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ARTICLES

Modeling Livestock's Contribution to the Duration of the Village Farming Lifeway in Pre-State Societies



BRANDON M. GABLER

ABSTRACT

This study expands previous research by Carol Raish (1992) on duration and stability of village farming societies in which she argued that the presence of domesticated livestock enhances the stability of pre-state farming societies. The study uses methods developed by Lewis Binford in Constructing Frames of Reference (2001) and contributes to the growing modeling literature using environmental frames of reference to understand archaeological sequences. The 16 archaeological sequences in Raish's study and standardized environmental variables are used to generate regression equations to project duration, while discriminant function equations are used to project presence or absence of domesticated animals for a global dataset of weather station locations. This manuscript explains the modeling strategy, demonstrates the resulting patterns, and discusses this technique's potential for future research in archaeology. The models developed here attempt to find cross-cultural patterns to determine if rates of social change and subsistence patterns vary with specific environmental properties. The results of the models show that societies with domesticated animals persist longer without developing hierarchies or other signs associated with state-level societies. Additionally, the presence of domesticated animals correlates with decreased secondary biomass, a shorter time between the warmest and wettest months, and shorter distances to the nearest coast.

INTRODUCTION

This study attempts to predict patterns of village duration and medium to large animal domestication at the global scale using environmental, archaeological, and ethnographic data. It builds on previous research concerning duration of pre-state farming societies in the archaeological record (Raish 1992) using methods presented in Binford's *Constructing Frames of Reference* (2001) and adds to an expanding literature base that uses Binford's environmental frames of reference to model archaeological sequences (Johnson 2004, 2008a, 2008b; Johnson and Hard 2008). The research presented here differs from these other approaches in that the focus is on societies of established farmers

and/or herders, rather than on hunter-gatherer societies or those in the transition to agriculture phase which is the target of other works. It is argued that domesticated animals provide an added element of stability to pre-state farming societies, thus allowing the societies to persist longer without needing to move to a completely new landscape, redefining their social and institutional hierarchies, or perishing.

Raish (1992) argues that presence or absence of domesticated animals serves as the dividing factor between long and short duration, stability and instability. She analyzed 16 village farming sequences, using

a global scale of comparison for the development of patterns of human behavior. These 16 sequences were prime candidates for collective analysis with Binford's (2001) hunter-gatherer techniques, which were developed for analysis of variation in hunter-gatherer societies but are adapted here for use in assessing the duration of village farming societies. The models developed here attempt to find cross-cultural patterns to determine if rates of social change and subsistence patterns vary with specific environmental properties. In addition, these models build on Raish's work by connecting the patterns she observed with a wide range of environmental variables as well as Binford's frames of reference so that archaeologists may anticipate the potential structure of variation in places lacking such data in the known archaeological record. It is important to understand precisely why individual societies differ from the mathematical expectations. Individual style, cultural beliefs, religious developments, and access to resources all play integral roles in making every village dynamically different from those in similar environments. The models in this research show the level at which individual societies may vary from a common trajectory arguing it can be predicted by environmental frames of reference. This strategy can lead us to investigations of social aspects, decisions, and behaviors (the remaining variation not explained by the environmental models) that contribute significantly to the direction in which societies evolve.

In this study, environmental variables are shown to account for 90 percent of variability in duration among village farming societies. Dean et al. (2000:25) state that one of the most interesting uses of models is the ability to discover the social and demographic institutions that cause real systems to differ from their simplified, modeled counterparts. Thus, the expectations produced here allow researchers to consider the cause of deviation from the models.

Research Problem and Definitions

The research problem under consideration is the link between sequence duration and the possession

of medium to large domesticated animals which are defined by Raish (1992:1) as cattle, sheep, goats, pigs, and llamas. In her study, Raish (1992) considers the difference in duration as a function of stability in 16 archaeological sequences in the Old and New Worlds. She concludes that medium to large domesticated animals increase stability and therefore regional sequence duration (Raish 1992).

Stability is defined as "persistence through time without major modifications or changes...in means of production, organization of production, and resources produced and consumed" (Raish 1992:1). Duration, then, is the temporal measure of this period of persistence. Thus, a wide range of subsistence strategies can reduce economic pressure and fluctuation that can lead to instability (Hardesty 1977:43-45; Raish 1992:1; Santley 1984), including the use of domesticated animals (Flannery 1969). In the context of this research, domesticated animals constitute the critical model parameter in relation to stability within village farming societies.

The societies Raish analyzed are *village farming*, or neolithic (pre-state), societies whose agricultural crops provide at least one-third of their total subsistence. The communities generally contain between 100 and 1,000 persons, and are organized like those at the lower end of Fried's (1960) ranked society category (Raish 1992:5). Archaeologically, cultigens must be unequivocally associated with the villages (Flannery 1972:23-53; Redman 1978:178-213, 214-243). As economic, social, and political complexity increase in a given society, variation in subsistence patterns, the development of public architecture, craft specialization, and intercommunity economic cooperation appear (Raish 1992:6; Redman 1978:178-213, 214-243). These parameters, in sum, describe the boundaries within which the models operate when calculating duration and domesticated animal use. Raish's sequences are used as an intact dataset, as she selected and thoroughly investigated their fit to the village farming definition as stated above.

As in Raish's study (1992), the end of village farming occurs when a village is no longer occupied or develops a hierarchical structure, as in a state society.

A return to a less agriculture-dependent way of life could also mark the end of village farming, but this criterion is not identified by Raish and therefore does not apply to her 16 sequences or this research. One indicator of the development of a state society is the appearance of a highly centralized government, sometimes expressed archaeologically as a palace containing both habitation areas and audience halls (Flannery and Marcus 1983:79-83; Raish 1992:6). Other indicators are the appearance of public buildings, religious buildings, religious specialists, and the archaeological signatures of war, tribute, and taxes (Flannery and Marcus 1983:82-83).

Schelberg (1984:6) and Halstead and O'Shea (1982) state that risk reduction and stability maintenance can influence increased internal organization and technological complexity. Hence, Raish suggests that the end of village farming is a result of systemic instability and is accelerated by a lack of domesticated animals (1992:6).

As a basis for statistical modeling, the research presented here uses Raish's analyses regarding the presence or absence of domesticated animals and environmental variables (see Table 1 for a list of variables and their definitions) to investigate hypotheses about the duration of neolithic societies and the domestication of animals around the world. Binford's frame of reference is a solution space of more than 200 environmental and ecological variables; however, the statistical calculations to be discussed select only from the purely environmental ones because environmental variables are shown to account for 90 percent of variability in duration among village farming societies. Table 1 defines only those variables used in the resulting models which are those with the strongest significant relationships with duration of pre-state farming and presence/absence of domesticated animals. Binford (2001) provides a full description of all environmental variables.

