 3, we first determine the proportion of the study area covered by block survey and the momentary household density of small sites in this surveyed area. Then, we multiply the small-site momentary household density in the surveyed areas by the inverse of the sampling fraction to get total momentary household estimates for small sites. We then add the total momentary households in the community centers (for which we believe we have a census, not a sample) to the estimates for small sites to estimate the total momentary households in the study area. Then, we convert total momentary households into estimates of the momentary total persons who resided in the study area during each period by multiplying the total momentary household figure for each period by six.
4. This results in a view of the frequency of warfare in this region that is generally, but imperfectly, correlated with other measures such as instances of cultural modification and disarticulation of human bone (e.g., Kuckelman, Lightfoot, and Martin 2000) or burned structures and unburied bodies (e.g., LeBlanc 1999). Our measure does not separate raiding and feuding from village-level conflict as was attempted by Lekson (2002). Discovering why there are some differences in our views of warfare frequency depending on which measure we choose is a fruitful area for future investigation.
5. In Matlab, see "help fminsearch," "help ode45," and "help optimset." Initially, one defines the function optimset that creates an optimization options structure OPTIONS in which a, b, and c are the default parameters. Next we create a function $f =$ ODE45 (N,W) that solves the system of differential equations [1,3]. Finally, the fminsearch (@f, (*Ndata*, *Wdata*), OPTIONS) returns optimal parameters a, b, and c that bring the functional J closest to zero. For further details, see Lagarias et al. (1998).

REFERENCES CITED

Billman, B. R., P. M. Lambert, and B. L. Leonard. 2000. Cannibalism, warfare, and drought in the Mesa Verde region during the twelfth century A.D. *American Antiquity* 65: 145–178.

Boserup, E. 1965. *The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure*. Chicago: Aldine.

Boyd, R., and P. J. Richerson. 1985. *Culture and the Evolutionary Process*. Chicago: University of Chicago Press.

Breternitz, D. A., C. K. Robinson, and G. T. Gross, comps. 1986. *Dolores Archaeological Program: Final Synthetic Report*. Denver: USDI Bureau of Reclamation, Engineering and Research Center.

Chagnon, N. 1988. Life histories, blood revenge, and warfare in a tribal population. *Science* 239: 985–992.

Cole, S. M. 2006. Population dynamics and sociopolitical instability in the central Mesa Verde region, A.D. 600–1280. Master's thesis, Department of Anthropology, Washington State University, Pullman.

Cowan, J. A., T. A. Kohler, C. D. Johnson, and K. D. Cooper. 2006. Supply, demand, return rates, and resource depression: Hunting in the village ecodynamics world. In *Archaeological Simulation: Into the 21st Century*, ed. A. Costopoulos. Salt Lake City: University of Utah Press.

Dice, M. H. 1993. *Disarticulated Human Remains from Reach III of the Towaoc Canal, Ute Mountain Ute Reservation, Montezuma County, Colorado*. Four Corners Archaeological Project, Report No. 22. Cortez, CO: Complete Archaeological Service Associates.

Divale, W., and M. Harris. 1976. Population, warfare, and the male supremacist complex. *American Anthropologist* 80: 379–386.

Driver, J. C. 2002. Faunal variation and change in the northern San Juan region. In *Seeking the Center Place: Archaeology and Ancient Communities in the Mesa Verde Region*, ed. M. D. Varien and R. H. Wilshusen, 143–160. Salt Lake City: University of Utah Press.

Ehrlich, P. R., and A. H. Ehrlich. 1970. *Population, Resources, Environment: Issues in Human Ecology*. San Francisco: Freeman.

Ember, C. R., and M. Ember. 1992. Resource unpredictability, mistrust, and war. *Journal of Conflict Resolution* 36: 242–262.

Ember, M. 1982. Statistical evidence for an ecological explanation for warfare. *American Anthropologist* 84: 645–649.

Flannery, K. V. 2002. The origins of the village revisited: From nuclear to extended households. *American Antiquity* 67: 417–434.

Gould, R. R. 1982. The Mustoe site: The application of neutron activation analysis in the interpretation of a multi-component archaeological site. PhD diss., Department of Anthropology, University of Texas, Austin.

Harriman, R. G., and J. N. Morris. 1991. Excavations at Dripping Springs Stockade (site 5MT2527): A multiple-occupation, Pueblo I–Pueblo II Anasazi habitation. In *Archaeological Excavations on the Hovenweep Laterals*, ed. J. M. Morris, 327–399. Four Corners Archaeological Project, Report No. 16. Cortez, CO: Complete Archaeological Service Associates.

