CONVERGENCE IN THE NEOLITHIC: HUMAN POPULATION GROWTH AT THE DAWN OF AGRICULTURE

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Abstract

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Prehistorians generally agree that the origin of agriculture was associated with a transition in demography, namely that there was a substantial increase in human population defined as the Neolithic demographic transition (NDT). Researchers have focused little attention on how the origin of agriculture prompts such a shift and why 1) fertility increased and 2) why human behavior accommodated the demands to invest in more children, ultimately allowing population to grow. This dissertation is focused on understanding why this occurred.

In order to gain a better understanding why the NDT is a shift in fertility and human behavior, I develop a model of past population growth rates utilizing extensive archaeological data. Several variables are utilized as proxies of population: frequency of ^{14}C dates, frequency of sites occupied, total depth of deposits, and total area occupied. These variables are tracked in 50-year increments from 22,000-8,000 calibrated years ago from the Early Epipaleolithic to the end of the Pre-Pottery Neolithic periods in the southern Levantine area of the Near East.

Results suggest that population mimicked zero-growth throughout much of prehistory until approximately 11,200 years ago, when an apparent increase in population occurs in line with the first evidence of intensive food storage. I argue that this population growth was due to the temporal convergence of foundational elements including: foods that are associated with increased fertility, a series of technological inventions that increase processing and harvesting of those resources, a stabilization of human diet through storage technology, and a behavioral shift that incorporated younger age brackets into the labor force.

For anthropologists the origin of agriculture is one of the most discussed events in human history. However, this study is novel by contributing a new methodology to model past population growth rates. Consequently, this study is significant because it initiates a discourse on why the NDT happened when it did, and not before, ultimately providing a greater understanding of major changes in human adaptive strategies.

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CHAPTER ONE

WHEN DO HUMAN POPULATIONS GROW? CATALYSTS OF DEMOGRAPHIC CHANGE IN PREHISTORIC SOCIETIES

In North America, archaeology developed as a sub-discipline in the greater study of humans known as anthropology. Anthropologists and archaeologists in general are charged with the daunting task of understanding the evolution of human behavior and the distinct yet interrelated components of both our biology and social behavior. There are two primary goals associated with the responsibility of understanding our past. First, we must examine the attributes of our genetics that have evolved over the course of millions of years to produce our large brains and our behaviors. Second, we must attempt to understand our culture or the learned information that we gather, process, and transmit throughout our lifetime. Both components of our behavioral and biological evolution have a strong link to our interaction with each other and with our natural surroundings.

Through interacting with our social and natural environments, humans have negotiated several major adaptive transitions. Undoubtedly, the adaptation and perpetuation of such adaptive transitions significantly shaped the daily lives of individuals, their families and communities from the distant past through modern times. These significant transitions include 1) our behavioral evolution and migration out of Africa (Klein 2008), 2) the independent invention and transition to food production in several areas of the world including the Near East (11,000 BP), China (9,000 BP), Central Mexico (5000-4000 BP) and Eastern USA (4000-3000 BP) (Bar-

Yosef 1998; Diamond 1997; Heiser 1990) and, 3) the transition to industrialization and modernization, just to name a few. The focus of this study is the second of these significant transitions with specific attention to the interaction of human behavior and the fundamental elements associated with intensified food production in the Near East.

Population size is strongly interconnected with the transition to agriculture largely based upon the link between food production and subsistence requirements of living organisms. In social terms, this relationship provided dynamic change within past societies including the number of roles (niches) for individuals to occupy, the situations that structure the nature of teaching and learning, and the number of people to interact with in social situations.

Anthropologists and archaeologists have long recognized that fluctuating population densities had an intricate association with the long-term process of humans settling into semi-permanent to permanent residences (Cohen 1977a, b). In most instances, the origin of these communities is associated with the transition to agriculture (Flannery 1972:1) and in others; the transition to resource intensification (Kramer and Boone 2002). This study focuses on population dynamics and the transition to agriculture/resource intensification in the Near East, where it took place leaving behind abundant archaeological data to interpret the role of population densities during the transition.

The Origins of Agriculture and Demographic Change

As agreed upon by most archaeologists, the origin of agriculture was associated with demographic change, or a significant increase in the number of humans defined as the Neolithic demographic transition (NDT) (Bocquet-Appel 2002). While we maintain this general agreement and definition, we currently need to explore more specifically why fertility increased and how human behavior shifted to invest in more children and larger families, ultimately allowing populations to grow. Bocquet-Appel (2002) suggests that fertility increase was linked to food quality and Kohler et al. (2008) specifically link the introduction of efficient storage technology that allowed upland dry farming to expand in the American Southwest. The result of this expansion of dry farming comes in the form of a population explosion in many areas of the Southwest (Kohler et al. 2008).

The goal of this study is to build upon these hypotheses and explore in a more specific manner how food may be linked to increased fertility and why populations subsequently grew when they did, and not before. While this topic has been previously addressed, other proposals emphasize environmental factors (e.g., Richerson et al. 2001) and a significant departure from this is warranted to hypothesize the degree to which other factors contributed to population growth. This study represents a departure from environmental catalysts as a significant contributor and instead examines the food nutrient content, technology, and human behaviors that could have worked together to increase fertility and permit population growth.

In this study, an evolutionary perspective is utilized to examine humans' shifting resource bases and their sensitivity (although maybe not in a conscious manner) to diets that enhance fertility (as other organisms are). These conclusions are supported by recent research which indicates certain foods provide nutrients that increase fertility in women. Additional archaeological evidence outlines that the advent of technology allowing those specific foods to be part of a stable diet likely contributed toward increased fertility. In other words, these foods associated with fertility were available on a longer basis than just the harvest season through the use of storage technology. Yet, just because people can have more children, this does not necessarily mean that they will invest more energy in their rearing. Subsequently, the demographic transition had to incorporate a change in human behavior allowing population growth. I suggest one potential explanation for this change is the introduction of younger age classes into the labor force, essentially underwriting the costs of having larger families (Hassan 1981; Kramer and Boone 2002).

In this study I utilize abundant archaeological data to model population growth rates from 20,000 to 8,000 years ago in the southern Levant of the Near East. By utilizing new techniques and multiple variables as proxies for human population growth, we can demonstrate that population mimicked zero growth until approximately 11,200 cal BP, when the first growth rate increase is detected that is significantly larger than any before. I argue that this coincided with the development of food storage technology, allowing certain foods associated with increasing fertility to be available on a longer than seasonal basis, thus stabilizing human diet. Utilizing new data and techniques in this study is significant because we can both test current models of the Neolithic demographic transition (e.g., Bocquet-Appel 2002 and others) but also complement and provide a potentially more detailed representation of population growth during the transition.

Dissertation Organization

This study is organized into eight chapters and the following is a brief outline of the topics covered. Chapter Two covers evolutionary theory by presenting a generalized model of energetic budgets and nutrition utilizing optimality theory which I use to explore the nature of humans negotiating their diets and the potential that we will optimize behaviors to exploit the nutrients that will increase fertility. Chapter Three defines demographic transitions in general, as well as how the Neolithic demographic transition has been defined, detected and understood. This allows for the argument to be made that additional data and analytical techniques can greatly enhance our understanding of the NDT. Chapter Four discusses the interconnection of the invention of storage technology, nutrition, and fertility. This chapter also examines ethnographic examples of labor force composition with specific attention to the age classes that are included in forager and farmer economic strategies. This sets the stage for providing an explanatory framework for why population increased when it did, and not before. Chapter Five provides the archaeological context for the southern Levantine NDT by focusing on the culture history and archaeological record of the area. Chapter Six presents the methods used to build the population growth rate model. In this chapter I also cover the analytical techniques utilized to argue that the variables of population proxies are monitoring and tracking population growth in a similar manner through time and thus, we are able to utilize them simultaneously to examine population growth rates. Chapter Seven presents the results and the overall characteristics of the Near East NDT and how it articulates with evolutionary trends revealed by population modeling. Chapter Eight then provides a discussion regarding the NDT and the convergence of fertility, food nutrition, storage technology, and labor organization with population growth. Chapter Eight also provides the conclusions to this study and argues for the utility of this approach to understand the past. Ultimately, while it has become clear to archaeologists that the Neolithic Revolution was a long process, it is still highlighted by several revolutions and is clearly associated with a significant increase in fertility. Due to the flexible nature of human behavior and associated foods that enhance fertility the NDT incorporated a substantial increase in the number of humans.

CHAPTER TWO

EVOLUTIONARY THEORY AND FOOD ACQUSITION: THE TRANSITION FROM FORAGING TO FARMING

The Neolithic period was specifically defined as the New Stone Age (Childe 1925), yet this period, more importantly, also incorporated a significant change in human subsistence strategies – namely, the transition from hunting and gathering to agriculture. The Neolithic transition around the world is regularly regarded by researchers as 1) the first time that people started to plant crops, which 2) led to a morphological change in those plants over time making them more productive, resulting in 3) a dramatic increase in human population. A central question in the evolution of human societies is how nutrition may affect human fertility and why it appears that agriculture provided the possibility of decreasing birth spacing; ultimately setting the stage for population growth.

Evolutionary theory has been utilized to address many questions regarding human behavior. Yet it has seldom been applied to the understanding the forager farmer transition. It is important to develop a theoretical perspective from Human Behavioral Ecology (HBE) which, with its economic orientation, can be applied to understand the transition in adaptive strategies from foraging to farming. In this way we may be able to provide a greater understanding of some of the circumstances that encouraged population growth to be associated with the transition to food production.

I argue that significant new insights can be gained by understanding why there was a large-scale demographic change associated with the transition to food production. This is useful because we now have explanatory frameworks for detecting the demographic transition associated with the onset of the Neolithic (Bocquet-Appel 2002), yet we lack a clear understanding of why it happened when it did and what parameters outside of environmental shifts potentially influenced demographic change.

As a potential solution to this problem, in this chapter I examine the evolutionary costs and benefits of participating in social and economic behaviors and their association with both food *quantity* and *quality*. In other words, food nutrient quality may be just as, if not more, important as food quantity which is the traditional focus of HBE research. At the same time I highlight the competitive social nature of engaging in activities related to acquiring food. I argue that building theoretical models that incorporate both resource quantity (a traditional focus of HBE) and quality (minimally addressed by HBE) are necessary for providing explanatory frameworks regarding why the transition to agriculture resulted in a substantial increase in population.

Evolutionary Theory Applied to the Origins of Agriculture

The transition to agriculture, most notably in the Fertile Crescent, has been explained by an almost countless number of theories ranging from crowding of people and potential domesticates into oases (Childe 1925), population pressure and food stress (Cohen 1977a, b), marginality models and population expansion (Binford 1968; Flannery 1973), culturally and socially driven origins model (Braidwood

1960), environmental models associated with the Younger Dryas (Bar-Yosef 1998); coevolution and incidental domestication (Rindos 1980, 1984); and over-zealous entrepreneurs whose appetites for surplus set the stage for competitive feasting (Hayden 1990). While this only highlights the broad range of perspectives, it is not the goal here to provide a detailed overview of these or other theories, as this has recently been accomplished (Bar-Yosef and Meadows 1995; Kuijt and Goring-Morris 2002; Twiss 2007; Verhoeven 2004).

In the Near East, the application of evolutionionary models to understanding the transition to food production has been primarily a descriptive endeavor, focused on how artifact assemblages, mobility patterns, and site morphologies change through time (i.e. Bar-Yosef 1998). In contrast, there has been limited application of the actual principles of evolution via processes of natural selection and drift to understand the broad-scale adaptive changes associated with the transition (although see Munro 2004; Russell 1988; Zeder 2009).

Kennett and Winterhalder (2006) recently brought together researchers utilizing HBE (most consistently optimal foraging and patch choice) to discuss circumstances under which humans shifted from utilizing foraged resources to those that are cultivated. Interestingly, not one paper in the volume is dedicated to the origins of agriculture in the Near East, nor more specifically, the Fertile Crescent. In actuality, only one paper, McCorriston (2006), directly attests to the significance of this area and the adoption of agriculture throughout Arabia. None of the papers specifically apply theories from HBE to the transition to agriculture in this area of the world. This underscores the need to explore evolutionary theory as a means for understanding the transition to agriculture in the Near East.

The tradition of using Darwinian principles to understanding the origins of food production has been situated within the framework of HBE (Cowan and Watson 1992; Gremillion 1996; Kennett and Winterhalder 2006 and papers therein; Rindos 1980, 1984; Smith 2002). Within this paradigm, food production has been considered as “a long-term uncertainty that promotes short-term tactics” (Bettinger 2006:314) where cultivation is associated with efficiency maximization in times of plenty and risk minimization in times of scarcity (Gremillion 1996). This finding demonstrates the implicit importance of applying an evolutionary understanding to the possible reasons why food production began because it posits the explicit importance of optimization (whether sensitivity to risk or efficiency) in relation to human decision-making practices (Winterhalder and Goland 1997:126).

Optimization and Energy Budget

One of the base assumptions of evolution via natural selection is the importance of the energy budget, since it is assumed a person who allocates time and energy efficiently will be more reproductively fit. The energy budget encompasses both reproductive effort, including time spent obtaining mates and providing for offspring, and somatic effort, or maintenance of oneself in terms of growth, development, and resource procurement (Boone 2002). Although reproductive and somatic efforts support the same ultimate goal of fitness, actions to achieve one or the other may at times be in opposition. Because of this, humans must make a decision as to when it is more advantageous to invest in one arena to the possible detriment of the other.

A central focus of HBE and the energy budget concept is the idea of optimization. A researcher utilizing optimality reasoning will directly ask how an individual decides when to invest in one effort at the possible detriment to another (Foley 1985). Optimization is a process whereby humans weigh the cost, risk, and benefit of a behavior before making the decision to participate, when to participate, or at what level they will participate. HBE suggests that in food-acquisition activities, humans will tend towards optimization (Winterhalder and Kennett 2006)s when deciding whether (and how) to expend energy on food gathering or any other efforts. In other words, if participating in food acquisition may impact other efforts, its costs and benefits will be weighed. Because of issues of adaptive lag and changing optimal outcomes, c*onstrained optimization* implies that humans will not always make the most efficient decisions but over the course of many decisions, behaviors will tend towards optimum. (Winterhalder and Kennett 2006). In this instance, optimization may be situational and what is an optimal outcome at one point in time may not be at another.