A limiting factor of the model is the lack of paleoclimatic reconstructions for the global dataset. I do *not* suggest identical past and present climate conditions. Archaeologists can compare their sites to locations in the final model that have matching

environmental conditions, or enter known paleoclimate reconstruction data into the final equations (Johnson 2004:272).

Utility of Statistical Modeling

This research develops methods that simplify the interactions of individuals, groups, and villages. The methodology ignores individual agency in favor of overarching patterns of agriculture. It abbreviates hierarchy into pre-state and state varieties. The models rely on environmental determinism as the primary social change instigator, even though I am not advocating environmental variables as causal determinants of culture change. The question remains: is this methodology oversimplified with respect to the variables used?

Mathematical models exist so that complex systems in the real world can be examined in a controlled arena; they exist so that researchers can further break apart systems that are too complex to understand when fully assembled. In addition, simplified models allow for examination of known variable interactions so that more attention can be given to variables with unknown interactions. A simple model is quite often the best model, and as such it is often best used as a tool for investigating ecological effects of human decisions (Lansing 2000:313). A simple computer model can eliminate some of the possible parameters and parameter values, using mathematical algorithms to make sense of the issues at hand (Lansing 2000:312). Environmental variables are shown to account for 90 percent of variability in duration among village farming societies. Climate has a large impact on farming life; these models attempt to show just how much of an impact climate *could have had* in the past. These models do not entail an environmentally deterministic view of culture change. Rather, they produce expectations that, when compared with known data, allow researchers to consider the cause of deviation from the model. Yet there is still an element of surprise in the quantity of variables eliminated by the regressions and discriminant function analyses. It was not hypothesized that sequence duration in

TABLE 1. Definitions of environmental variables from Binford (2001) used in this study.

Variable	Definition (Binford 2001 variable name)	Binford 2001 page
<i>DURATION</i>	Number of years a given archaeological sequence exists in the village farming lifeway based on Raish's (1992) indicators; that is, the amount of time after a community gains at least one-third of its subsistence from agricultural crops, and before the community becomes a state .	N/A
<i>expected prey biomass (EXPREY)</i>	Secondary (specifically, ungulate) productivity in kg/km ² ; in this study, provides an estimate of local wild animal resources, from which farming populations can draw additional subsistence.	109-110
<i>log coastal kilometers (LCOKLM)</i>	Log ₁₀ value of COKLM, the shortest distance to the nearest coast in km; suggests potential use of maritime resources as supplements to farming and foraging diets.	156
<i>rainfall range (LRRANGE)</i>	Log ₁₀ value of the range in degrees Celsius between a location's mean wettest month and mean driest month; factors significantly into the productivity and length of the growing season.	70-72
<i>temporal correlation between peak temperature and peak rainfall (RRCORR2)</i>	Number of months separating the warmest month from the wettest month; factors significantly into the productivity and length of the growing season.	70-71
<i>successional stability (SUCSTAB2, also SSTAB2)</i>	Measure of probable fire-related burning and primary biomass reduction in plant communities of the given localities; this factor inflates the differences between regions with very wet and very dry growing seasons, where a high successional stability value implies a high probability of fire/community destruction.	169-172
<i>water retention during the growing season (WATRGRC)</i>	Number of months in the growing season with water retention in the soil.	79
<i>average soil water retention (WRET, also WATRET and WATR)</i>	Amount of water (mm) that is actually stored in the soil, averaged for one year based on calculated monthly values; this indicates water that is accessible to local plant communities, as opposed to runoff.	75

such a large-scale study could be explained by just a few key variables, several of which appear in multiple equations. Attempts to understand why societies adopt different agricultural and social practices and how they are maintained can be answered more thoroughly through simplified interactions and data common to multiple sequences.

In more general terms, the approach used here and advocated by Binford (2001), Johnson (2004, 2008a, 2008b) and Johnson and Hard (2008) informs researchers about differences between our expectations and the modeled environmental projections. The importance of this type of modeling lies in our response to contrasts between the two instead of rejecting the models because they contradict or fail to match our expectations; we use them to explore possible reasons for the departures from expectations. On the other hand, we must refrain from blindly accepting a model if it matches expectations or known circumstances (Dean et al. 2000), and rather continue to apply such models to new regions and data to “lead to explanations of general cultural relevance” (Raish 1992:2).

METHODS

In order to determine if rates of social change and subsistence patterns vary with specific environmental properties cross-culturally, in this study I employ the concept of a “frame of reference” proposed by Binford (2001). A frame of reference is defined as something that “allows the researcher to juxtapose one domain of knowledge about which there is a history of productive learning with another, less well-known domain” (2001:48). The frame of reference concept (Binford 2001:55-113) is developed through a climatological approach to study ecology, and specifically to quantify the ways in which hunter-gatherers interact with the environment. This research, then, demonstrates methodology for implementing Binford’s (2001) concepts to the non-hunter-gatherer archaeological record. Previous work using Binford’s frame of reference approach has focused on the development of agriculture by foraging societies (Johnson 2004, 2008a, 2008b; Johnson and Hard 2008); this study

differs by instead focusing on the environmental conditions influencing cultural development throughout the village farming period, thus impacting the duration of groups as farmers and/or pastoralists. The environmental variables are developed and collected as data independent of human interaction, therefore providing the frame of reference for statistical methods such as regression, discriminant function analysis, and projection. In this study I use the environmental variables as the “climatological frame of reference” (Binford 2001:xix) for the 16 farming societies from Raish’s (1992) study where five lack domesticated animals and 11 contain domesticated animals (Table 2). Sixteen weather stations (not necessarily included in the 1,429-weather station dataset), one nearest each of the 16 sequence locales, were used to gather data regarding temperature, rainfall, soil, vegetation, latitude and longitude, elevation in meters, and distance to the nearest coast in kilometers (Oxford University Press 1993; Wernstedt 1973). The 1,429 weather station dataset is a collection of climate data from 1,429 weather station locales assembled by Binford that serve as a climatological frame of reference (Binford 2001) for constructing the models used in this study.