Hayes, A. C. 1998. *Two Raven House, Mesa Verde National Park, Colorado*. Archaeological Research Series, No. 7-E. Mesa Verde National Park, CO: Mesa Verde Museum Association.

Henrich, J. 2004. Demography and cultural evolution: How adaptive cultural processes can produce maladaptive losses—The Tasmanian case. *American Antiquity* 69: 197–214.

Hill, D. V. 1985. Pottery making at the Ewing site (5MT927). *Southwestern Lore* 51: 19–31.

Hussain, K., D. B. Wijetunge, S. Grubnic, and I. T. Jackson. 1994. A comprehensive analysis of craniofacial trauma. *Journal of Trauma* 24: 40–44.

Johnson, C. D., T. A. Kohler, and J. Cowan. 2005. Modeling historical ecology, thinking about contemporary systems. *American Anthropologist* 107: 96–107.

Johnson, G. 1982. Organizational structure and scalar stress. In *Theory and Explanation in Archaeology: The Southampton Conference*, ed. C. Renfrew, M. J. Rowlands, and B. A. Seagraves, 389–421. New York: Academic Press.

Kantner, J. 1999. Survival cannibalism or sociopolitical intimidation? Explaining perimortem mutilation in the American Southwest. *Human Nature* 10: 1–50.

Keeley, L. H. 1996. *War before Civilization*. New York: Oxford University Press.

Kohler, T. A. 2000. The final 400 years of prehispanic agricultural society in the Mesa Verde region. *Kiva* 66: 191–204.

Kohler, T. A., C. D. Johnson, M. Varien, S. Ortman, R. Reynolds, Z. Kobti, J. Cowan, K. Kolm, S. Smith, and L. Yap. 2007. Settlement ecodynamics in the prehispanic central Mesa Verde region. In *The Model-Based Archaeology of Socionatural Systems*, ed. T. A. Kohler and S. van der Leeuw, 61–104. Santa Fe: SAR Press.

Kohler, T. A., G. J. Gumerman, and R. G. Reynolds 2005. Simulating ancient societies: Computer modeling is helping to unravel the archaeological mysteries of the American Southwest. *Scientific American* July: 77–84.

Kohler, T. A., and K. Kramer Turner. 2006. Raiding for women in the prehispanic northern Pueblo Southwest? A pilot examination. *Current Anthropology* 47(6): 1035–1045.

Kohler, T. A., and S. van der Leeuw. 2007. Introduction: Historical socionatural systems and models. In *The Model-Based Archaeology of Socionatural Systems*, ed. T. A. Kohler and S. van der Leeuw, 1–12. Santa Fe: SAR Press.

Kuckelman, K. A. 1988. Excavations at the Dobbins Stockade (site 5MT8827), a Pueblo II habitation. In *Archaeological Investigations on South Canal*, comp. K. A. Kuckelman and J. N. Morris, 231–297. Four Corners Archaeological Project Report No. 11. Cortez, CO: Complete Archaeological Service Associates.

———. 2002a. The bioarchaeology and taphonomy of violence at Castle Rock and Sand Canyon Pueblos, southwestern Colorado. *American Antiquity* 67: 486–513.

———. 2002b. Thirteenth-century warfare in the central Mesa Verde region. In *Seeking the Center Place: Archaeology and Ancient Communities in the Mesa Verde Region*, ed. M. D. Varien and R. H. Wilshusen, 233–253. Salt Lake City: University of Utah Press.

Kuckelman, K. A., R. R. Lightfoot, and D. L. Martin. 2000. Changing patterns of violence in the northern San Juan region. *Kiva* 66: 147–165.

Lagarias, J. C., J. A. Reeds, M. H. Wright, and P. E. Wright. 1998. Convergence properties of the Nelder-Mead simplex method in low dimensions. *SIAM Journal of Optimization* 9: 112–147.

Lange, F., N. Mahoney, J. B. Wheat, and M. L. Chenault. 1986. *Yellow Jacket: A Four Corners Ceremonial Center*. Boulder, CO: Johnson.

LeBlanc, S. A. 1999. *Prehistoric Warfare in the American Southwest*. Salt Lake City: University of Utah Press.

Lekson, S. H. 2002. War in the Southwest, war in the world. *American Antiquity* 67: 607–624.

———, ed. 2006. *The Archaeology of Chaco Canyon: An Eleventh-century Pueblo Regional Center*. Santa Fe: School of American Research Press.