Strongly grounded in economic theory, HBE uses several key concepts. These include *marginal value*, *opportunity costs*, *discounting*, and *risk-sensitivity* (Winterhalder 1983; Winterhalder and Kennett 2006) as useful explanatory frameworks in decoding decision making tactics. Specifically, this relates to understanding how one makes the decision when to engage in one activity instead of another. These concepts are useful for interpreting both short-term situational events (mostly utilized in ethnographic studies) and long-term trajectories in human decision making related to shifts in entire socioeconomic systems (seldom used but becoming more commonly applied in archaeology, e.g., Prentiss and Chatters [2003]).

Any resource package has a *total value* expressing the overall utility of the package throughout the consumption process (following some total utility function) (Winterhalder 1996). However, the total value is made up of the summed marginal values. The *marginal value* is the return rate of a particular *n*th unit of a resource to a person already holding n-1 units (Rhoads 2002; Winterhalder 1996; Winterhalder and Kennett 2006). The marginal value is directly linked to where that *n*th unit falls on the total utility function as well as what that function looks like (such as a decaying exponential). In a given context where resources are procured, the immediate payoff when quantity is high and presumably the highest quality portions are still available to be consumed, the total utility is near maximum. As quantity (amounts) and quality (less desirable portions) decrease, the total value also decreases. In contrast, the marginal value is proportional to how much of the resource package is divided amongst the consumers. The total utility with differing unit marginal values may be illustrated by the analogy to a pot of stew. The first time that one eats from the pot of stew, its total utility will likely be high. This is because quantity is still high, the best ingredients are still available and the desire to consume it is high (Burger et al. 2005). During the second consumption period the total utility may still be very high but as consumption continues, the marginal value may drop as the best parts are consumed (Burger et al. 2005:1148) assuming that the total utility function is similar to a decaying exponential.

Following Kennett and Winterhalder (2006) and Smith and Winterhalder (1992), we may envision circumstances where the marginal value in relationship to the total utility function may be applicable to a broad range of products from a single to multiple large-bodied prey (e.g., elk or bison), abundant smaller prey (salmon harvest with a variety of sizes and fat contents), to lithic raw material procurement (e.g., further from source may equate to less quantity but also less desirable pieces) (Andrefsky 2008). In all of these circumstances, the total utility will be high during the initial use, and the marginal value will be governed by the shape of the total utility function. For example, if a concave utility function is detected, during the consumption of a resource the marginal value will decrease as less desirable portions or those that will require greater energy to turn into a consumable resource are left behind. Thus, as the marginal value decreases, the decision to participate in some other activity might become increasingly likely, as its payoff (utility) may become relatively greater. In other words, the decision to switch from one activity to another is directed by opportunity costs (Smith and Winterhalder 1992; Winterhalder and Kennett 2006).

Opportunity costs are therefore strongly linked to the concept of marginal value. Opportunity costs consider when an individual chooses to switch from engaging in one enterprise to another. This is related to both the marginal value of the first activity and also the return of engaging in that enterprise when it may be more productive with higher payoffs to participate in another activity (Winterhalder and Kennett 2006:11-12). Thus, a hunter may stop hunting large game if encounter rates favor small game. In another circumstance, a flintknapper may stop utilizing a core when correcting knapping errors is more costly than getting a new cobble and starting over (Brantingham 2003; Goodale et al. 2008b).

Marginal values and opportunity costs are both subject to time discounting. *Discounting* is commonly associated with the discussion of immediate versus delayed food economies that has been thematically central to many models of hunter-gatherers socioeconomic systems (Bettinger 1991; Binford 1980). Discounting can be defined as the modification that the costs being considered undergo before a decision is made. Specifically, discounting refers to anticipated payoff discounted by the anticipated delay. The decision to invest in an activity in anticipation of future payoff is an assessment of risk that weighs the likelihood of success or failure for those investments. For example, a farmer may invest less in a crop that has less tolerance for small climatic variations (such as premature spring frosts) than one having more tolerance. This is due to the greater certainty for success in the later. However, discounting also has a strong relationship with the marginal value of the crops as well with the opportunity cost. If the crop with a greater chance of failure will have a greater payoff (high total value) in the event of success, a trade-off must be negotiated when the opportunity cost becomes so great that the farmer will invest at least some energy in the crop more likely to succeed but with a lower payoff. The articulation of these three variables is at the heart of the application of HBE to the origins of agriculture as the transition from immediate to delayed subsistence economies.

The final important concept in optimality reasoning is risk-sensitive behavior, which incorporates neutral behaviors (those that are stochastic) and the statistical likelihood of encounter rates for some given targeted resource (Brantingham 2003; Winterhalder 1986). The important aspect of risk-sensitive models is that they take into account discount, that is, when there are shortfalls in resources and payoffs from resource capture are not averaged across the landscape. In other words, payoffs may only be specific to a few people and are not averaged out to all individuals (not everyone can capture the targeted resource every time they set out to do so). For example, Kohler and Van West (1996) argue that households will (or will not) share depending on where they are on the production function (i.e. how much they have grown). If they had a large crop they should be risk-avoiding and share. In contrast if they had a small crop they should be risk-seeking and hoard the goods that they have. In general, to be risk sensitive means to modulate one's behavior with respect to the degree of risk depending on one's circumstances.

Risk-sensitive models are predominantly more heuristic, having preference in computer simulated models (Brantingham 2003) and have shown to be difficult to apply to prehistoric foraging patterns such as lithic raw material procurement (Andrefsky 2009). This is not to say that risk-sensitive models examining stochastic patterns in resource procurement are impossible to apply to either living populations or the remains in the archaeological record, instead it appears to be a difficult endeavor (Winterhalder and Kennett 2006).

Optimization and Nutrition

Researchers have only minimally integrated issues of food nutrition in discussions of foraging patterns and optimization. Rather researchers focus predominantly on package size and handling times. Package size and handling times roughly equate to the amount of kilocalories (kcals) a given resource may provide versus the energy it takes to procure and process the resource into a usable end product. However, there are recent suggestions that we should move beyond kcals (Winterhalder and Kennett 2006) and how energy may play into larger social frameworks, as is proposed for example by the concepts of tolerated theft, sharing, show-off, and costly signaling (Blurton-Jones 1991; Hawkes and Bliege Bird 2002; Winterhalder 1996). I would argue that examining the nutrient quality of food (amounts of protein, fat, vitamins, and carbohydrates) in relationship to quantity is another line of evidence that may be a very promising avenue of research going beyond calories. As a result, food nutrient content is one of the focal points in this study.

Specifically, I want to begin to remedy a lack of concentration on the actual nutritional content of the foods that prehistoric peoples were eating. There has been some recognition of food nutritional qualities in nonhuman species' foraging patterns (Altman and Wagner 1978; Belovsky 1978; Rapport 1980; Rapport et al. 1972;

Westoby 1974). Nutritional analysis is a critical aspect of resource targets, and plays a significant role in the general health of a population, just as (if not more) important than package size and kcals. While prehistoric hunter-gatherers did not have labels on their foods depicting the amount of calories, fat content, vitamin content, and percentage of daily requirements for certain nutrients, *would humans be sensitive to changing health conditions* over the long-term? In other words, as diets change due to potentially depleting resource bases (due to over-hunting, climatic shifts, etc.), shifts in food economies may be related to health and targeting resources providing a balanced diet and potentially higher fertility. While research in human diets with regard to nutritional content and optimal decision making is scarce, several studies (Altman and Wagner 1978; Belovsky 1978; Rapport 1980; Westoby 1974) have examined both generalized and specific diets and how these shifts influence reproductive success.

As noted, most HBE research focuses on the economic value of resources. In contrast, examining nutrient content of targeted foods allows us the opportunity to examine the nutritional nature of a diet. In nonhuman species, nutritional content and some food resources are argued to be complementary (Covich 1972; León and Tumpson 1975; Pulliam 1975; Rapport 1980: 324; Pyke et al. 1977; Westoby 1974). For example, Clutton-Brock (1977) found that herbivore Gorillas utilize grubs, obtaining vitamin B_{12}, and other primates balance their diets to obtain adequate amino acids, carbohydrates, and protein. This is referred to as the synergistic effect, or the interaction of two (or more) chemicals together to have a greater influence than would each compound in isolation (Rapport 1980). If other primates are sensitive to this situation, it seems that humans should also be sensitive to nutrient needs, even though in prehistoric times we may or may not have been aware of the specific nutritional contents of the foods that we were eating. One significant problem that nutritional content poses in optimal foraging is how to estimate some values for nutrition, rather than just package size, although it would seem that a quantitative means should easily be attainable for important nutrients to the overall health of an individual. This is not an issue of either package size or nutritional content; rather, these issues conspire to make up the overall benefit of the resource package.

As one example of how living organisms adjust their diet to benefit reproductive success, Rapport (1980) demonstrated how predator *Stentor* ciliate protozoa populations and their fertility are directly impacted by diet preference in relationship to prey type and abundance. In a laboratory setting Rapport et al. (1972) found that when the relative numbers of prey *Euglena* (unicellular protists) to *Tetrahymena* (protozoa) were changed, *Stentor* dietary preferences changed, although not in a one-to-one relationship. When *Euglena* density increased in comparison to *Tetrahymena*, *Stentor* preference for *Euglena* declined, producing a more generalized and equal subsistence strategy. Conversely, when *Tetrahymena* increased in relation to *Euglena, Stentor* preference shifted to favor *Tetrahymena* potentially signaling that *Stentor* preferences distinguished the need for a balanced diet and the nutrients that each resource provides (Rapport 1980:345).

With these results Rapport (1980:340) argued that in both cases of changing prey abundance, preference shifted but complete specialization in consuming one prey item did not emerge. In the case of *Stentor* economic strategies, the consumption and preference of certain prey items is related not only to a trade-off between energy gain but also considers nutrient content. Lastly, *Stentor's* reproductive success was much higher under diets that included more *Tetrahymena* and was decreased when *Euglena* were present in higher numbers proportional to *Tetrahymena*. While this case is much more simplistic that human foraging, it provides direct evidence that organisms will shift their diets to enhance reproductive success based upon what foods are available. The other important parameter here is that *Stentor* strategies for enhancing reproductive success were related to both the quantity and quality of the available prey. This suggests that not only food quantity, but also quality, may have played an important part in the reproductive success of humans in the past. Ultimately, the impacts of changing prey targets may have been correlated to increasing reproductive success.

Natural selection has shaped humans to be behaviorally and cognitively plastic, enabling us to adaptively adjust to changing socioeconomic conditions (Flinn 1996). Under optimality reasoning, it is plausible to suggest that humans would be prone to seeking diets that are balanced, to the extent that these produce the greatest reproductive success. If one resource providing a major portion of the protein contribution to their diet becomes scarce, or if another resource becomes attainable through a technological invention that provides greater reproductive success, we would predict that humans would shift subsistence strategies to rely more heavily on the resource contributing greater reproductive success.

Optimality and the Harvest of Food Resources: A General Model

How does optimal decision making influence human behavior with respect to the resources we procure? More specifically, when will evolution orient humans to switch from intensively utilizing one resource to another? As noted above, researchers traditionally focus on calories and package size; here I frame a discussion to include these components but also broaden it to account for the actual nutritional content of foods.

Natural selection has the consequence of optimizing design features for individual gene propagation (Krebs and Davies 1997). Design features that optimize somatic interests (e.g., access to resources such as food and space) have the potential to be converted into individual reproductive success (Krebs and Davies 1997; Smith and Winterhalder 1992). Where resource access is highly competitive, and variation in strategies to obtain a particular goal exists, selection should favor the strategy that can solve the problem with the least cost in relation to the other strategies present (Foley 1985). The rationale is that organisms have limited energetic budgets. Individuals that solve particular adaptive problems efficiently can divert energetic surpluses into reproductive or other somatic interests (Kaplan et al. 2000). This is not to say that humans (or other organisms) are optimally adapted to their environment;

rather, natural selection tends toward the optimal solution given the range of available phenotypes present in the environment (Foley 1985; Smith and Winterhalder 1992).

Humans are a cognitively and behaviorally plastic organism, suggesting that selection pressures have favored a human phenotype that could adaptively respond to fluctuating social and ecological pressures (Flinn 1996). Additionally, humans are at times aware that returns can diminish as a result of applying specific strategies. This allows individuals to adjust investment accordingly (Kaplan and Lancaster 2000). Thus, humans will generally pursue behavioral strategies (for specific goals) that tend to optimize opportunity costs within specific socio-ecological settings (Smith 2000).

The degree to which optimization is likely to occur is dependent upon the selection pressures surrounding a particular resource (Foley 1985). For resources characterized as having a large impact on fitness (i.e., resources associated with strong selection pressures), individuals can achieve greater fitness returns by selecting strategies that focus attention on the attainment of that resource (Hames 1992; Winterhalder 1983). As a result, optimization of strategies to attain that resource is a likely outcome. Conversely, when a resource has a limited effect on fitness (i.e., resources associated with low selection pressures), selection could tend towards optimization; however, due to the limited energetic budgets of individuals, selection should favor phenotypes that divert their time and energy to the acquisition of other resources with higher fitness outcomes (Foley 1985; Hames 1992; Winterhalder 1983). As a consequence, satisfactory solutions become viable and diversity in strategy sets become tolerated for resources that have limited effect on fitness.

Additionally, pressures for optimization become stronger under competition; in the absence of competition there is little incentive to optimize (Foley 1985). Winterhalder (1983) provides a graphical solution that demonstrates the conditions favoring decisions to invest in an additional unit of time and energy into a focal activity (conditions of limited energy) or to divert these scarce resources into other activities (conditions of limited time).

The idea that the time and energy budget of humans participation in gaining reproductive and somatic interests plays a significant role in regulating the growth of human societies has become a topic of great interest (Belovsky 1988; Boone 2002; Hawkes and O'Connell 1992; Winterhalder et al. 1988). Because human populations rely on food resources for access to reproductive and somatic interests, the nature and access of food resources impact survivorship. Food resources approximate a zero-sum game (when one individual accesses the resource, it represents a loss for other individuals in the population). When the food resource is proportionally present in high densities compared to a hypothetical population or of limited contribution in terms of nutritional value, the depletion of the food resource may seem inconsequential to individuals within the populace. In this case access to this food resource has low fitness consequences as there is little competition. Alternatively, when a food resource exists at proportionally low densities or is an important contribution to nutrition in comparison to a hypothetical population, its depletion is consequential. Such a resource has high fitness consequences as it is likely to be under intense competition for its procurement and consumption.