By assembling the climatic data in this fashion, it is possible to derive the necessary environmental variables in accordance with Binford’s approach (2001:55-113). A computer program developed by Amber Johnson and Lewis Binford transforms the collected climate database into one that has the environmental variable dataset mentioned in the introduction. I ran a Paradox version at Southern Methodist University in July–August 2001.

Raish’s (1992) data is used without modification so that the resulting equations represent village farming as she has defined it; this is justified due to the goal of developing a heuristic device useful in future research to understand why sequences deviate from projected duration values, while also testing some methodologies presented by Binford (2001).

Four general analytical procedures are used in different combinations throughout this research. The first is the construction of correlation matrices (SPSS

TABLE 2. Locations and observed durations (in years) from Raish (1992) with projected durations from these models (in years) with and without domesticated animals.

Number	State	Station	Latitude, Longitude	Domesticated Animals	Observed Duration	Projected Duration	
						Animals Present	Animals Absent
1	American Southwest	Chacoan Interaction Sphere	36 N, 107 W	Absent	800	2585	782
2	Eastern North America	American Bottom (Cahokia)	52 N, 1 W	Absent	1073	5072	1081
3	Mexico	Basin of Mexico	19.68 N, 98.85 W	Absent	1400	4297	1409
4	Mexico	Valley of Oaxaca	18 N, 97 W	Absent	1400	2491	1546
5	Mexico	Tehuacan Valley	17 N, 97 W	Absent	1750	3584	1604
6	Southern Mesopotamia	Sumer	38 N, 90 W	Present	1900	1964	816
7	Egypt	Upper Egypt	25 N, 30 E	Present	2400	2385	1430
8	Pakistan	Indus River System	47 N, 20 E	Present	3000	2986	828
9	Northern China	Bchung Yang or Central Plain	36 N, 48 E	Present	3150	3741	514
10	Peru	Ayacucho Basin	32 N, 46 E	Present	3650	3939	1350
11	Northern Mesopotamia	Hassunan, Halafian, Samarran	38 N, 114 E	Present	3660	3396	1686
12	Britain	Southern Britain	28 N, 68 E	Present	4000	4044	904
13	Anatolia	Konya Plain	39.5 N, 22 E	Present	4600	4033	1032
14	Greece	Thessaly	42 N, 25 E	Present	5000	4612	1408
15	Southeastern Europe	South-Central Bulgaria	14 S, 74 W	Present	5000	5641	1170
16	Hungary	Carpathian Basin, Great Hungarian Plain	40 N, 35 E	Present	6200	5819	948

10), which are statistical tables that show the correlation — Pearson's r —for each pair of environmental variables, independent of all other pairs. The matrices also provide the statistical significance for the correlations. This process identifies which variables correlate most strongly with duration.

The second procedure is the use of partial linear regression, in which duration is the dependent variable; the independent variable chosen is the one from the corresponding matrix most strongly correlated with duration. This yields an equation that calculates duration based on the value of the independent variable. In addition, it provides the percentage of variability in duration accounted for by the independent variable, along with a p -value (P) for assessing the significance of the regression result. The residuals—the portion of variability in duration *not* explained by the first independent variable—are then entered into a partial regression as the dependent variable against the rest of the environmental variables. Again, the most strongly correlated variable is added to the equation, and the process is repeated. Thus, one can examine the effect of multiple independent variables on duration. The process of running regressions on the residuals is repeated until there is no independent variable having a statistically significant regression with the residuals for the current regression model. This is also known as forward stepwise regression, but is conducted manually here due to the large number of independent variables.

The third procedure is discriminant function analysis, performed to determine which environmental variables account for variability between a sequence coded for domesticated animals as absent and present. This process establishes a set of equations (*AnimalsAbsent* and *AnimalsPresent*) that projects whether or not a society in a given environment or region would possess medium to large domesticated animals. The test is conducted using the equations such that if *AnimalsAbsent* > *AnimalsPresent* for a given location, it is coded as a “1” and projected to lack domesticated animals. If *AnimalsPresent* > *AnimalsAbsent*, the location is coded as a “2” and projected to contain domesticated animals. The

discriminant function equations were generated from Raish's 16 sequences and their corresponding ecological variables; the equations were then used to assign 1 (absent) or 2 (present) to all 1,429 locations in the world dataset in the next procedure.

The equations from the linear regressions and discriminant function analysis were applied to the global weather station database from Binford (2001); this projection is the fourth procedure. The equations were calculated for presence or absence of domesticated animals, followed by duration, for each location in the 1,429-station database. Each duration value is projected using the appropriate equation based on the discriminant function value at that location. For a location projected to lack domesticated animals, the duration regression for sequences lacking domesticated animals is used; for those projected to contain domesticated animals, the opposite duration regression is used. The usefulness of this calculation is that archaeologists working in specific areas can use their climate data to calculate how long they should expect village farming to last based on the presence or absence of animal domestication evidence. This provides a foundation for future research, which will be discussed more fully below.

RESULTS

The following sections (1) describe the various outcomes of the models, (2) explain the interactions between variables in each model, and (3) identify the applicability of each model as a tool for learning about past societies. Throughout this section variable names are given in italics - please refer to Table 1 for full definitions of variables. The goal is to learn which environmental variables have the strongest correlation with duration of village farming. This allows for the development of an understanding of human relationships with the environment, and according to Raish (1992), allows a statement to be made about stability within a system. In addition, longer durations also correlate with communities possessing domesticated animals. Generally, based on Raish's data, domesticated animals allow a society to diversify their subsistence base, which, in turn, provides advantages in years of poor crops (1992:55-72).

The Duration Models

For the first model, a correlation matrix is constructed using the environmental variables in the 16-sequence database with duration as the dependent variable. The correlation matrix shows *successional stability* (*SUCSTAB2*) as being significantly correlated with duration (Figure 1); however, the resulting equation fails to accurately predict project the durations used in its creation. The regression yielded an r^2 value of 0.337, which can be interpreted as explaining 33.7 percent of the variation in duration. The fact that it fails to predict the original durations suggests *successional stability* (*SUCSTAB2*) is not adequate as a predictor for duration in this version of the model.

However, one important reason for the weakness of the above regression is the fact that five of the 16 sequences lack domesticated animals, and 11 contain them. Raish (1992:39 and Appendix) conducted tests for duration between the two groups and showed that there is indeed a significant difference in mean duration between sequences with and without domesticated animals (one-way ANOVA: $F = 17.0$, $P < 0.01$; Mann-Whitney $U = 0$, $P < 0.01$); therefore,

dividing the sequences into these two groups and calculating separate duration regressions for each is a critical step. Duration will vary significantly depending on the presence or absence of domesticated animals, a variable that is controlled for by dividing the 16 sequences in such a way.