Lipe, W. D., and M. D. Varien. 1999. Pueblo II (A.D. 900–1150). In *Colorado Prehistory: A Context for the Southern Colorado River Basin*, ed. W. D. Lipe, M. D. Varien, and R. H. Wilshusen, 242–289. Denver: Colorado Council of Professional Archaeologists.

Lipe, W. D., M. D. Varien, and R. H. Wilshusen, eds. 1999. *Colorado Prehistory: A Context for the Southern Colorado River Basin*. Denver: Colorado Council of Professional Archaeologists.

Mooney, D., and R. Swift. 1999. *A Course in Mathematical Modeling*. Washington, DC: Mathematical Association of America.

Morris, J. N. 1988. Excavations at Casa Bisecada (site 5MT8829), a Pueblo I field house/Pueblo II habitation. In *Archaeological Investigations on South Canal, Volume 1*, comp. K. A. Kuckelman and J. N. Morris, 108–151. Four Corners Archaeological Project, Report No. 11. Cortez, CO: Complete Archaeological Service Associates.

———. 1991. Excavations at Roundtree Pueblo (Site 5MT2544), a multiple component, Euro-American and Anasazi habitation. In *Archaeological Excavations on the Hovenweep Laterals*, ed. J. N. Morris, 401–572. Four Corners Archaeological Project Report, No. 16. Cortez, CO: Complete Archaeological Service Associates.

Odum, E. P., and G. W. Barrett. 2005. *Fundamentals of Ecology*. 5th ed. Belmont, CA: Thomson Brooks/Cole.

Ortman, S. G., M. D. Varien, and T. Lee Gripp. 2007. An empirical Bayesian approach to analysis of archaeological survey data from southwest Colorado. *American Antiquity* 72: 241–272.

Robertson, I. 1999. Spatial and multivariate analysis, random sampling error, and analytical noise: Empirical Bayesian methods at Teotihuacan, Mexico. *American Antiquity* 64: 137–152.

Shennan, S. 2000. Population, culture history, and the dynamics of culture change. *Current Anthropology* 41: 811–835.

Sutherland, W. J. 1996. *From Individual Behaviour to Population Ecology*. Oxford: Oxford University Press.

Tainter, J. A. 2004. Plotting the downfall of society: Review of *Historical Dynamics: Why States Rise and Fall* by P. Turchin. *Nature* 427: 488–489.

Turchin, P. 2003. *Historical Dynamics: Why States Rise and Fall*. Princeton, NJ: Princeton University Press.

———. 2005. Dynamical feedbacks between population growth and sociopolitical instability in agrarian states. *Structure and Dynamics: Journal of Anthropological and Related Sciences* 1(1), http://repositories.cdlib.org/imbs/socdyn/sdeas/vol1/iss1/art3.

Turchin, P., and A. Korotayev. 2006. Population dynamics and internal warfare: A reconsideration. *Social Evolution and History* 5(2): 112–147.

Turner, C. G., II, and J. A. Turner 1999. *Man Corn: Cannibalism and Violence in the Prehistoric American Southwest*. Salt Lake City: University of Utah Press.

Varien, M. D. 1999. *Sedentism and Mobility in a Social Landscape*. Tucson: University of Arizona Press.

Varien, M. D., S. G. Ortman, T. A. Kohler, D. G. Glowacki, and C. D. Johnson. 2007. Historical ecology in the Mesa Verde region: Results from the Village Project. *American Antiquity* 72: 273–299.

Varien, M. D., and R. H. Wilshusen, eds. 2002. *Seeking the Center Place: Archaeology and Ancient Communities in the Mesa Verde Region*. Salt Lake City: University of Utah Press.

Walker, P. L. 1997. Wife beating, boxing, and broken noses: Skeletal evidence for the cultural patterning of violence. In *Troubled Times: Violence and Warfare in the Past*, ed. D. L. Martin and D. W. Frayer, 145–179. Amsterdam: Gordon & Breach.

Weiss, K. M. 1973. Demographic models for anthropology. *Memoirs of the Society for American Archaeology* 27: 1–186.

White, T. D. 1992. *Prehistoric Cannibalism at Mancos 5MTUMR-2346*. Princeton, NJ: Princeton University Press.

Wilcox, D. R. 1999. A peregrine view of macroregional systems in the North American Southwest, A.D. 750–1250. In *Great Towns and Regional Polities in the Prehistoric American Southwest and Southeast*, ed. J. E. Neitzel, 115–141. Dragoon and Albuquerque: Amerind Foundation and University of New Mexico Press.

Wright, K. I. 1994. Ground stone tools and hunter-gatherer subsistence in Southwest Asia: Implications for the transition to farming. *American Antiquity* 59: 238–263.