Optimality reasoning would lead one to conclude that when there is competition for the use of a food resource, strategies for converting the resource into a usable end product (including both harvest and processing) will be constrained, with the likely solution (or solutions) being the most economical given the range of possible solutions in the environment (such as harvest techniques or the actual people who harvest the resource) (Krebs and Davies 1997). A possible outcome is that only a few individuals might specialize in procurement of the food resource, while other individuals consume the little that is available yet it brings high fitness to the individual(s) who procured the resource. If a resource is easily depleted, individuals may better redirect their time and energy into other goals or somatic interests (Winterhalder 1983). The rationale is that not everyone can effectively engage in an economic enterprise where there are constraints on the resource. In this situation we would expect that only certain individuals would have access to the resource package or the choice portions (Krebs and Davies 1997; Stephens and Krebs 1986). Theoretically, in an archaeological setting, the storage of such constrained resources may be private, signaled by underground pits within residential contexts.

Alternatively, foods for which there is little competition, optimality reasoning suggests that strategies for converting the resource into a usable end product will diversify. The rationale is that individuals can minimize opportunity costs by not investing heavily in the procurement and/or processing of the resource, but investing in some other arena where high selection pressures exist (Krebs and Davies 1997). Thus, satisfactory solutions are likely to emerge with the procurement of resource products. Because the cost of accessing and manufacturing the resource is low, many individuals can access and participate in the enterprise with few negative repercussions. As a result, a greater proportion of people may act as both producers and consumers of the consumable product. In the situation where there are a high proportion of both producers and consumers, the access to the useable end product would likely be public with each consumer having nearly equal access. Theoretically, in an archaeological context we may see resource storage in public contexts, such as purposely built structures for storage.

Summary

Human nature is behaviorally and cognitively flexible. Because of this anthropologists have focused on energy budgets in association with food procurement and changing socioeconomic systems. The focus of this chapter was the general notion of how optimality reasoning could be applied to resource acquisition. This is both in terms of the traditional focus of acquisition based on energy budgets, but also including the potential that humans will be sensitive to general nutrition. I have argued that humans will be especially sensitive to both food quantity and quality as they influence fertility; just as simple protozoa. This provides one of the foundational elements that I later argue enabled population growth rates to increase during the NDT.

CHAPTER THREE

DEFINING, DETECTING, AND UNDERSTANDING THE NEOLITHIC DEMOGRAPHIC TRANSITION

The study of people in the past and human behavioral strategies employed at the origin of settled communities, centers on the aggregation of people with economies dependent on certain predictable and abundant resources (Bocquet-Appel 2002; Bocquet-Appel et al. 2008; Kohler et al. 2008; Livi-Bacci 1992). The recently developed concept of the Neolithic demographic transition (NDT) provides new insights into the origins of settled communities as the main focus is on detecting population growth (Bocquet-Appel 2002). Bocquet-Appel (2002) following Livi-Bacci (1992) defines the NDT as a detectable and quantifiable increase in human population numbers which occurred in several regions of the world at different times in our past (Bocquet-Appel 2002). It is thought that the NDT is directly linked to the origins of food production, or more generally, resource intensification (Bocquet-Appel 2002).

The broad aim of this chapter is to provide the link between the origins of settled communities, population growth, and the origins of agriculture. To accomplish this task I intend to review the definition of a *demographic transition* and how it is linked with paleodemographic transitions, discuss and critique attempts to utilize archaeological data to assess the NDT, and propose datasets that may lend additional and significant information to monitoring and tracking population growth through the NDT. The examination of these issues provides a foundation for a greater understanding of the prehistoric demographic transition in the Near East southern Levant.

Defining the Neolithic Demographic Transition

Livi-Bacci (1992) was the first to formally express that the Neolithic represented a critical demographic shift in tandem with the transition to food production. He linked demographic growth during the Early Upper Paleolithic expansion out of Africa and the Neolithic advance of agriculture throughout Europe (Simoni et al. 2000). Subsequently, the term has broadened to encompass the phenomenon of human population increase upon the advent of intensified food production in several regions of the world including the American Southwest (Bocquet-Appel et al. 2008; Kohler et al. 2008), North America in general (Bocquet-Appel and Naji 2006), the Near East (Guerrero et al. 2008), and Europe (Bocquet-Appel 2002). As the geographic and temporal perimeters of the NDT have expanded, so has its definition. In turn, the detection and understanding of this significant transition in human history has become more complex.

Demographic Transition Theory and the NDT

Although predominantly focused on population shifts in modern communities, demographic transition models in sociology offer a foundation for understanding the NDT. Demographic Transition Theory (DTT) incorporates health and fertility as the major components of significant changes in demography (Kirk 1996). The Modern

Demographic Transition is defined as a shift in population that doubles life expectancy and halves the number of births of each woman (Chamberlain 2006:23; Kirk 1996). Increase in life expectancy is predominantly due to the introduction of modern medicine and fewer births a primary result of increased use of effective birth control (Potts 1997). DTT has also been utilized to investigate differences in fertility rates in several modern and historic contexts of increasing and decreasing population. This includes differences in fertility between less and more developed countries (El-Ghannam 2005; Potts 1997); families with differing socioeconomic standing (Potts 1997); those with different levels of education (El-Ghannam 2005); communities with dissimilar governments (Potts 1997); societies before and after industrialization (Hall 1972); and societies that do not have regular access to contraceptives (Potts 1997).

Unfortunately, the definition used to describe modern demographic transitions is not suitable for defining the NDT. Average life expectancy did not double during the transition to agriculture (Eshed et al. 2004), and population would not have grown as it did if women were having half the number of children. In fact, the authors demonstrate that the transition to agriculture in the Near East may actually be characterized by a decrease in life expectancy in the age of women from 32 pre-NDT, to 30 years of age during the NDT (Eshed et al. 2004:325). They suggest that this decrease in life expectancy may be due to an increase in deaths during child birth as a consequence of having more children (Eshed et al. 2004).

This indicates that although there may not be a universal character of demographic transitions, DTT poses a number of potential factors that affect human population in prehistoric times. In the Modern Demographic Transition, societies go from having high birth rates and high death rates to having low birth rates and low death rates, but population increases rapidly nevertheless because death rates decline first. In the NDT the significant demographic shifts share similarities in population increase but in this case birth rates increase first and then later death rates increase. In either case, there is a common result due to the almost opposite causes of increase and decrease of birth and death but they happen in different orders.

Universal characteristics of the NDT

Bocquet-Appel et al. (2008) argues that the NDT is a multi-phase process. Although disparate in region and time, the NDT is similar in each region highlighted by an initial increase in fertility with a later deterioration of health with associated increased death rates (Bocquet-Appel 2002; Bocquet-Appel et al. 2008). Why did fertility dramatically increase at the beginning of the transition to agriculture? This simple question, while largely unexplored, represents the core of active debate.

At the most basic level, a handful of factors in concert with one another universally drive population growth and decline. For instance, Chamberlain (2006:23) argues any demographic transition is usually considered to be both extensive (in time and space) as well as consistent (in numbers). Demographic transitions must occur over long periods of (defined) time and space and show measurable change (increase or decrease) in population numbers. In addition, at the center of demographic change are both intrinsic (births and deaths) and extrinsic (migration) factors (Chamberlain 2006:19-20). Thus, all demographic transitions are driven by some combination of death, birth and/or migration.

Health and fertility are major factors in demographic change. Based upon data from the American Southwest, North America in general, the Near East and Europe, Bocquet-Appel and colleagues (Bocquet-Appel 2002; Bocquet-Appel et al. 2008 Bocquet-Appel and Naji 2006; Guerrero et al. 2009; Kohler et al. 2008; Kuijt 2008a) have defined the NDT as being characterized by two phases. In the first phase there is a dramatic increase in fertility and thus in population size since death rates are approximately constant, whereas in the second phase, there is an increase in mortality due to increased disease parasitic infection (Bocquet-Appel 2002; Bocquet-Appel et al. 2008). This model not only suggests that health and fertility were factors in the NDT, but indicates the archaeological data in these regions (and in every other NDT) can be defined by a time sequence where first came an increase in fertility and second a decrease in health with increasing death rates.

The NDT as a two-phase phenomenon is demonstrated by Bocquet-Appel and colleagues to be evident in several regions of the world; however, its accuracy has not been explored in its entirety in the Near East. This is because the data is available to test increases in fertility, but not the second phase of deteriorations in health (Guerrero et al. 2009). In addition, although suggesting increased fertility as the primary motivator for population growth, Bocquet-Appel (2002:647) provides an explanation that there may be some link between the increasing intake of better quality foods and rising population as well as increased sedentism allowing decreased inter-birth spacing.

Quantifying Paleodemographic Change

Bocquet-Appel (2002:637) defines the NDT as a "substantial increase in human numbers." While accurate, this definition is limited in that it does not incorporate enough detail for detecting the NDT in the archaeological record. It is important that the NDT be defined more broadly to include the processes by which populations increase, in turn, providing the quantitative assessment of past demographic transitions.

It is essential to expand on the processes that occur within a demographic transition. In turn, this will allow a quantifiable measure of detecting demographic change in the archaeological record. To accomplish this, researchers need to be able to utilize the most basic factors witnessed universally in demographic change that are also variables commonly reported in the archaeological literature. These include factors of time measurement, differential use of space, and the scale of archaeological remains that people leave behind. These variables modeled over long periods may aid in our understanding of changes in population growth rates.

Here, I propose a definition for a demographic transition as *any significant departure in population growth rates over a defined period of time brought about through changes in birth, death, or migration.* In this way, measures can be made regarding differences in population growth or decline between two defined time periods. Theoretically, if we are able to accurately estimate temporally-defined population sizes in a region based on archaeological evidence, we may contribute further understanding of prehistoric paleodemographic transitions.

Detecting the NDT: Archaeological Attempts and Viable Data

Bocquet-Appel (2002:637) argues that a Neolithic demographic transition may be inferred from three lines of evidence: 1) genetic markers of migration (Ammerman and Cavalli-Sforza 1984), 2) paleoanthropological markers in cemeteries (Bocquet-Appel 2002), and 3) interpretive models based on examining the densities of archaeological sites through time (similar to Hassan 1981 and references therein), each of which is discussed in detail below. All of these models have been used to some extent to suggest a demographic transition associated with the origins of food production. However, to date there has been very little use of population estimates based on multiple variables from archaeological assemblages to specifically detect a large-scale NDT.

Genetic Markers and Migration

Until recently, the most frequently used technique to detect an NDT is through genetic markers of migration and expansion of the spread of food production from the Near East to Europe (Ammerman and Cavalli-Sforza 1971, 1984; Cavalli-Sforza and Cavalli-Sforza 1995; Simoni et al. 2000). Ammerman and Cavalli-Sforza developed a demic diffusion model focused on detecting genetic clines generated by a wave of advance (estimated through the geographic placement of radiocarbon dates) where farmers outcompeted foragers through population growth and territorial expansion. This model views population growth reaching carrying capacity at some defined point in time after the initial diffusion of the technology/idea (for instance the spread of domesticated plants and the techniques to efficiently use them). Population growth rate reaches equilibrium and then returns to zero, as specified by the logistic growth curve. Bocquet-Appel (2002:638), following Fix (1996), argues the model is weak because there is an ambiguous interpretation in that "The demographic signal itself - the change representing the transition - is not…directly observable in the data presentation" (Bocquet-Appel 2002:638). In other words, a substantial increase in human numbers is not directly evident in the in the archaeological record.

Paleoanthropological Markers in Cemetery Data

The second component of research supporting a world-wide NDT is age estimates based on osteological data that indicate an increase in the number of individuals between the ages of 5-19 in relationship to the entire population (Bocquet-Appel 2002; Bocquet-Appel and Naji 2006; Bocquet-Appel et al. 2008; Guerrero et al. 2009; Kohler et al. 2008). These studies utilize cemetery data and loess fitting statistical procedures to recognize the NDT in Europe, the Near East and in North America.

The logic behind Bocquet-Appel and colleagues reasoning for examining the 5-19 age bracket follows that the youngest age individuals (those under the age of 5) are usually over-represented in archaeological assemblages because of their susceptibility to mortality. These remains are also the least likely to be presearved in many instances. Measuring the number of individuals from the ages of 5-19 should show larger numbers in growing populations (both in the living population, and as sampled by death from it) relative to the entire population 5 years of age or older. We would expect the opposite in stable or declining populations. Their model is interesting in that they are able to detect both the timing and the rate of an NDT in multiple regions and have suggested universal characteristics of the worldwide NDT. While universal, the NDT occurs more slowly in centers of independent invention than in areas where it spread due to the movement of people or exchange of ideas (Guerrero et al. 2009; Kuijt 2009).

Methodological Means to Detect the NDT

There are several critical aspects to the analyses Bocquet-Appel and colleagues (2002; Bocquet-Appel and Naji 2006; Bocquet-Appel et al. 2008) conduct focusing on the results obtained through the loess smoothing procedure (see below) as well as how to apply the results in terms of our understanding of the long process of the transition to agriculture.

Originally developed by Cleveland (1979), LOWESS or more commonly referred to as loess fitting, is a nonparametric regression technique commonly used by political strategists examining voter patterns in relationship to amount of education, race, economic standing and so forth (Cleveland et al. 1993; Jacoby 2000). The strengths of loess are that it provides an easily interpreted graphical summary of the underlying structure within a dataset (usually depicted as a scatter plot with a line drawn as a goodness of fit in the overall trends of the data). The technique is also relatively robust against extreme outliers unlike least squares regression, its parametric counterpart.

Nevertheless, there are potential problems with the loess procedure that are inherent in its implementation. As a *non-model-based* method, there is no strict definition of *goodness of fit* and therefore requires the analyst to make several arbitrary decisions about the fitting parameters and what line is a best fit for representing the major structure within the data (Jacoby 2000:608) (although Cleveland and Grosse have outlined procedures to get statistical verification of the best fit line, it has only been utilized in Kohler et al. 2008). Instead, in most instances goodness of fit is determined through *eyeballing* by the analyst until the trends are close to what is expected. In this instance, eyeballing refers to the analyst, rather than a statistical software package to make the final decision of what is the best fit is (this is not true for Kohler et al. 2008 following Cleveland and Grosse 1991). Second, as demonstrated by Kohler et al. (2008), loess fitting should always be used in tandem with parametric fitting procedures or ones where statistical verification can be achieved as to the best fit line (also noted by Jacoby 2000:608).

The loess method can be thought of as a sliding window, and the size of the window predicates how much of the data is analyzed at a time and therefore how the best fit line is drawn. The data are scaled in some format such as years before present. The actual loess fitting procedure is contingent on three main parameters. The first is α, which controls the size of the window as it slides from left to right over the data. The function of the window is to set a limit of how much data are incorporated into drawing the best fit line at each shift. In all of Bocquet-Appel's analyses, the α values are consistently provided and range from α = .3 - .6. The second parameter important in loess fitting is λ, which relates to the type of polynomial whether 1^{st}, 2^{nd}, 3^{rd} etc. order that is being fitted to the structure of the data, a parameter not specified in Bocquet-Appel's analyses. Finally, the weighting algorithm specifies how the data are weighted with respect to the sample size of each data point and can often include where the data point is in relationship to the center of the window. The specific weighting algorithm used (or if one was used) in Bocquet-Appel's analysis is also absent from his writings although it is provided by Kohler et al. (2008).