A correlation matrix was constructed for all of the environmental variables and duration in those sequences *lacking* domesticated animals. The two variables with the highest Pearson's r values are *rainfall range* (*LRRANGE*) and *water retention during the growing season*. The correlation (r) between duration and rainfall range (*LRRANGE*) is 0.958, $P = 0.01$. This is strongly significant at the 0.05 level. The r value between duration and *water retention during the growing season* (*WATRGRG*) is 0.928, $P = 0.02$, also statistically significant (Figure 2).

The resulting linear regression equation, with *rainfall range* (*LRRANGE*), is: $DURATION = 947.8 * (LRRANGE) - 561.430$

This yielded an r^2 value of 0.918, suggesting that *rainfall range* (*LRRANGE*) explains 91.8 percent of

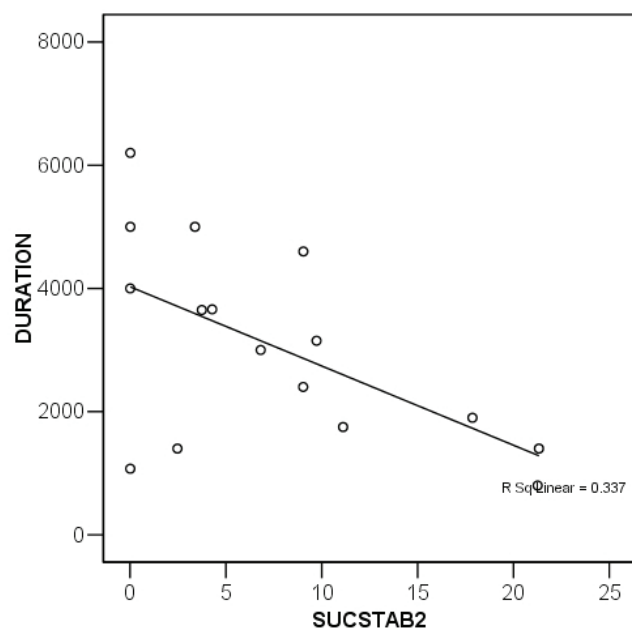


FIGURE 1. Scatterplot showing the relationship between duration of the 16 sequences and their corresponding value for *SUCSTAB2*.

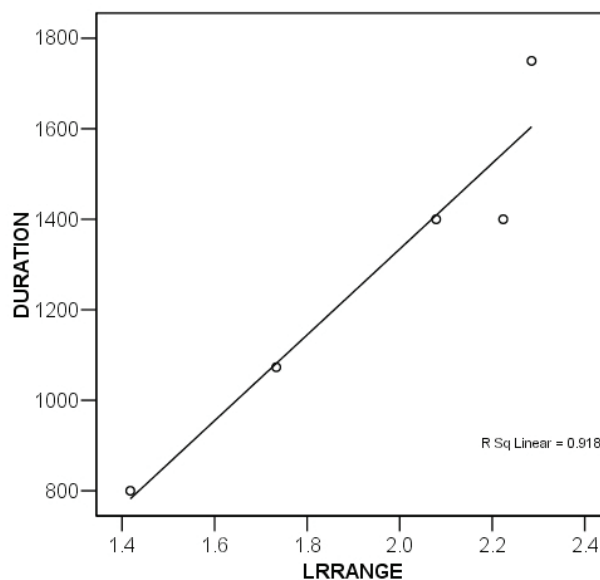


FIGURE 2. Scatterplot showing the relationship between duration of the 5 sequences lacking domesticated animals and their corresponding value for *LRRANGE*.

the variation in duration; this is extremely high, and is significant ($P = 0.01$). There is only approximately 8.2 percent of variation that could be accounted for by other variables, such as *water retention during the growing season (WATRGRG)*. Plotting *water retention during the growing season (WATRGRG)* against the residuals revealed a very weak positive relationship ($r^2 = 0.054$, $P = 0.71$) and therefore *water retention during the growing season (WATRGRG)* was not used in the final regression equation.

Similarly, for the next model a correlation matrix was constructed for all of the environmental variables and duration in those sequences *having* domesticated animals. The results of the correlation matrix showed that the two variables with the highest Pearson's r values are *average soil water retention (WRET)* and *successional stability (SUCSTAB2)*. The correlation (r) between duration and *average soil water retention (WRET)* is 0.806, $P = 0.003$, significant at the 0.05 level. The r value between duration and *successional stability (SUCSTAB2)* is -0.766, $P = 0.01$, also significant (Figure 3).

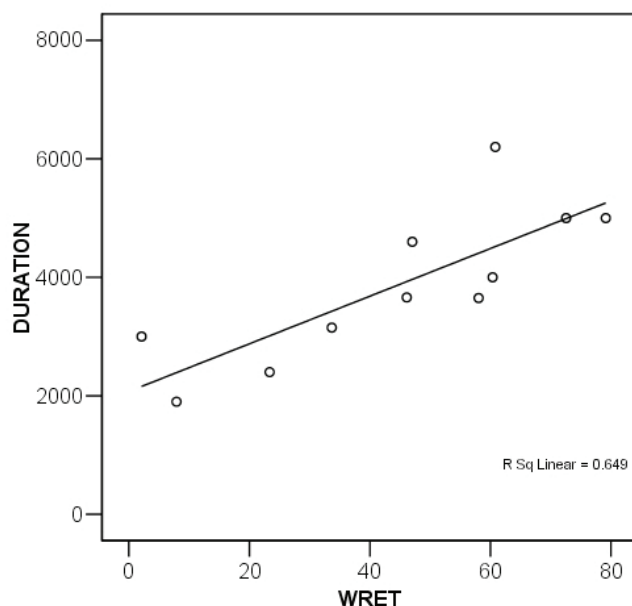


FIGURE 3. Scatterplot showing the relationship between duration of the 11 sequences containing domesticated animals and their corresponding value for WRET.