We can illustrate potential problems of this method by conducting an analysis of the data presented in Bocquet-Appel (2002: Table 1). The data represents skeletal populations from Mesolithic and Neolithic cemeteries from across Europe. In Figures 3.1-3.2, the loess fitting procedure is run with a series of α values from .1-.9 and λ values of 1 and 2 with a tricube weighting algorithm (to weight sample size). One can readily see that as the α value increases the less detailed the best fit line is drawn, or in other words, the line becomes smoother. Examining λ values of 1 and 2, we can see that the lines do not appear visually distinct (Figures 3.1 and 3.2). It should be mentioned that I could never exactly duplicate the line drawn by Bocquet-Appel

(2002), likely because the weighting method that I used differed from Bocquet-Appel's (because the method he used is not mentioned).

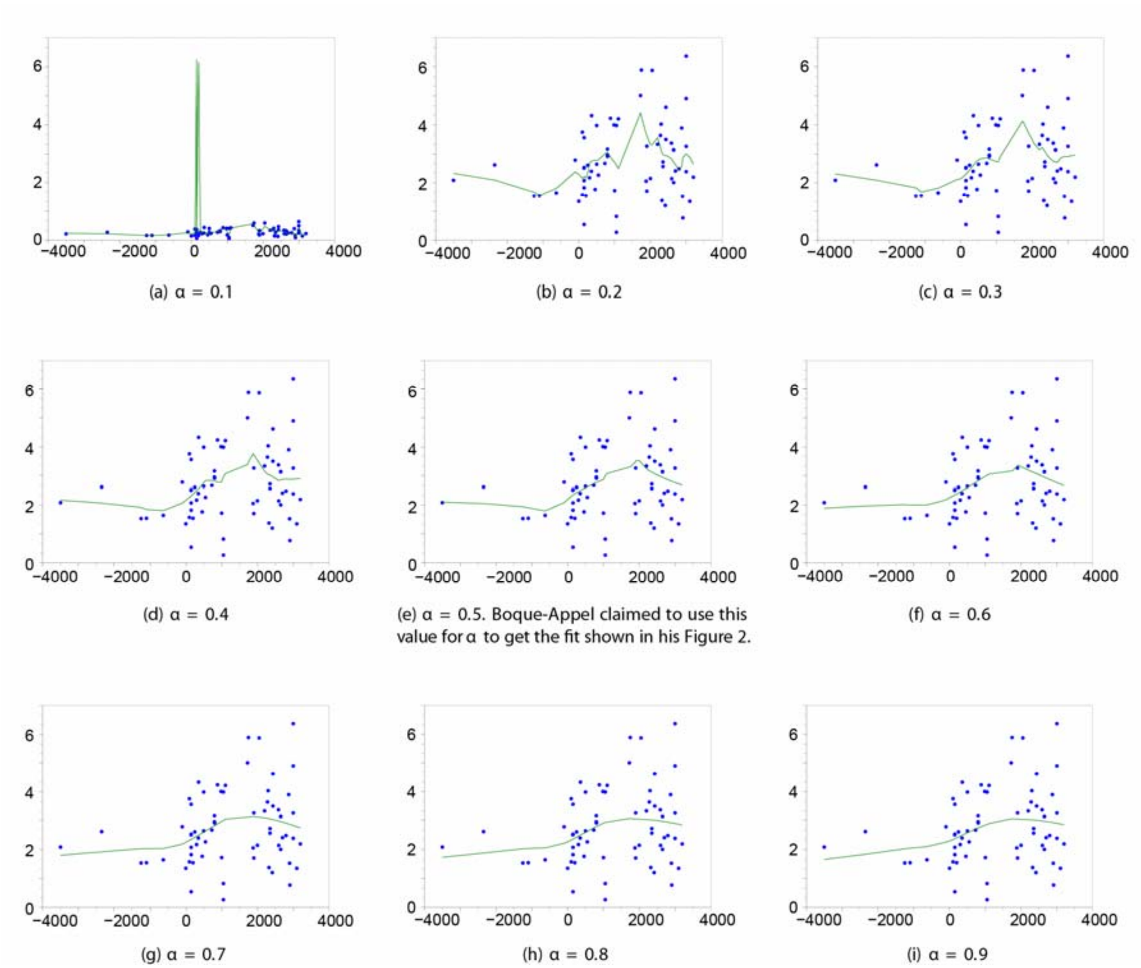

Figure 3.1. Loess fits to the data, with λ = 1. The α parameter is indicated by the individual captions. Data from Bocquet-Appel 2002:640-641, Table 1.

Other questions arise on close examination of the methods used with paleoanthropological data from cemeteries with regard to relating the data to some aspect of temporal reality. The definition of *dt*=0 (supposedly, *dt* = is the temporal point of the demographic transition) as the local introduction of agriculture (Bocquet-Appel 2002) seems overly simplistic as well as problematic. For example, in the case of independent invention of agriculture in the Near East, one must ask if *dt*= 0 is when people started cultivating plants, storing plants, or when the foods had evolved into their fully domestic form? In the Near East, this was a very long process; on the order of several thousand years. It is not clear, then, how *dt* = 0 is determined since it is not clearly defined in any of the publications utilizing this method (Bocquet-Appel 2002; Bocquet-Appel and Naji 2006; Guerrero 2008).

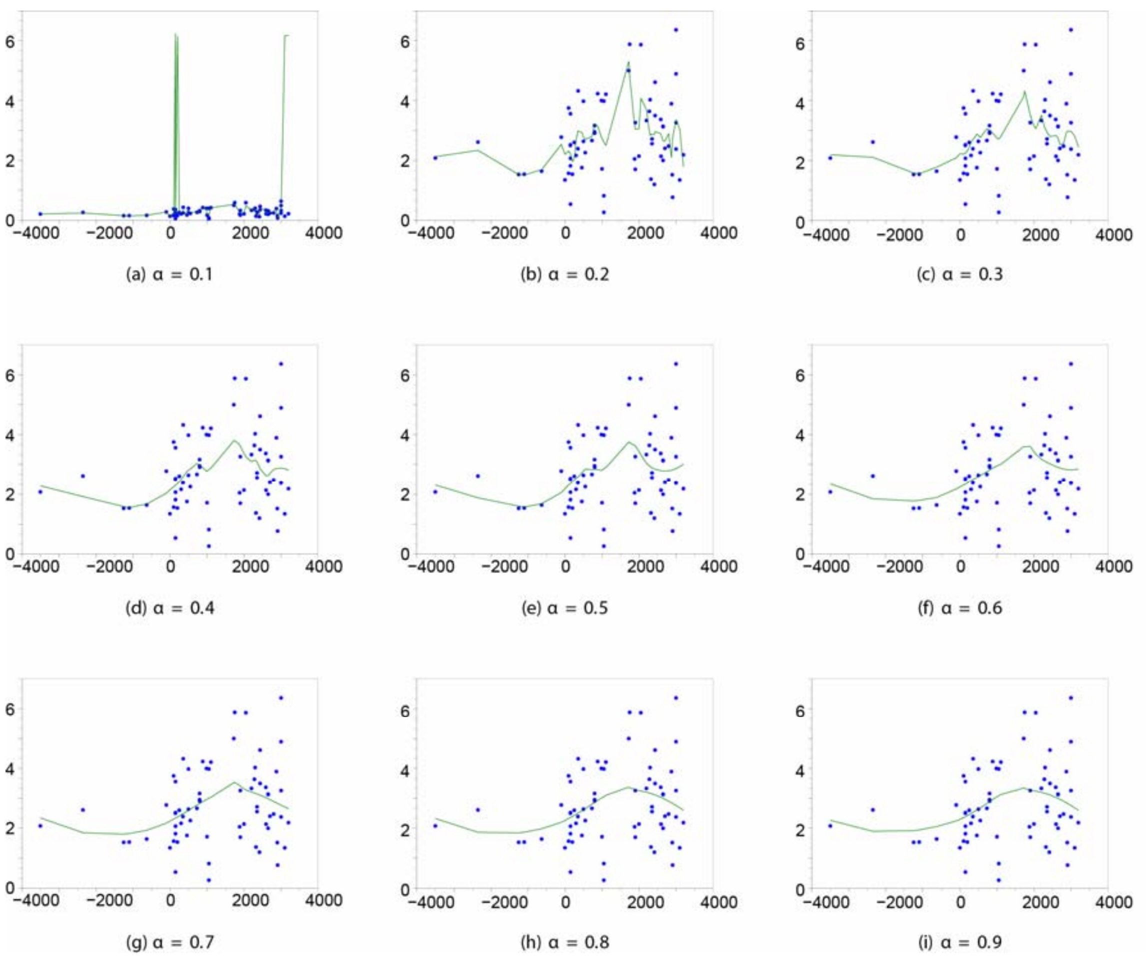

Figure 3.2. Loess fits to the data, with λ = 2. The α parameter is indicated by the individual captions. Data from Bocquet-Appel 2002:640-641, Table 1.

Lastly, in relationship to other facets of archaeology discussed below, in most of the analyses presented by Bocquet-Appel and his colleagues, the data points representing hunter-gatherer cemeteries are extremely few in number, and small in sample size, since hunter-gatherer cemeteries are very rare. Could this cause problems with the way in which the best fit line is drawn pre-*dt = 0* in relationship to post-*dt* = 0? We can investigate this by simulating random data and applying the loess procedure to them. In Figures 3.3 and 3.4, when there are equal amounts of data on each side of *dt*=0, variation in the data is lost by $\alpha = .5$. This demonstrates that α values less than .5 may be subject to random variations in the data. This is interesting because most of the α values used by Bocquet-Appel and colleagues are between .3 and .6 suggesting that these are probably well fit lines that are not subject to random variations in the data but reflective of overall patterns within the data.

I also make this point because, in several of the analyses presented thus far, some proportions of ${}_5P_{15}$ (the number of individuals between 5 and 19) samples of hunter-gather datasets are on a par with those of agricultural populations (for example Bocquet-Appel and Naji 2006: Figure 3 and Guerrero et al. 2008: Figure 2), making it likely that as more data is utilized, the line may be drawn significantly different.

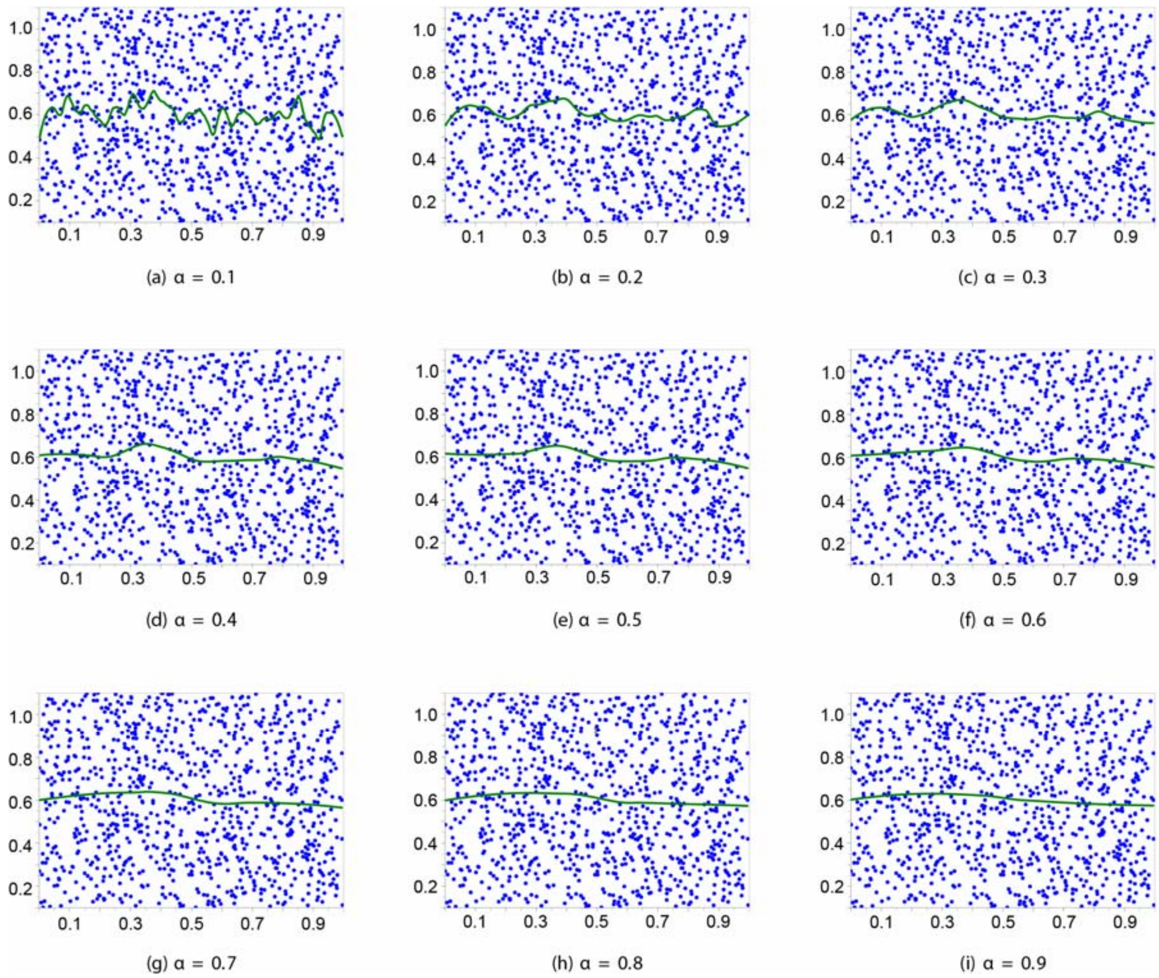

Figure 3.3. Loess fits to randomly generated data, with $\lambda = 1$. The α parameter is indicated by the individual captions. Note how the best fit line behaves the smaller the window size and the size of the dataset dramatically influences how the line is drawn.

While I have these critiques, I do not suggest that these analyses are ultimately futile, but an important aspect to a greater understanding of the NDT. Instead, what I suggest is that these potential issues open the door for the need to employ new and different techniques as well as different data to examine the timing, rate, and characteristics of the NDT.

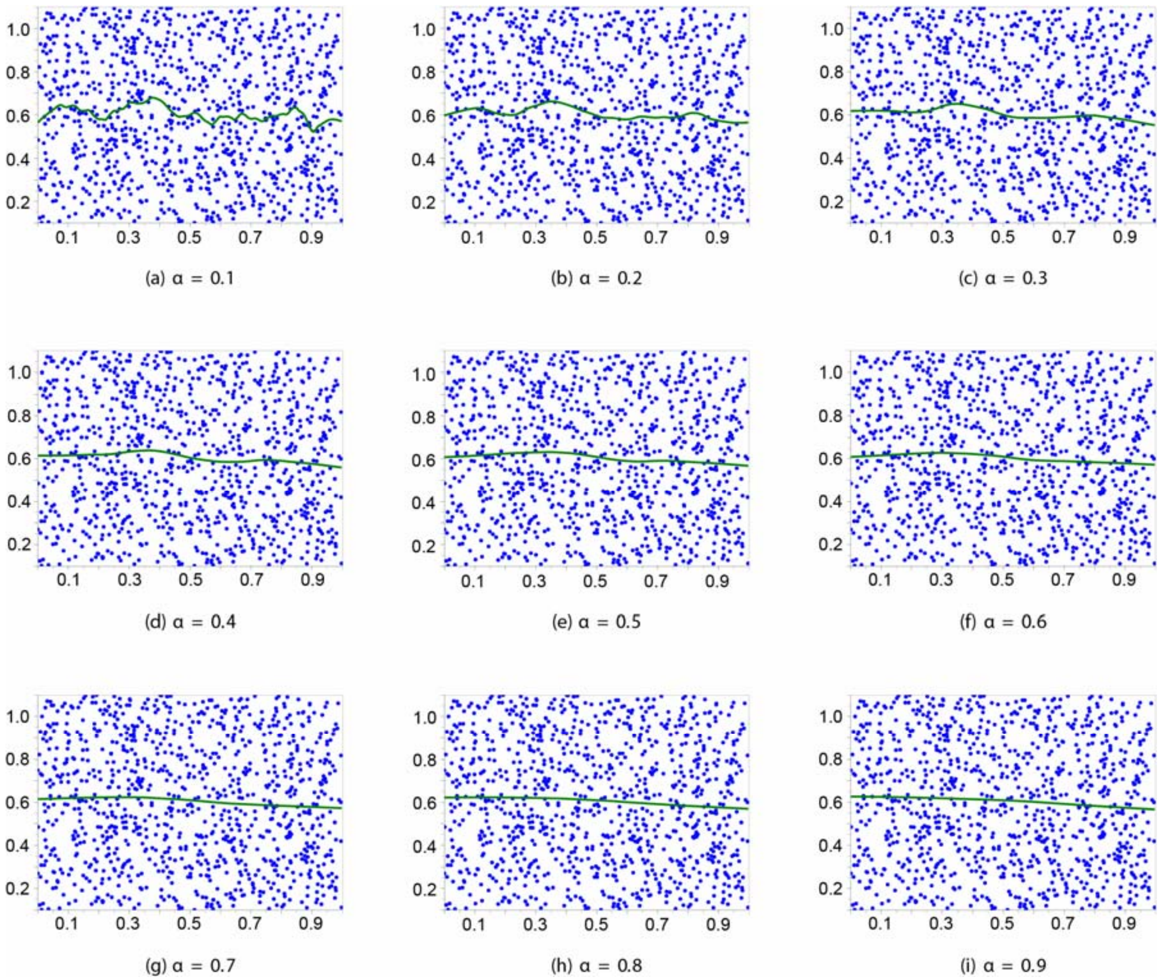

Figure 3.4. Loess fits to randomly generated data, with $\lambda = 2$. The α parameter is indicated by the individual captions. Note how the best fit line behaves the smaller the window size and the size of the dataset dramatically influences how the line is drawn and the line is less curved with smaller window sizes than when $\lambda = 1$.

Viability of Human Osteological Data

While both genetic markers of migration and demographic inquiry into cemetery data have provided significant information relevant to understanding the NDT in several regions of the world, all are limited by the following: 1) in many areas of the world cemeteries are not common and/or human skeletons are rare; 2) the sensitive nature of human skeletal material makes access to these data difficult, if not impossible to obtain in North America by the Native American Graves and Repatriation Act (enacted into federal US law in 1990); and 3) the expertise and precision to conduct the osteological analysis needed requires a highly trained specialist.

Although our sociopolitical climate is partly to blame for some of these issues of availability of human osteological data – rather than any fault on the part of Bocquet-Appel and his colleagues – the lack of standardization and restricted availability of these data limits the replicability of their approach. In addition, due to the paucity of data for both hunter-gatherers and farmers throughout the demographic transition in many of their case studies, I remain skeptical of the actual signals in several instances, ultimately drawing some questions regarding the methodological techniques and the amount of data available to detect the patterns of the NDT.

In light of these issues, I suggest that other techniques and datasets for detecting the NDT be explored to supplement patterns found using paleoanthropological data from cemeteries. I do not mean to suggest that these studies I have just reviewed are unimportant, rather I seek to strengthen and extend them by developing additional data sources that should, if the NDT model is correct, yield complementary results.

Population Proxy Models

Models built with extensive archaeological data including the frequency of sites occupied, the number of radiocarbon dates, the depth of deposits, or site sizes all encompass the third data set which Bocquet-Appel (2002:637) suggests may lend information to detecting an NDT. This entails utilizing several variables that are signatures of population size (a detailed review can be found in Hassan 1981). While this approach has been suggested as viable, it has not been thoroughly tested for the NDT. In this study I will present research indicating that construction of population growth rate models based on attainable archaeological data is an effective method of investigating and modeling the NDT.

There have been a number of methods proposed to determine human population sizes utilizing archaeological assemblages (for detailed reviews see Chamberlain 2006; Hassan 1981). It is not the goal here to cover all of the means by which archaeologists have attempted to reconstruct past population densities as well as population growth rates. A quick summary would include the use of ecological modeling (Nickles and Sappington 1999), artifact densities (Turner and Lofgren 1966), estimated population totals for ceramics (Kohler 1978), annual dietary intake indicated through remains (Clark 1954; Evans and Renfrew 1968), number and size of dwellings (Hayden 1997; Hill 1966), community size (Adams 1965; Kramer 1978), depth of deposited materials (Ammerman 1975; Ammerman et al. 1976), and radiocarbon date frequencies (Bocquet-Appel and Demars 2000; Goodale et al. 2004, 2008a; Housley et al. 1997; Pettitt 1999; Rick 1987; Surovell and Brantingham 2007;

Surovell et al. 2005). This study is focused on utilizing frequency data (apart from calculating proportions of human remains in various age categories as reviewed above) to establish long-term population trends in the distant past during the transition to agriculture. The means in which we can do this are covered in detail in Chapter Six.

Summary

The literature concerning the assessment of past population growth rates has increased substantially in the past two decades (Bocquet-Appel 2008) with special attention given to inferring fertility rates across the transition to agriculture in many regions of the world (Bocquet-Appel et al. 2008; Boone 2002). The link between fertility and the NDT appears at first to be fairly obvious: if there is greater fertility, there is a greater chance at producing more offspring which in turn increased population. As with many things in life, what initially appears to be a simple solution turns out to be much more complicated.

Boone (2002) argues that much of human history is characterized by periods of large-scale population decline mimicking near zero population growth. In contrast to the form of argument used by Bocquet-Appel (2002), Boone (2002:8) asserts that:

> "broad changes in population growth rates across subsistence modes in prehistory are probably best explained in terms of changes in mortality due to the dampening or buffering of crashes rather than significant increases in fertility."

However, I believe that the analysis presented later supports Bocquet-Appel's claim that the NDT did ni fact represent a substantial increase in the number of humans.

In reference to the NDT, the distinction depends on whether fertility significantly increased during the early part of the transition to agriculture, or whether mortality substantially decreased.

Recent research regarding the demography of human societies transitioning into settled life and resource intensification (Bocquet-Appel 2002, Bocquet-Appel et al. 2008; Bocquet-Appel and Naji 2006) has provided more in-depth analysis of long-term population trends. Even so, in archaeology actual estimates of population growth rates over such long-term trajectories during this significant transition in human history are infrequently addressed. The majority of archaeological studies that address these trends have been qualitative (Cohen 1977b; Cohen et al. 1980) with rare exceptions of quantification (Bocquet-Appel et al. 2008; Hassan 1981). But cases that attempted to quantify population growth rates during the transition are problematic because they do not represent temporally or spatially extensive population densities and focus rather on site level population estimates over a short period of time (see examples in Hassan 1981). Bocquet-Appel and colleagues have contributed toward this goal with the analysis of human remains throughout the NDT. In this study I seek to contribute toward this goal by analyzing other variables that should be proxies for human population.

Building upon this, researchers need to reframe debate on the NDT, in order to gain a deeper understanding of the timing, rate and characteristics of the transition.

Defining a demographic transition in suitable terms for investigation in the prehistoric archaeological record requires a foundation for empirical investigation of the NDT and deciphering the casual structure behind its occurrence. Utilizing readily available archaeological assemblages to build population growth rate models provides the capability of assessing prehistoric demographic change associated with the NDT in many regions of the world. It is important that we corroborate the NDT model proposed by Bocquet-Appel and colleagues with other variables to test for its universality (Bocquet-Appel and Naji 2006).

CHAPTER FOUR

FERTILITY AND POPULATION GROWTH: CONVERGENCE AND THE FOUNDATION OF THE NDT

One could argue that aside from genetics, the factors resting at the crux of health are nutrition and exercise. These components are cited in nearly every health magazine and book at the counters of most major supermarkets. Inherently, it seems that fertility should in some way be linked to health but exactly how is up for debate. In this chapter I outline several concepts associated with not only detecting a NDT in the Near East, but also providing significant correlates for the NDT that may help us explain why fertility increased as well as how to resolve the apparent conflict between the evolutionary requirement of minimizing energy expenditure and the bearing and raising of more children that seem to be implied by the NDT.

In order to explain both these parameters, it is necessary to examine the archaeological correlates that may be signaling why population grew. This includes the development of storage techniques that allowed wild foods to be stored for longer than just the harvest season. Importantly, these foods are correlated with high fertility, and long-term and consistent access to them could have increased total fertility rates. Moreover, I will argue that the social impetus for investing in more children which produced the "substantial increase in human numbers" (Bocquet-Appel 2002), was the shifting roles of a younger aged people to the labor force, ultimately providing the ability to feed larger families.

As defined in Chapter Three, a demographic transition is *any significant departure in population growth rates over a defined period of time brought about through changes in birth, death, or migration.* Modern demographic transition theory indicates fertility and health are important factors in demographic change. As noted, Bocquet-Appel proposes a two-phase aspect to the NDT that includes first, a dramatic increase in fertility and second, an increase in mortality due to a decrease in health (Bocquet-Appel 2002; Bocquet-Appel et al. 2008). However, a detailed discussion regarding why fertility increased at the beginning of the NDT has yet to be accomplished.

The purpose of this chapter is two-fold: to discuss the influence of subsistence on health and fertility and their influence in turn on birth, longevity, death and ultimately demographic change; and how considerations of optimality, economics, and child-rearing strategies may have favored the investment in more children. I focus on both current explanatory models and new data in the modern science of fertility that strongly correlate with the patterns we see in the NDT. I suggest that storage technology was significant not only in the organization of communities but also as a major contributor to the increase in fertility in concert with accessible foods at the start of the NDT.

The Convergence Model

This chapter presents what I believe to be important components of the convergence model that can provide insight to why fertility increased when it did, and not before. The fundamental elements for this explanation are the availability of foods associated with increased fertility and the presence of behaviorally and cognitively modern humans who interacted with those foods. Moreover, there is a series of technological inventions that result from human action that increased efficiency of harvesting and processing those resources. Two other components of behavior allowing fertility to increase included sedentism which provides certain advantages that are associated with fertility and decreased birth-spacing, as well as the development of storage technology.

My general argument here is that all of the hallmarks of what we consider the transition to agriculture are in place before major changes occurred in the socioeconomic system. What is unique is the later demonstration that until all of these hallmarks were in place, population growth rates remained low, essentially mimicking zero-growth. It is only when the convergence of these factors occurred that we begin to see population growth rates increase substantially.

As fertility increased there had to be some behavioral reorganization which underwrote the cost of having larger families, thereby allowing population to increase (Kramer and Boone 2002). This underwriting was most likely accomplished through incorporating younger, non-dependent offspring into the labor force – a phenomenon to which the ethnographic literature attests.

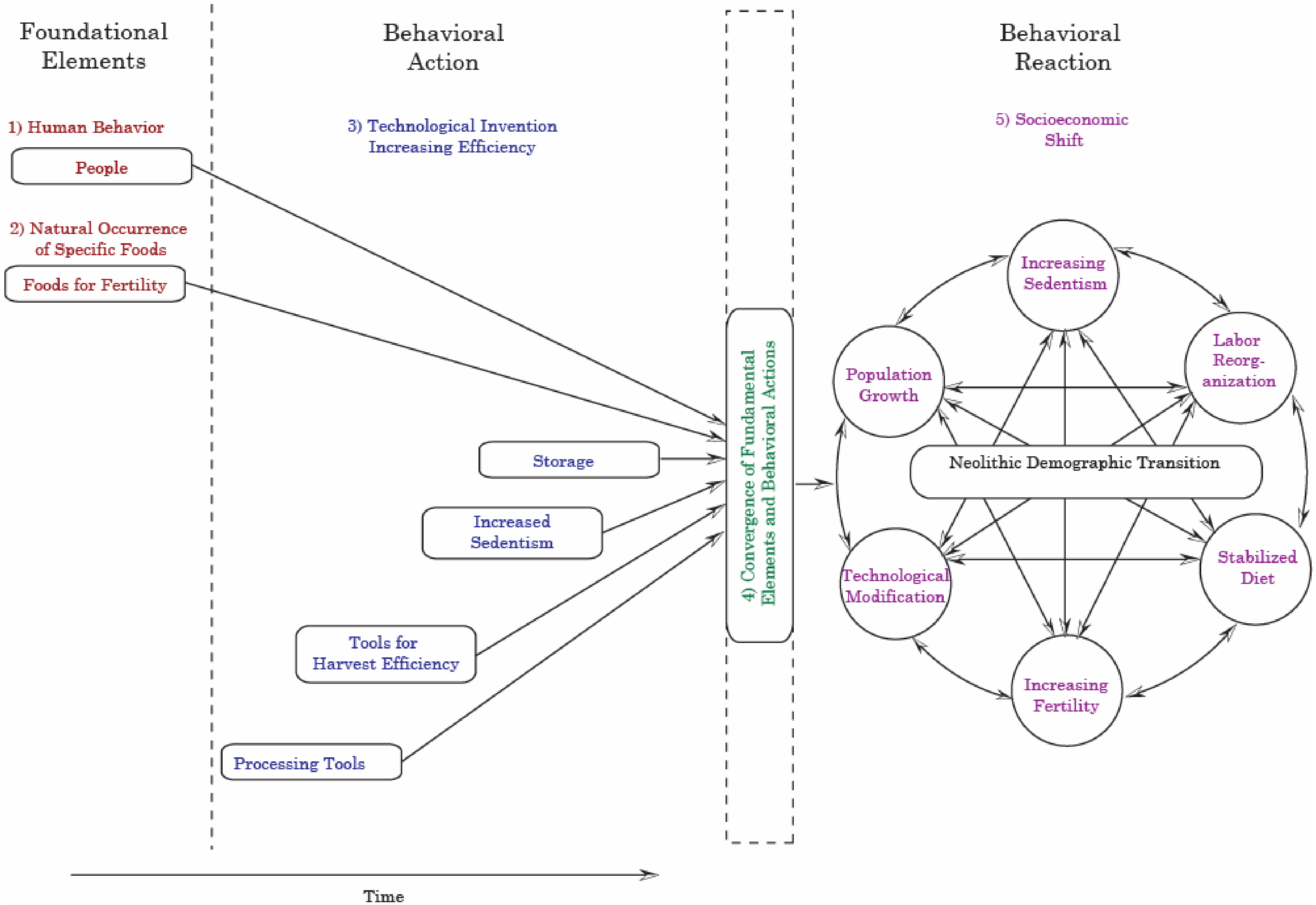

Figure 4.1. A theoretical model of natural occurrences, and behavioral actions converging to cause the NDT and the subsequent behavioral reactions and changes in socioeconomic systems.