The resulting linear regression equation, with *average soil water retention (WRET)*, is: $\text{DURATION} = 40.224 * (\text{WRET}) + 2073.279$

The linear regression yielded an r^2 value of 0.649, therefore explaining 64.9 percent of the variation in duration, $P = 0.003$. Approximately 35.1 percent of variation is accounted for by other variables, such as *successional stability (SUCSTAB2)* or quite possibly by non-environmental or social variables. Plotting *successional stability (SUCSTAB2)* against the residuals revealed a weak negative relationship ($r^2 = 0.054$, $P = 0.490$) that is not used in the final regression equation. It is evident, based on the test results from Raish's (1992) study and a comparison of the duration values at the 16 sequences, that the addition of domesticated animals statistically increases average duration. In actuality, this is probably not a true causal factor but a strong correlation between the use of domesticated animals and stability (Raish 1992). Figure 4 illustrates that the equations are successful at predicting duration

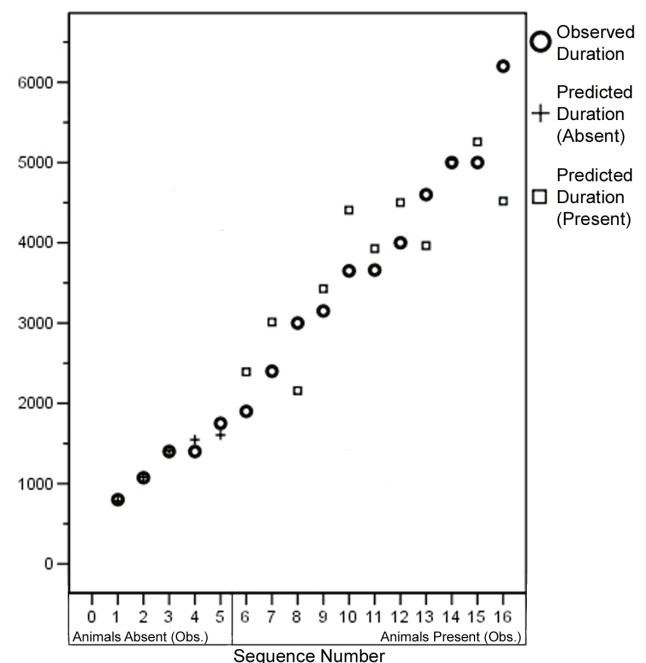


FIGURE 4. Plot of observed durations from Raish (1992) against predicted durations with and without domesticated animals, showing goodness of fit of each equation against its source dataset.

for the dataset from which they were formed. In this respect, the two equations resulting from the split-file regression analyses are useful for projecting onto the 1,429-weather station database. This depends on whether the data values from the weather station data for the 16 cases can reasonably be considered to be a random sample from the weather station data.

The values for the global database are not given in table format in this paper; rather, Figure 5 is a contour map of projected duration as if all global locations contain domesticated animals. Figure 6 is a contour map of duration as if all locations lack domesticated animals (please note that the scale for duration is different for Figure 6 than for the other duration maps).

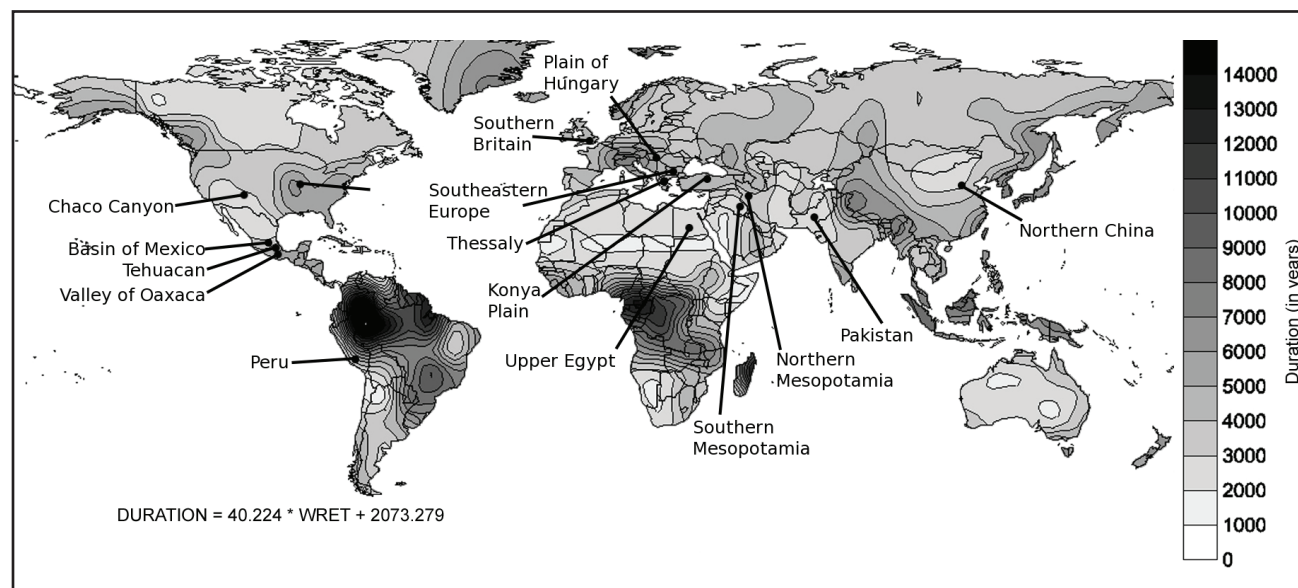


FIGURE 5. Projected duration (in years) of pre-state farming societies given the presence of domesticated animals at each station in the world data set.