Finally, after the foundation was in place, we see the consequences of all those elements through a series of behavioral reactions to increasing population. These reactions include modifications to storage technology in order to feed more people, increased sedentism with architectural modifications to house more people, increased fertility with the addition of more resource bases associated with increased fertility and an increasingly stabilized diet. The significance of each of these components are described in detail here as is their intricate association with 1) increased fertility and 2) why their convergence may have increased population growth rates causing the NDT.

Subsistence Mode and Total Fertility Rates

Identifying the NDT as occurring in tandem with increasing subsistence intensification and the transition from foraging to farming, in itself, suggests that this change had at least something to do with subsistence. Subsistence intensification is defined as a process of change in socioeconomic systems where there is an increase in the return relative to land area or labor input (Morrison 1994; Prentiss et al. 2006:58). There has been a significant debate as to how the mode of subsistence (or subsistence intensification) correlates with demographic patterns motivated by fertility and health (Bentley et al. 1993 a, b; Campbell and Wood 1988; Hewlett 1991; Sellen and Mace 1997). Specifically the debate centers on whether agriculture does or does not increase the total fertility rate (TFR or the mean number of children born to a woman over her lifetime assuming normal age-specific fertility and survival from birth to menopause) of a population (Bentley et al. 1993b; Sellen and Mace 1997). Campbell and Wood (1988) argued that technological developments or subsistence intensification will ordinarily increase mortality rather than fertility. However, due to errors in Campbell and Wood's (1988) dataset related to transcription as well as potential problems with categorizing a socioeconomic system as agricultural, horticultural or foraging, Bentley et al. (1993a) used a revised data set and found that people within agricultural systems have significantly higher TFR than societies relying on horticultural and forager systems.

Using ethnographic data on TFR and subsistence modes from 56 cultures around the world, Sellen and Mace (1997:884) provide a number of interesting conclusions regarding how people integrate different subsistence modes, and they also show how subsistence mode correlates with TFR. First, among these cultures, hunting and gathering subsistence strategies correlate positively, indicating that they are practiced together. However, there is no correlation between hunting and gathering and increased TFR. Second, among the sampled cultures, hunting and agriculture negatively correlate suggesting that these modes "substituted for each other across cultures" (Sellen and Mace 1997:884). Third, the addition of and increased reliance on domesticated animals decreased the need for all other modes of subsistence (hunting, gathering, and agriculture). Fourth, dependence on agriculture was the only variable positively correlated with increased TFR. This suggests that dependence on agriculture is possibly linked to the Neolithic demographic transition, though caution is necessary in moving from a cross-sectional correlation study to one that attempts to cope with the time-dynamics present in the archaeological record.

Health and Nutrition

Associated with both fertility (birth) and longevity (death), health is a frequent topic associated with the transition to food production (Bocquet-Appel et al. 2008; Cohen 1977b; Cohen and Armelagos 1984; Hassan 1981; Hassan and Sengal 1973). Often discussed in a negative manner, the discussion of health during the NDT usually centers on decreased health due to increased carbohydrate intake (Cohen 1977b; Cohen and Armelagos 1984; Starling and Stock 2007; Steckel et al. 2002; Yesner 1980; Yudkin 1969). But it has never been entirely clear why a marked decrease in health would be linked to a significant increase in population.

Investigating Health

Building upon the idea of a two-phase aspect to the NDT discussed in Chapter Three, Bocquet-Appel et al. (2008) have provided a detailed model of health change during the second phase of the transition in the American Southwest. Within this discussion they examine the proportions of caries (tooth decay), porotic hyperostosis (osteoporosis), cribra orbitalia (pores in bone indicative of anemia), and sexual dimorphism found in human remains spanning the transition (Figure 4.2). Interestingly, the results indicate that porotic hyperostosis and cribra orbitalia, both results of heightened red blood cell counts coinciding with chronic iron-deficiency anemia, occur very late in the transition to agriculture (see also Roosevelt 1984:572). In light of this observation, the question becomes, why do these health risks occur so late in the sequence?

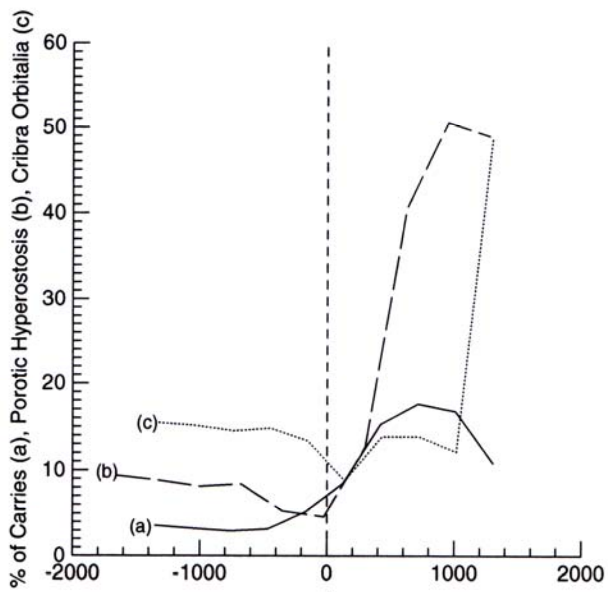

Figure 4.2. Signatures of health in relationship to the transition of agriculture in the American Southwest where a = frequency of caries, b = porotic hyperostosis and c = cribra orbitalia. Redrawn from Bocquet-Appel et al. (2008:Figure 7).

For the southern Levant, Eshed et al. (2006) indicate differences in nutrition for Natufian and Neolithic populations through examination of dental attrition versus ecological zones, but they provide no real direct evidence for a shift in health. Their study focuses on dental attrition (wear on the enamel), caries, calculus (plaque), antemortem tooth loss, periapical lesions (defense of microbial infection of the root canal), and periodontal disease. The results indicate that dental attrition is significantly higher in Natufian and Early Neolithic populations than in Late

Neolithic populations, suggesting that earlier diets were associated with the consumption of coarser foods. On the other hand, dental caries, antemortem tooth loss, and periapical lesions, were all similar for both the Natufian and the early and late Neolithic. One of the most substantial distinguishing factors differentiating the Natufian and early Neolithic populations from the late Neolithic populations is the amount of calculus present on the teeth. Late Neolithic populations had far greater amounts of calculus than all other samples, suggesting a higher rate of dependence on agricultural products and increased carbohydrate intake (Eshed et al. 2006:155). However, other components besides diet can influence the amount of calculus present on teeth such as hygiene and the use of teeth for other purposes than to eat (such as tools).

Currently there is little osteological data available in the Near East regarding the health of people living in the Epipaleolithic and Neolithic periods. Current data indicate, based on very minimal research, that good health was maintained throughout the Pre-Pottery Neolithic (Smith et al. 1984:129), suggesting that either the two-phase definition of the NDT (Bocquet-Appel et al. 2008) may not always be apparent or that this early work lacked samples from the latest Neolithic periods (such as the Pre-Pottery Neolithic C or the Pottery Neolithic discussed in Chapter Five). Without sufficient osteological data, for the time being we must turn to other measures of health, namely the known nutritional qualities of the foods that people were eating, to gain some measure of health during this time period. However, we have to also consider that people with access to good-quality food, but too little of it, will be just as bad off, or worse off, than people with access to plenty of bad-quality food.

Quantity vs. Quality

In the archaeological literature, health and fertility are usually closely related to food quantity (Jackes and Meiklejohn 2008; Kramer and Boone 2002) but much less effort has been expended measuring quality, or the nutritional content of foods. When quality is discussed in terms of the Neolithic diet, it is usually briefly addressed or in a qualitative manner, citing too many carbohydrates and not enough protein (Cohen 1977b; Cohen and Armelagos 1984; Starling and Stock 2007; Steckel et al. 2002; Yesner 1980; Yudkin 1969). While I agree that the late Neolithic diet in general may have been characterized as high in carbohydrates, this is less likely to be the case for the Early Neolithic (Eshed et al. 2006; Smith et al. 1984:129). In actuality, the NDT as a long process of plant domestication where both the morphological and nutritional signature altered over time can offer insights as to why this demographic transition may have occurred.

Examining food to determine carrying capacity has ordinarily assumed that certain quantities of food constitute the key limiting factor (Cohen and Armelagos 1984; Roosevelt 1984:567). However, this relationship is somewhat uncertain and the concept of carrying capacity itself has been called into question as an over simplification of reality (Boone 2002), potentially best attributed to how difficult it is to provide an accurate estimation of carrying capacity for past environments.

Additionally, an estimation of carrying capacity is particularly difficult in areas without a detailed paleoclimatic record.

Contemporary studies suggest that wild forms of the foods we have in domesticated form today have very different nutritional profiles than did their ancestral wild forms (Chavarro et al. 2008). Domestication not only changed the morphology of the plants, but also their nutritional quality. Moreover, early discussions of Neolithic health did not benefit from the much more detailed information that we now have regarding the initial parts of the transition in the Near East and instead focused on characteristics of populations with full-scale agriculture diets. Cohen and Armelagos (1984:587) acknowledge this problem pointing out that most of the early studies were conducted on human remains recovered from contexts associated with full-scale agriculture during the late Neolithic.

Taking these nutritional components into consideration, as well as the evolutionary process of selection that have changed more that just the morphology of plants over the last 10,000 years, we essentially assume that hunting and gathering provides a diet that more adequately balanced protein, carbohydrates and other nutrients. Of course, this is an oversimplification in that the foods associated with the NDT are exactly those which modern physicians recommend for women who want to get pregnant; these foods could in themselves have increased fertility rates in early Neolithic populations (Chavarro et al. 2008). Moreover, the invention of storage technology (and intensively storing foods as defined below) provided a more stable diet where foods were potentially available on a longer than seasonal basis.

The Science of Fertility and Food

While recent research has demonstrated that the Neolithic demographic transition was a real phenomenon, we lack a detailed discussion as to why there was an increase in fertility at the beginning of the transition. One potential explanation is that there is good reproductive health (Chavarro et al. 2008), and a growing literature on the foods that can lead to increased fertility in women, and to a lesser extent in men, corroborate this assertion (Chavarro et al. 2004; 2007a, b, 2008). This literature is especially important because the foods that people were eating dramatically changed, albeit gradually, through the transition to agriculture. While this body of literature is growing, there are still many questions regarding how the fertility diet (described below) could influence the large-scale demographic transition that people went through over the course of several thousand years in the southern Levant. Nevertheless, new approaches to understanding the increase in fertility at the start of the NDT merits a discussion of those foods that help to increase fertility.

The following review is focused on recent publications of Chavarro et al.'s (2007a, b, 2008) findings from the Nurse's Health Study that included a total of 289,700 participants. The size of this dataset no doubt lends credence to its findings. While the results were obtained through the study of modern women and men, this is the best dataset we have to provide insight into what components of the prehistoric diet could have helped generate higher fertility rates and a subsequent NDT.

"The Fertility Diet"

The diet that Chavarro et al. (2008) suggest to best promote fertility has an uncanny correlation with the foods that people had access to during the transition to agriculture in the southern Levant and for that matter, other locales where the NDT occurred. Based on abundant research, the fertility diet is suggested to be balanced, low in saturated fats, containing no trans-saturated fats, with low amounts of red meat (but enough maintain iron levels), a great deal of protein from plants as well as foods high in omega-3 oils, including some species of fish and whole wheat. Omega-3 fats are prevalent in some fish including wild and farmed salmon, Atlantic Mackerel, and sardines.

Dairy products are also suggested as one of the most important dietary staples for increased fertility, but only whole or high-fat dairy, as the process of making reduced-fat dairy products extracts estrogen and leaves testosterone and prolactin (both bad for fertility) (Chavarro 2008:112; Chavarro et al. 2007a). Interestingly, goat milk on average contains 1-2 more grams of fat on average per serving than cow milk, suggesting it may be even more beneficial to fertility.

Another interesting, recent development is the understanding of nutritional content in both wild versus domesticated wheat. Uauy and colleagues (2006) found that the modern domesticated wheat contains significantly (over 30 percent!) less protein, iron and zinc than its wild ancestors. In addition, wild emmer wheat (*Triticum turgidum sp.*) – the ancestor to one species of domesticated wheat (*T. turidum* ssp. *durum*) – carries the NAC gene which "accelerates senescence and increases nutrient remobilization from leaves to developing grains" (Uauy et al. 2006:1298), increasing the amount of plant protein, iron, and zinc. In fact, it has been suggested that cloning the NAC gene found in wild emmer and breeding it into domesticated wheat, would significantly reduce nutritional deficiencies in developing countries. As discussed in Chapter Five, archaeological evidence indicates that emmer was one of the primary early pre-domesticates in the southern Levant.

Other differences between domesticated and wild wheat could have had important effects on fertility. Refining domesticated wheat has a major impact on the nutritional content by removing the majority of the bran and the germ. This process takes away 70 percent of the iron and 50 percent of the B vitamins that are very important for fertility (Chavarro et al. 2008:46, 2007). Additionally, refined wheat is much easier to digest than unrefined wheat, which gives a fast rush of sugars to the bloodstream. In contrast, unrefined wheat with bran and germ intact is digested much more slowly, yielding a steady increase in blood sugar and insulin while providing many more nutrients (Chavarro et al. 2008:46).

Within the digestive system then, easily digestible domesticated wheat provides "a roller-coaster ride" (Chavarro et al. 2008:47) relative to the slow and steady digestion of wild wheat. Because of this, domesticated and refined wheat often lead to health issues with weight gain and low fertility. Chavarro et al. (2008) demonstrate a very strong positive correlation between high ingestion rates for wild and minimally processed cereals grains and increased ability for women to get pregnant. They found that women with high glycemic loads, or those who eat a high amount of easily digested carbohydrates were 92 percent more likely to experience infertility. In contrast, women who ate slowly digested carbohydrates, such as rice and dark bread, increased their fertility substantially. Interestingly, Chavarro et al. (2008) found that the amount of carbohydrates did not have an effect on fertility, whereas the type and quality of carbohydrates did have significant effects. Consequently, the consistent ingestion of wild unrefined grains during the initial phases of the NDT provided through storage technology, could have been a significant factor increasing fertility.

While some of the suggestions for the fertility diet do not transfer directly to an early Neolithic diet, there are arguably striking similarities. The following is a summary of the dietary requirements suggested by Chavarro et al. (2008) for increased fertility in modern humans.

1. Increased slow carbohydrates, no highly refined ones.
2. Unsaturated fats, no trans-saturated fat.
3. More protein from plants, less from red meat.
4. A serving or two a day of whole milk or other full-fat dairy foods with no skim milk and low-fat dairy foods.
5. Daily ingestion of iron and folic acid.
6. Coffee, tea, and alcohol in moderation, if at all, but no sugared sodas.
7. A body mass index between 20 and 24, physical activity (thirty to sixty minutes a day).

The fertility diet and the NDT

By relating recent advances in understanding how fertility is affected by the nutrients in our foods to the origin of a Neolithic demographic transition we can begin to understand why this demographic transition occurred in tandem with intensified food production. Here, and in following chapters, it will become apparent that the foods our ancestors ate and started to cultivate not only had the properties of being predictable and abundant, but the wild and early domesticated forms had the nutrient content ideal for increasing and/or sustaining fertility.

Examination of staple resources associated with all the areas where agriculture developed independently and where an NDT occurred indicates these resources were not only predictable and abundant, but share the qualities Chavarro and colleagues (2008) demonstrate increase fertility. These resources include, slowly digested carbohydrates such as rice in China, wild emmer wheat (and probably barley) in the Near East, and maize in Mesoamerica. As well, salmon is associated with a major demographic transition in the Pacific Northwest of North America (Goodale et al. 2004, 2008a). Finally, the use of goat dairy farming, and probably cattle later in the Near East, added the whole-fat dairy products that Chavarro et al. (2008) indicate could have a significant impact on fertility.

Diet and Fertility in the Southern Levant

It is plausible that subtle changes in the structure of wild plants brought on by human selection produced enough variation in the nutrition of plants to be at least partially responsible for one of the major demographic transitions in human history. Of course, other human behavioral elements also played critical roles in the NDT, including technological developments and flexible parenting to invest in more children that ultimately enabled population to grow.

Contrary to assumptions of poor health during the entirety of the NDT (Cohen 1977b; Cohen and Armelagos 1984; Starling and Stock 2007; Steckel et al. 2002; Larsen 2006), the initial cultivation and increased use of wild emmer wheat and legumes in the southern Levant would have afforded good health and fertility to late Natufian and early Neolithic populations. Moreover, the change from a predominately meat-driven subsistence economy of hunting gazelle to focusing on fewer and smaller juveniles (Techernov 1994) with an increase reliance on plant protein modified the type of proteins people were ingesting. This generalized dietary shift from one that incorporated large amounts of animal protein (Munro 2004; Techernov 1994) (which was not very good for fertility) to one that incorporated higher amounts of still-wild plant protein, would have increased fertility probably some time around the start of the Pre-Pottery Neolithic. Importantly, however, this new diet was in detriment to the intake of iron, zinc, or other nutrients found in high quantities in wild cereals (wheat and probably to a lesser but still important extent, barley). Additionally, by the Middle to Late Neolithic transition, sheep and goat domestication likely provided high-fat content dairy products further complementing the fertility diet. In other words, the geographic area of the southern Levant contained all of the types of foods required by the fertility diet and once intensive storage technology was invented (as noted below this occurs during the Early Neolithic), diets stabilized and fertility increased.

Storage Technology and Fertility

Food storage may be defined as a technique which allows the preservation of food for significantly longer periods of time than the harvest season. However, not all storage strategies are the same. We might define *abated storage techniques*, where only minimal amounts of foods are kept for longer periods of time than end of the harvest season (Testart 1982). A different type of storage might be defined as *intensive storage techniques*, where significant portions of foods are kept for longer than just when resources are available (Testart 1982). In this section I address the general connection that has been suggested by Alan Testart (1982) between these storage technologies and the rise of civilization, yet my focus is on the NDT. Through particular attention on the archaeological evidence for the development of storage technology in the Near East, I examine new significant studies in experimental archaeology concerning storage technology, and its importance to the fertility diet.

Storage and the NDT

The ability of people to store foods has been discussed in a variety of ways including as a very important aspect which provides the foundation for civilization (Testart 1982), or just one of several variables of which may not be “its (civilization) cornerstone" (Forbis 1982:531 comments on Testart 1982). In 1982, Testart and comment reviewers presented a *Current Anthropology* discussion piece in which the importance of intensive food storage economies was highlighted and correlated to mobile/sedentary population densities and social organization. Testart's position was very clear on the issue: intensive storage is a crucial aspect to the rise of civilization and the foundations of complex social organization. He argued that "sedentism triggers population increase, and intensive food storage enables the population to stabilize at a higher level of density" (Testart 1982:525), and further suggests that "all the material, social, ideological, or political prerequisites for the emergence of social inequalities seem to be present in societies with a storing economy" (Testart 1982:528).

It is pretty obvious that Testart puts a high level of importance on storage practices as basically the foundation of modern civilization. As one would expect with these lofty expectations based on a single variable; several of the discussants on the topic flatly refused to lend this much significance to the development of storage technology (Forbis 1982; Ingold 1982). Even so, the basis to my argument tends to agree with some of Testart's assertions by placing a high importance on storage technology for the origins of agriculture and the NDT. The difference is in how storage relates to the bigger picture of the foundations of social inequality, which I would argue is multi-faceted.

Storage Technology in the Near East

In the Near East we see potential examples of both abated and intensive storing economies. Although controversial, abated storing techniques might be found during the Natufian tradition as evidenced by rare small pits and the suggested use of baskets above ground (Bar-Yosef 1998). However, recent arguments suggest that the Natufians were not storing food at all (Boyd 2006). On the other hand, intensive storing techniques appear to be invented in the Early Neolithic during the Pre-Pottery Neolithic A (11,700-10,500 cal BP) (Kuijt 2008a; Kuijt and Finlayson n.d.). Conclusive evidence appears from the site of Dhra' (Finlayson et al.2003; Kuijt and Finlayson n.d.), where at least four granary storage structures were recovered with what appears to be a dedicated use of food storage (namely wild cereals). Other sites in the region contain evidence of storage technology, including Netiv Hagdud (Bar-Yosef and Gopher 1997); Wadi Faynan 16 (Finlayson and Mithen 2007) and Jericho (Kuijt 2008a). A detailed examination of when and where storage technology is first evident in the prehistory of the southern Levant is discussed in Chapter Five.

Experimental Studies in Storage Technology

Surprisingly little experimental work has been directed to the appropriate climate for storing food (in terms of hot/cold or wet/dry conditions) and the duration of the storability of different types of food. The factors that would influence how long foods can be stored could include, but may not be restricted to, types of food being stored, the climate conditions of the area where the food is being stored, the type of storage facility, and any preparations that has been done to the food before it was stored (dried, smoked, etc.). In fact, I was unable to find one source in the published literature that experimentally treated these questions. There is one unpublished study that has addressed this specific problem and although it is preliminary, it correlates very strongly with what we see in the archaeological record (Ortmann n.d.).

Specifically, Ortmann (n.d.) organized her study around an experimental program to determine how long cereal foods will store in above- and below-ground storage facilities in hot and dry climates. Results indicate that regardless of whether the storage facility is above or below ground or in a hot or dry environment, cereal foods can be preserved at an edible state for ca. 13 months on average (Ortmann n.d.). If this were the case, and storage technology also functioned to prevent significant loss due to rodent infestation, foods would become available well beyond the harvest season, thus providing a highly stabilized diet of foods associated with higher fertility.

Results of Ortmann's (n.d) study demonstrate that once storage techniques became regularly practiced, cereal grains had the potential of being available year-round. Off-season availability of grain resources would have provided security from shortfalls of other harvested resources (Bettinger 2006) and long-term interaction of early plant domesticates (nutrient rich) with human biology. Significant to the early phase of the NDT, this aspect of long-term interaction with initially wild varieties of cereal grains could have enhanced fertility and general health.

While a more in-depth examination of food and fertility provides a foundation for understanding how the prehistoric nutrition shift could have affected fertility and total fertility rates, the question still remains as to what social mechanisms were in place to influence women to bear, and parents to invest in, more children. In other words, what is the difference between forager and hunter-gatherer socioeconomic systems that may encourage higher birth rates and potentially why population regulation mechanisms such as infanticide or birth spacing were not a significant factors, further allowing population to increase during the NDT?

Sedentism, Exercise, and Fertility

A shifting food economy to greater intensification and the development of long-term storage technology led to the availability of sufficient natural resources year-round and the change from more mobile to sedentary lifestyle. While still debated (Handwerker 1983; Sattenspiel and Harpending 1983), it is commonly suggested that population growth increased substantially among early agrarian societies due to semi-permanent settlement or full-time sedentism (Johnson and Earle 1987; Hassan 1981). There are ethnographic correlates around the world where hunting and gathering groups have smaller population densities than settled forager/agricultural groups. But why is this the case?

One explanation that has been cited for increased fertility among sedentary groups is the degree to which women participate in active exercise. Based on modern studies (Sanborn et al. 1982), excessive, strenuous, and long-duration exercise can make women (such as professional athletes) more susceptible to variable menstrual cycles. The logic follows that females, who participate in less excessive physical activity, but sufficient moderate exercise, will have more regular menstruation (Rich-Edwards et al. 2002). At the same time, obesity can cause problems with fertility (Green et al. 1986; Morris et al. 2006), and research suggests that women who correct being overweight through moderate exercise can greatly increase their chance of getting pregnant (Green et al. 1986; Rich-Edwards et al. 2002).

In the past couple of decades, research investigating a possible connection between excessive physical exercise and infertility has been based on the examination of female athletes, especially those undergoing professional training. Results indicate an overall decrease in fertility among these women, but not all female professional athletes have reduced fertility. This poses the concern that the relationship between exercise and fertility is much more complex than can be summed up in a simple statement (Morris et al. 2006; Rich-Edwards et al. 2002), and the correlations between these two variables have not been proven positive (Morris et al. 2006).

Morris et al. (2006) recently presented a large case study of 2,232 couples undergoing in vitro fertility (IVF) treatment for infertility. The couples were questioned about different aspects of their lives, tested for ovulatory cycles, and classified into groups based on exercise type and duration. Three main conclusions demonstrated the roles of exercise and fertility. First, women who exercised moderately, defined as 1-3 hours a week, for either one to nine years or 10 to 30 years before the study, showed similar positive responses in fertility and IVF. Women who regularly participated in excessive exercise, defined as exercise exceeding four hours per week, for one to nine years before the study, were as much as three times as likely to "experience cycle cancellation" still birth, or "implantation failure" (Morris et al. 2006:938). However, the really interesting point is that women who engage in intensive exercise for more than four hours per week but longer than 10 years before the study showed positive correlations in IVF treatment and fertility. Morris et al. (2006:946) suggest that there may be an exercise threshold incorporating a time period where the body acclimates to intense exercise that may be linked to a hormonal output adjustment. This relationship between exercise intensity and duration may be modeled similar to Figure 4.3.

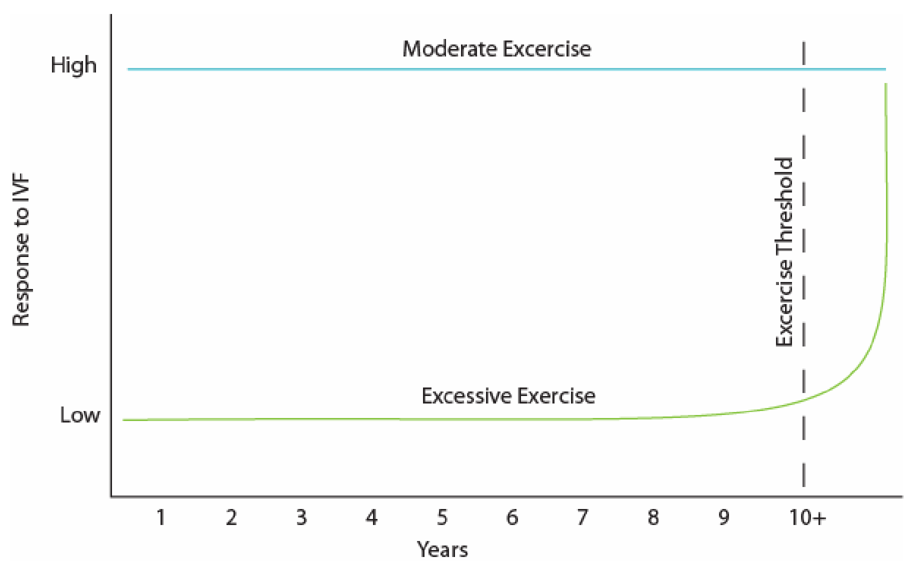

Figure 4.3. The exercise threshold model suggested by Morris et al. (2006).