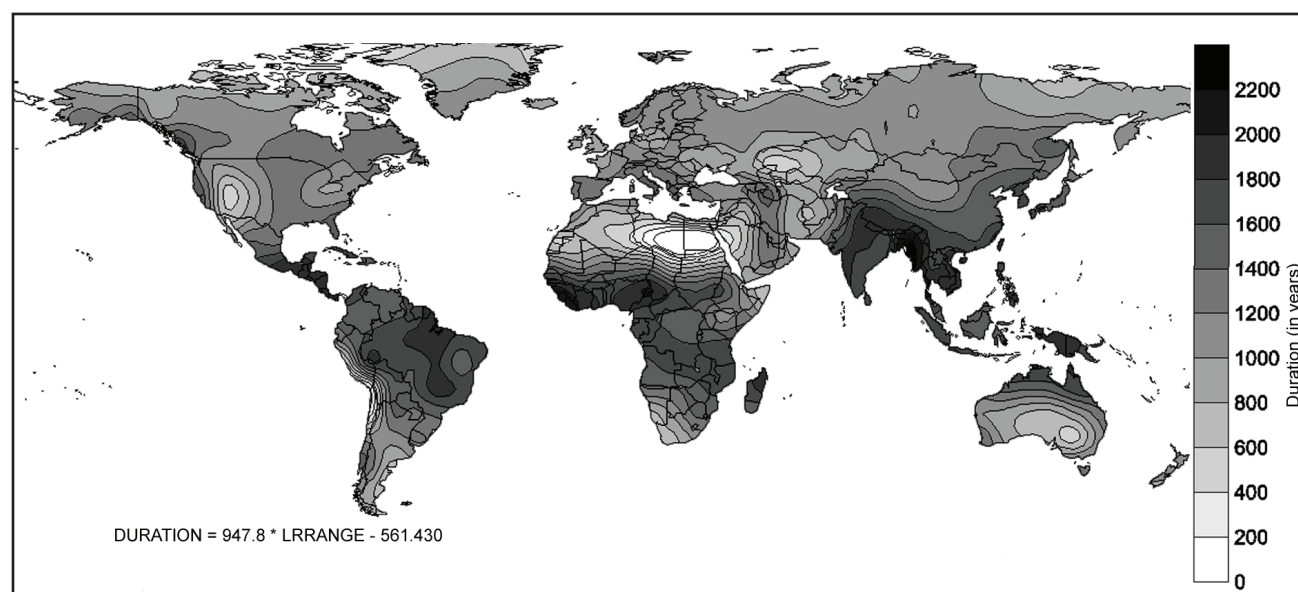


FIGURE 6. Projected duration (in years) of pre-state farming societies given the absence of domesticated animals at each station in the world data set.

Predicting Presence and Absence of Domesticated Animals

Analysis suggests that absence or presence of domesticated animals is correlated with the variables *expected prey biomass (EXPREY)*, *log coastal kilometers (LCOKLM)*, *temporal correlation between peak temperature and peak rainfall (RRCORR2)*, and a constant. *Expected prey biomass (EXPREY)* is the expected value of secondary animal biomass (Binford 2001:109-110); *log coastal kilometers (LCOKLM)* is the \log_{10} value of *COKLM*; and *temporal correlation between peak temperature and peak rainfall (RRCORR2)* is a calculation of the number of months separating the warmest and wettest months (Binford 2001:70-71). The discriminant function equations are:

$$\text{AnimalsAbsent} = (0.017 * \text{EXPREY}) + (95.352 * \text{LCOKLM}) + (8.913 * \text{RRCORR2}) - 163.312$$

$$\text{AnimalsPresent} = (0.014 * \text{EXPREY}) + (84.338 * \text{LCOKLM}) + (7.905 * \text{RRCORR2}) - 126.962$$

To reiterate, if the value (at any specific location) for *AnimalsAbsent* is greater than the value for *AnimalsPresent*, the location is coded as a 1 and is projected to lack domesticated animals. If the opposite is true, it is coded as a 2 and projected to contain

domesticated animals. These equations successfully predicted presence or absence of domesticated animals on 15 of the 16 source datapoints, incorrectly assigning the Valley of Oaxaca as a location containing domesticated animals.

A point-plotted map shows all the locations and their assignment of domesticated animal status (Figure 7). With the global database partitioned with respect to domesticated animals, the two duration equations can be applied to the appropriate locations and plotted again as was done for each duration model (Figure 8). This figure represents the prediction of duration length at each locale in the 1,429-weather station dataset given the results of discriminant function analysis; it shows the duration based on the projection of presence or absence of domesticated animals.

An analysis of the equations shows that as secondary biomass, separation between warmest and wettest month, and distance to the nearest coast increase, the probability increases that a society will lack domesticated animals. Conversely, as distance to the nearest coast and secondary biomass decrease, the probability increases that a society will have large domesticated animals. This is potentially because a society cannot rely on small game nearby, and local conditions make it desirable to domesticate animals

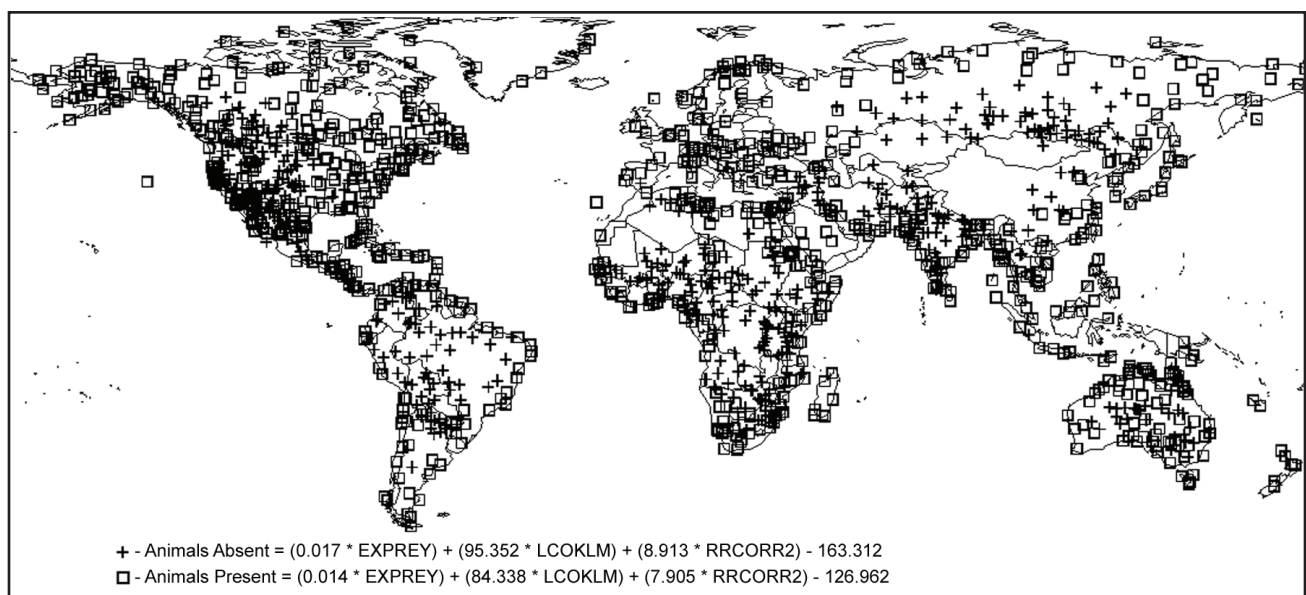


FIGURE 7. Projection of the presence or absence of domesticated animals.

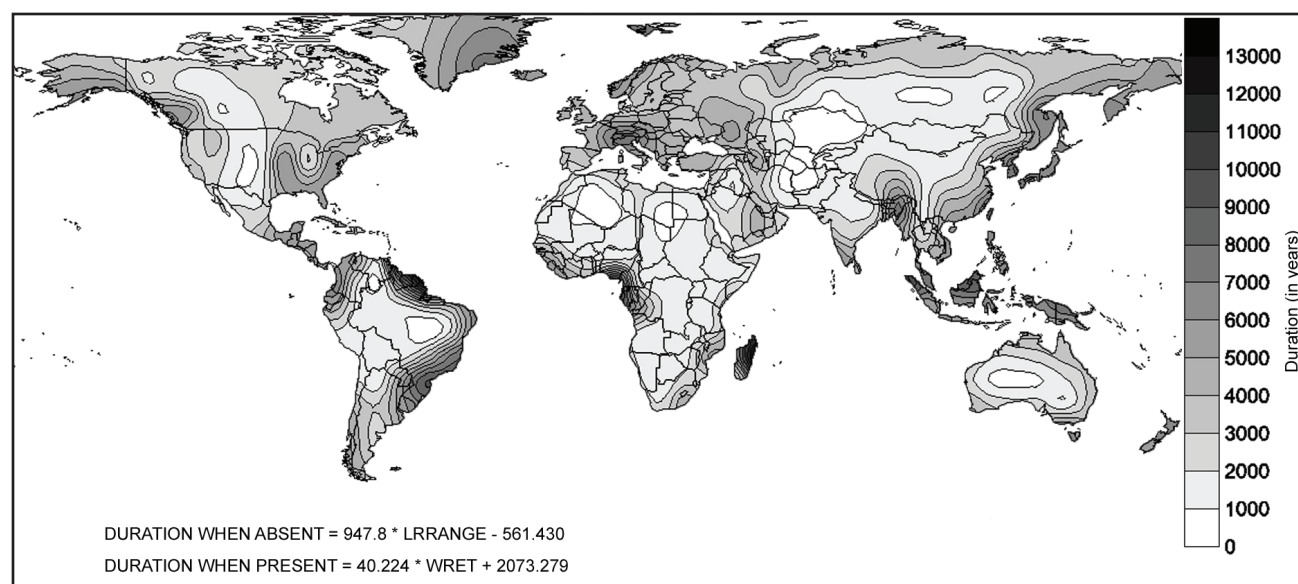


FIGURE 8. Projected duration (in years) of pre-state farming societies, applying the duration equation for presence/absence of domesticated animals based on the results of discriminant function prediction, shown in Figure 7.

and have them around as live storage of food and to help work the land (Raish 1992:55-58).

According to the partitioned-file regressions, and referring back to the initial problem statement, the variables *rainfall range* (*LRRANGE*), *water retention during the growing season* (*WATRGRC*), *successional stability* (*SUCSTAB2*), and *average soil water retention* (*WRET*) are the most strongly correlated with duration. Through the maintenance of social stability, owing in part to a reliable food supply, societies are able to remain as pre-state farming societies without the need to rearrange their social and/or subsistence systems. However, the equations also suggest that groups with domesticated animals have inherently more stability, in terms of their average lengths of duration. In a mathematical sense, this is evident in the discriminant function equations in that the slope of the line indicating animals are present is lower; therefore, the variables have less of an impact on the society than they do where domesticated animals are absent.

This research lends ecological support to conclusions drawn by Raish (1992) regarding the influence of large-scale domesticated animals on social stability.

The results of the duration regressions buttress the hypothesis that domesticated animals add stability to small farming societies. Prior to dividing the sequences by presence or absence of domesticated animals, the regression equation explains only 34 percent of the variation in duration between the original 16 sequences. However, when the database is divided, temperature, water retention, and rainfall range combine to account for 90 to 92 percent of the variation in the duration of pre-state farming societies. This suggests a strong link to the roles domesticated animals perform in our understanding of long-term patterns and stability.

In the introduction it was stated that environmental, archaeological, and ethnographic data provide the basis for examination of village stability. The first two categories of variables have been discussed at length. Ethnographic data, however, enter the picture as duration is examined in its correlation to presence and absence of domesticated animals.

The variables in each equation do not affect duration outside the context of human behavior and interaction with the environment. In the equation for sequences lacking domesticated animals, it is expected

that much of their duration depends upon precipitation-related variables; indeed, this is the case. Stability of agricultural production in farming societies is related to the predictability and timing of rainfall immediately preceding and during the growing season. Groups in the U.S. Southwest, for example, used the behaviors of animals in combination with late winter and spring precipitation to determine the potential productivity of the upcoming growing season. These observations would then dictate storage and rationing behavior through the coming year (Kurt Anschuetz personal communication 2008). The variables are not listed, but many of the other variables with high correlations for these five sequences were all related to water and the growing season. It is obvious that the range in temperature within the range measured by *rainfall range (LRRANGE)*—the temporal difference between the months with the highest and lowest precipitation—is important. If the majority of rainfall occurs during warmer months, hence, the growing season in the mid-latitudes, the growing season will be more productive, and so stability in the system slightly increases. Similarly, the number of months in the growing season with water in the soil (*water retention during the growing season [WATRGRRC]*) is an important factor for communities relying on agriculture for the majority of their subsistence and lacking domesticated animals as backup in times of low crop production.

In terms of the sequences containing domesticated animals, *successional stability (SUCSTAB2)* logically applies because of its negative correlation with duration: as biomass reduction resulting from fire decreases, stability of the system and therefore duration increases. Water retained in the soil, *average soil water retention (WRET)*, has a strong positive correlation because even though these communities contain domesticated animals they still rely on agricultural crops and a reduction in water in the soil available for plants means a reduction in stability of these systems; too many years in a row, and communities could deplete the live storage of animals that previously made them more stable.

DISCUSSION

This study built on Raish's work by connecting observed patterns with environmental variables to account for variability between societies due to climatic conditions; therefore to study the remaining variation in terms of social and societal differences. The study began with the hypothesis, per Raish, that domesticated animals add stability to small farming societies. This stability is measured by the number of years a society is able to persist as a small-scale farming society. Raish (1992) tested this hypothesis against the alternative that the presence of domesticated animals has no effect on the duration of a group as a small farming society. This study then proposed that environmental variables could be identified that predict the presence or absence of domesticated animals in the known 16 societies from Raish's research. Alternatively, the distinction between societies with and without domesticated animals would be shown to have no correlation with environmental variables. If both hypotheses failed to be disproved, then they could be combined to develop predictive models of duration at each of Binford's 1,429 weather station locales based on the presence or absence of domesticated animals and the environmental variable dataset.

The results of the models showed that duration is indeed longer for societies with domesticated animals, and that the presence of domesticated animals correlated with decreased secondary biomass, a shorter time between the warmest and wettest months, and shorter distances to the nearest coast. Overall, stability of a society increases based on the predictability and stability of their subsistence resources. The presence of domesticated animals simply enhances the predictability of resources in an area with increased rainfall, especially during the growing season. Raish's research provided the foundation to test hypotheses about cultural persistence, social change through time, and impact of domesticated animals at varying temporal and spatial scales. The models presented here are only a sample of the types of investigations possible using the methodology and data developed by Binford (2001).

Overall, the models discussed above provide a means for predicting the duration of neolithic societies given certain environmental conditions especially those related to precipitation and local growing season in the temperate zones. The models apply a strategy developed for hunter-gatherer population modeling (Binford 2001), expanding their utility as others have done for the transition to agriculture (Johnson 2004, 2008; Johnson and Hard 2008). The models presented here do not match the archaeological record in many areas, and yet they are still useful tools. For example, many of the 1,429 weather station locations were projected to contain domesticated animals even though we know they did not exist everywhere (such as in the majority of the western hemisphere). These models could have been fitted with regional variables controlling for the presence of animal domestication candidates – but that would have defeated the purpose of leaving the model to decide where domestication would have worked. For example, researchers of Spanish colonial contact may be interested in assessing communities in the U.S. Southwest after such animals were introduced.

Other recent research (Johnson 2004, 2008a, 2008b) uses Binford's (2001) environmental frames of reference to investigate niche breadth and the transition to agriculture. Johnson does this using a global scale of analysis, implementing the frame of reference variables to "control some of the variability at the global scale of analysis and discuss the value of relational arguments for building explanations in archaeological research" (2004:263). She focuses on system stability in the U.S. Southwest and Mexico, and shows how adaptational stability is higher where subsistence diversity is also higher. In a later analysis, Johnson (2008b) constructs a test case for the duration of the transition to agriculture using data from Mexico and Binford's (2001) frames of reference, providing a set of conclusions on what archaeologists can expect regarding the rate of the transition given certain starting conditions in different areas of Mexico. Johnson (2008a) further expands this methodology to assess change in subsistence and social organization for the western hemisphere during the mid-Holocene. Demographic and environmental variables are used

to show that changes in hunter-gatherer subsistence are ten times more likely to result from population density fluctuation than from environmental change (2008a:11).

Finally, similar methods used by Keeley (1995) to develop understanding about processes influencing the origins of agriculture might provide insights and lead to new avenues of research. Keeley's work involves cross-cultural comparisons of ethnographic hunter-gatherer societies with intent to understand the ecological, demographic, and socioeconomic interactions that correlate with aspects of plant exploitation. His research is applicable to the present study in his inclusion of "social demand" as a variable from which the stepwise regression may choose. The results are surprising in that social factors are uncorrelated or even negatively correlated with agricultural origins (Keeley 1995). In the present study, it has been proposed that variation in the longevity of pre-state farming societies not explained by the environmental variables might have been responsive to social factors, in contrast to Keeley's conclusions. Latitude, precipitation, and population density appear as common factors in the hunter-gatherer regressions (Keeley 1995:268).

Scale of Application

Levin discusses the importance of conducting research at both the large and small scale: what is unknowable at one scale may be knowable at another (1992:1950). In archaeological studies of human systems, there is a division between those who perform large-scale analyses and those who conduct small scale, local analyses. However, Levin would argue that the two researchers have much in common, and should examine what information is preserved and lost as one moves from large to small scale, and vice versa (1992:1950-1953). There is no single correct scale (1992:1960).

Additionally, each model and associated figure refers to the global database and how it is reflected on the world map. Each location in the global database (Binford 2001) has values for each variable in a form useful for study at regional and local levels¹. If

paleoclimate reconstructions have been compiled for a specific research area, the values for any necessary variable (i.e., *rainfall range [LRRANGE]* or *log coastal kilometers [LCOKLM]*) are easily substituted in the proper equation, eliminating the need to find a suitable substitution location from the global database.

The limitations of this study are directly relevant to the models' usefulness. Owing to the relatively small sample size (16 sequences), the applicability of projection equations should be variable. Application of the models to studies in the mid-latitudes will be more accurate than those in other climate zones, and studies of societies similar in size and agricultural practice to any of the 16 will yield expectations that are more accurate. These limitations should encourage future applications of the current models, thereby expanding the base data set to include a wider variety of locations and a larger number of reference sites.

CONCLUSION

This research has provided a tool for examining archaeological sequences in order to make predictions based on observed environmental conditions. The projections of duration and domesticated animal presence or absence allow us to create *expectations* and examine similarities and differences between projections and observed data. The most interesting aspects of these models will occur when the equations are more robust, yet still fail to predict the intricacies of human behavior in a specified region. Humans possess capabilities such as forethought, memory, and the ability to assign meaning where there is none (Holling et al. 2002; Janssen et al. 2000; Westley et al. 2002:107-119). These are some of the factors not amenable to quantitative study, and are some of the aspects that this model can open for discussion by eliminating the majority of fuzziness through the systematic removal of environmental characteristics that bear no weight on cultural response. It would be drastically more difficult to explore, for example, why the societies in Peru persisted in a Neolithic tradition for 3,650 years by starting with a narrowly focused, localized assessment of ritual, memory, and individual agency, without first identifying the envi-

ronmental and more general trends held in common with other societies and comparing their durations with Peru. This technique as applied to village farming societies can be applied to any collection of data spanning the scope of archaeological history for many traits other than those defined in Raish's (1992) study of pre-state farming societies. Versatility is a key factor in discovering the usefulness of any model; overall, this research is a tool that has a wide range of usefulness and much promise for improvement, expansion, development, and further analysis.

Future research using these methods may involve regional studies with adjusted models more accurately reflecting local, known conditions from the archaeological or historical record. They could then be compared to the original projections presented here for the same area. Future applications of this approach will likely include an examination of a wider range of latitudes in order to determine whether the equations break down beyond their evident regions of applicability. It is expected that alternate equations are necessary for alternate environments, especially in areas such as the tropics where societies are susceptible to much different stresses related to annual fluctuations in rainfall. The point is that, currently, there are not enough cases in each of the different climates to stratify the database in that manner; this calls for a larger and more environmentally diverse sample.

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NOTES

1. Global data with calculated frames of reference are available upon request, through the author, from Amber Johnson.

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