What are the implications of this with our question of fertility correlates and the transition to sedentism? If we compare the life ways of pre-industrial societies with intensive exercise (it seems probable that hunter-gatherer and early agricultural women would have the equivalent of more than four hours of intensive exercise a week), intuitively it is not exercise intensity that is influencing fertility but instead the duration of their lives in which they engage in exercise. In this scenario, women would be most prone to infertility due to intensive exercise for the first nine years after menarche. Ethnographically, most females in societies practicing hunter-gatherer subsistence strategies do not extensively contribute to the economic means of the family until 20+ years of age (Kramer and Boone 2002). If this were the case preceding the Neolithic, it is possible that hunter-gatherer women living before the Neolithic may not have engaged in more than ten years of intensive exercise preceding the onset of typical child-birthing years. This likely changed with the transition to agriculture, where females ethnographically begin to make a significant economic contribution by the age of 13 (Kramer and Boone 2002), suggesting that they may have engaged in intensive exercise earlier in their lives than that of hunter-gatherer women. The implications of this are that there may be a significant link between exercise, fertility, and the TFR between women participating in hunting-gathering versus agricultural subsistence modes; the later has the potential for significantly higher TFR.

Another issue somewhat related to the amount of exercise correlated to fertility is the amount of food an individual consumes. Related to the quantity of resources and the cyclical nature of the amount of food available throughout the year in a hunter-gatherer context, Van der Walt et al. (1978) found that San women in

South Africa had menstrual irregularities due to periods of the year when food supply was short. In general, seasonal short falls suppressed ovulation annually, which in hunter-gatherers could have been one mechanism that maintained small population sizes and densities with little dramatic change through time. However, under circumstances where agriculture and delayed return subsistence practices with the advent of storage technology were practiced, seasonal menstrual cycles could be maintained, although climatic variability and reduced crop productivity could have dramatically affected population levels. Logic would indicate that storage would permit more stable diets in terms of quantities; but even with agricultural practices, crop failure over the long-term or even short-term could result in catastrophe. This can be theoretically graphed in Figure 4.4. Note that once storage technology and cultivation are employed, when problems associated with crop failure, the effects may be of a much higher magnitude than when foraging strategies were employed (Figure 4.4).

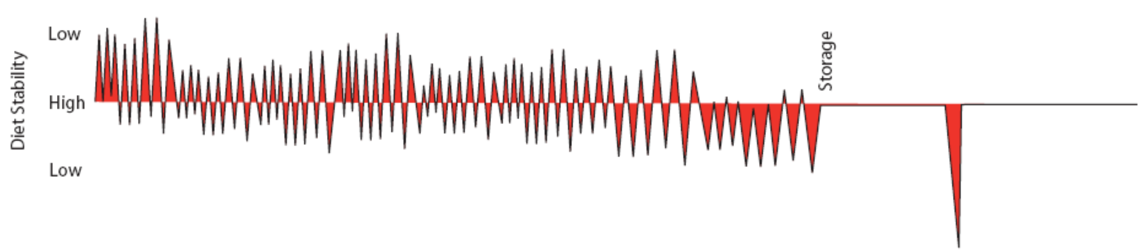

Figure 4.4. A simple graph of diet stability before and after the invention of intensive storage technology. Note that peaks above and below the high diet stability line indicate seasonal use of different foods. After storage is in place, certain foods would have been available for a long-term basis providing much more stabilized diets.

Research regarding the influences of exercise and quantity/quality of food on fertility appears to show a correlation where the duration (both in terms of hours and years) could have provided a situation for better reproductive health in agricultural than hunter-gatherer societies. Additionally, seasonal short falls may have influenced ovulation suppression in forager societies, which resulted in maintaining overall population sizes small but overall more stable. In contrast, agricultural systems may have promoted the quantities of food needed for sustained ovulation, but in bad times, population crashes could have been more severe. While not directly measurable, these appear to be at least two influencing factors for why fertility increased during the transition to agriculture; however, what are the other factors of changing life ways should have promoted parents to invest in rearing more offspring?

Optimality, Child Rearing and Economic Systems

"It is impossible to predict fertility on the basis of subsistence alone"
Bentley et al. 1993b:779

There is a growing body of literature that links the relationship between optimality to different subsistence modes, population growth rates, and natural fertility rates (Bentley et al 1993a, b; Boone 2002; Campbell and Wood 1988; Hewlett 1991; Kramer and Boone 2002; Munroe et al. 1984; Stecklov 1999; Sellen and Mace 1997) and to a lesser extent, the amount of work contributed by different sexes as well as different age groups (Kramer and Boone 2002). As noted in Chapter Two, evolutionary theory predicts that humans have a finite amount of energy, and the expenditure of that energy is devoted to somatic interests of survivorship (procuring food and shelter) and reproductive interests in terms of time spent in the process of finding mates and child rearing. Because humans have a finite amount of energy to ensure their reproductive success (discussed in Chapter Two), the number of children they can support is directly proportional to their ability to provide for their dependents as well as themselves. However, it seems intuitively correct that population growth and expansion during the NDT had to incorporate some negotiating factor that allowed for larger families.

Work Loads, Age Structure, and Subsistence Mode

When collecting or processing resources, the amount of time and energy invested is the labor cost of some defined unit of food. The time and energy increases in turning the resource into usable end products in relationship to the net return. This is referred to as subsistence intensification (Boserup 1972; Kramer and Boone 2002:512). The transition to agriculture fits this definition in most instances where there is decreased labor efficiency when the procurement is less energy-efficient than regular foraging (Kramer and Boone 2002; Bettinger 2006). This is generally argued to be due to factors related to not only increases in harvest and processing investments, but also to time spent maintaining fields and irrigation channels as well as planting.

Several studies related to subsistence mode and the gender/age groups that participate in the economic enterprise of harvesting food suggest that the addition of new groups to the economic system may be a way to negotiate potential bottlenecks in the time and resources devoted to raising a family (Bentley et al. 1993a, b; Campbell and Wood 1988; Hewlett 1991; Kramer and Boone 2002). In terms of active work between subsistence modes, Sackett's (1996) case study of 102 groups of agriculturalists, horticulturalists, and foragers focused on time spent engaged in active labor, and the study suggests major differences between hunter-gatherer and agricultural subsistence strategies. The results indicate that people practicing an agriculture subsistence mode spend many more hours a day engaged in food-related work than do foragers or horticulturalists.

Low (2000:144-145) notes the basic pattern that when offspring must compete for limited resources, parents shift their attention to investment in offspring rather than production of offspring, and unless there is a significant increase in resources, fertility rates will reflect this pattern. Additionally, Malthus (1970) argues that population size is restricted by the state of food production, or in other words, that technological improvements in combination with the amount of resources available control population growth.

Nonetheless, just because a woman can get pregnant does not necessarily mean that she will choose to raise more children. Agricultural groups around the world have significantly higher fertility rates than foragers and horticulturalists (Figure 4.5 and Table 4.1) (Bentley et al. 1993a; Boone 2002). It is important to explore the reasons to invest in those offspring that added to population growth witnessed during the early phase of the NDT. In other words, why was population size and density not regulated by some means such as infanticide or birth spacing during the NDT?

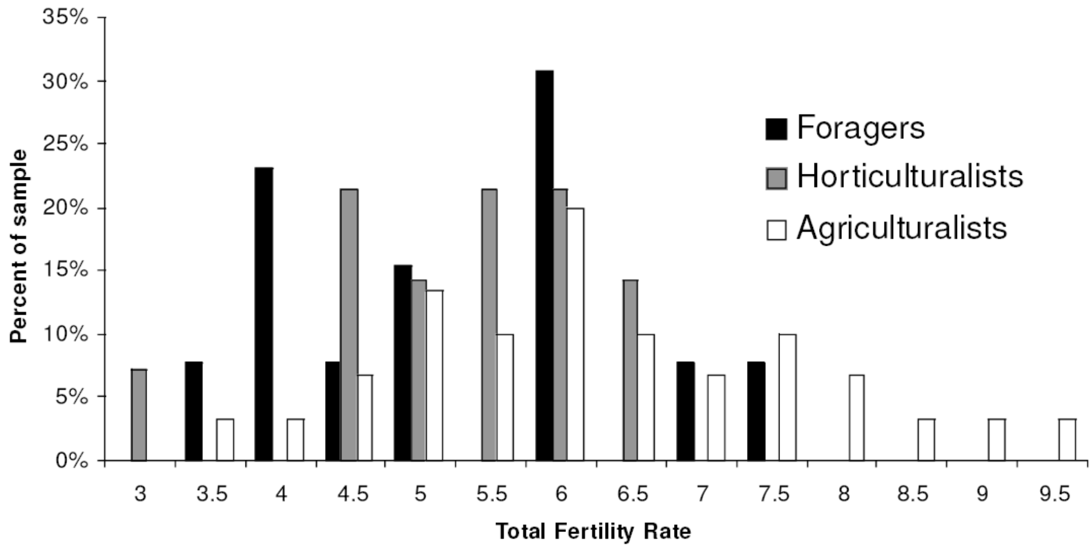

Figure 4.5. Total Fertility Rates (TFR) of 57 ethnographic groups subdivided by subsistence mode. Redrawn after Bentley et al. (1983a) with data from Appendix I and Boone (2002:16).

There are many examples in the ethnographic record where infanticide is utilized as a means to negotiate the social pressures of bearing and raising children (Hill and Hurtado 1996; Hewlett 1991). A search of infanticide in the HRAF database yields 769 matches in 80 cultures around the world. While infant death is more often a consequence of predators or other humans that may be reproductive competitors (Low 2000:75), infanticide does occur among genetic parents and is usually a way to either manipulate mating strategies to provide equal opportunities for each sex or because one sex may have a higher reproductive value based on wealth

(Dickmann 1979; Parry 1979). Birdsell (1968) estimated that during the Pleistocene between 15-50 percent of infants died due to limited resources. Logically it can be argued that there is an evolutionary benefit for either having and raising more children or the opposite, for not investing in more children. Consequently, there should be social components in settled societies that would promote child bearing/rearing that were relatively absent in mobile hunter-gatherer societies.

Table 4.1. Total Fertility Rates of 57 Forager, Horticultural, and Agricultural groups. Data is after Bentley et al. (1998).

Subsistence Regime	Mean	S.E.	Range	N
Foragers	5.6	.4	3.5-7.9	12
Horticulturalists	5.4	.2	3.0-6.9	14
Agriculturalists	6.6	.3	3.5-9.9	31

With this in mind, the NDT must have incorporated some restructuring of the socioeconomic system and potentially who could participate. Kramer and Boone (2002) suggest that data from Maya agricultural families indicate that children make economic contributions to food acquisition much earlier than horticultural and forager groups. Kaplan (1994, 1996) documents that among the foraging Machiguenga, Piro, and Ache that dependent offspring provided only around 20 percent of the total food that they consumed. Additionally, these dependents did not become net producers until their 20s, when they started having children of their own. In the case of Maya children, Kramer and Boone (2002) find that children become net producers as adolescents, five to seven years before they reproduce and while still living with their parents. They explain this contribution is not negotiated by the work load providing large families selected for wealth and status (the wealth-flow hypothesis of Caldwell [1982]), but instead to underwrite the cost of younger dependent siblings. In this circumstance the answer to the question of who keeps children alive may be predominantly themselves, in the case of non-dependent children, and predominantly their siblings, in the case of dependent children under an agricultural subsistence strategy (Kramer and Boone 2002). Additionally, it appears that "children's work funds parents' continued reproduction rather than wealth per se" (Kramer and Boone 2002:516). We could also expect that parents may benefit in other ways through this relationship where energy not invested in child rearing compensated for by non-dependent offspring may be invested elsewhere.

Epipaleolithic through Neolithic: A Case Study from the Near East

One potential place that parents may have been investing energy that has archaeological correlates in the early part of the NDT in the Near East is an expansion in the number of social roles among Early Neolithic versus Epipaleolithic communities as indicated by the development of more spatially defined communities, indicated by prepared activity area floors, formalized middens and much more investment in the scale of architecture (Kuijt and Goodale 2009). These elements are largely absent from Natufian communities (Hardy-Smith and Edwards 2004). The activities associated with these developments may be the social outcome that adaptively shifted parents from the major (or sole) contributor to the economic adaptive systems by adding younger children to the work force.

If Kramer and Boone (2002) are correct, and this case study can be applied to other regions of the world, one explanation for the why the transition to agriculture and the NDT happened may then be significantly correlated to the introduction of younger non-dependent offspring into the work force. This likely enabled parents to explore other social niches, including investments in exploring new technologies such as food storage. The origins of agriculture may then be viewed both as an economic revolution but also as a means in which to engage children into the entire economic process. Kramer and Boone (2002:514) articulate very clearly at least in terms of the Puuc Maya community of agriculturalists that *"parents' work effort alone does not meet the family's combined labor requirements"* (emphasis in original). In other words, the parents alone were not producing enough food to meet the daily requirements of the family as a whole.

Summary

In this chapter I have outlined several concepts associated with not only detecting a NDT in the Near East, but also significant correlates that may provide an explanatory framework in terms of why fertility increased, as well as how to compensate for limited energetic budgets of bearing and raising more children. This includes the development of storage techniques that allowed wild foods to be stored for longer than the harvest season. Importantly, these foods are correlated with high fertility, and the long-term, consistent access to them could have increased the TFR allowing higher population densities. Moreover, I have argued that a potential social impetus for investing in more children which produced the "substantial increase in human numbers" (Bocquet-Appel 2002), was the shifting social roles of a younger age bracket to the work force.

While it is out of the scope of this project to directly test the effects of the fertility diet on a large scale demographic transition due to the restricted nature of the Nurse's Health Study data, we can examine the direct correlates of when it may have started to influence female fertility. We can also not directly test the addition of younger age classes into the work force; however, it appears that in general, kids contribute more to the economic system in agriculture than in hunting and gathering contexts.

CHAPTER FIVE

THE TRANSITION TO AGRICULTURE IN THE SOUTHERN LEVANT: THE CULTURE HISTORY

The cultural chronology of the Near East encompasses some of the most interesting advances in human culture and evolutionary adaptation. These include the advent of subsistence intensification potentially as early as 14,500 cal BP during the Early Natufian, invention and use of systematic cultivation and food storage sometime after 12,000 cal BP in the Pre-Pottery Neolithic A (Bar-Yosef 2004; Verhooven 2004), domestication of animals during the Middle to Late Pre-Pottery Neolithic B (Kuijt and Goring Morris 2002), and the development of pottery during the Yarmukian Pottery Neolithic (PN) (Finlayson et al. 2003) (Table 5.1). These major revolutions set the stage for dramatic shifts in human settlement, subsistence strategy, religious and sociocultural beliefs, and technological organization.

The purpose of this chapter is not to provide a detailed cultural chronology of the southern Levant, since that has recently been undertaken by Kuijt and Goring-Morris (2002). I instead offer a broad overview of the archaeological record of the southern Levant from the Early Epipaleolithic (roughly 22,000 cal BP) through the Late Pre-Pottery Neolithic (approximately 8,250 cal BP) (Figure 5.1 and Table 5.1), derived from decades of cultural historical research.

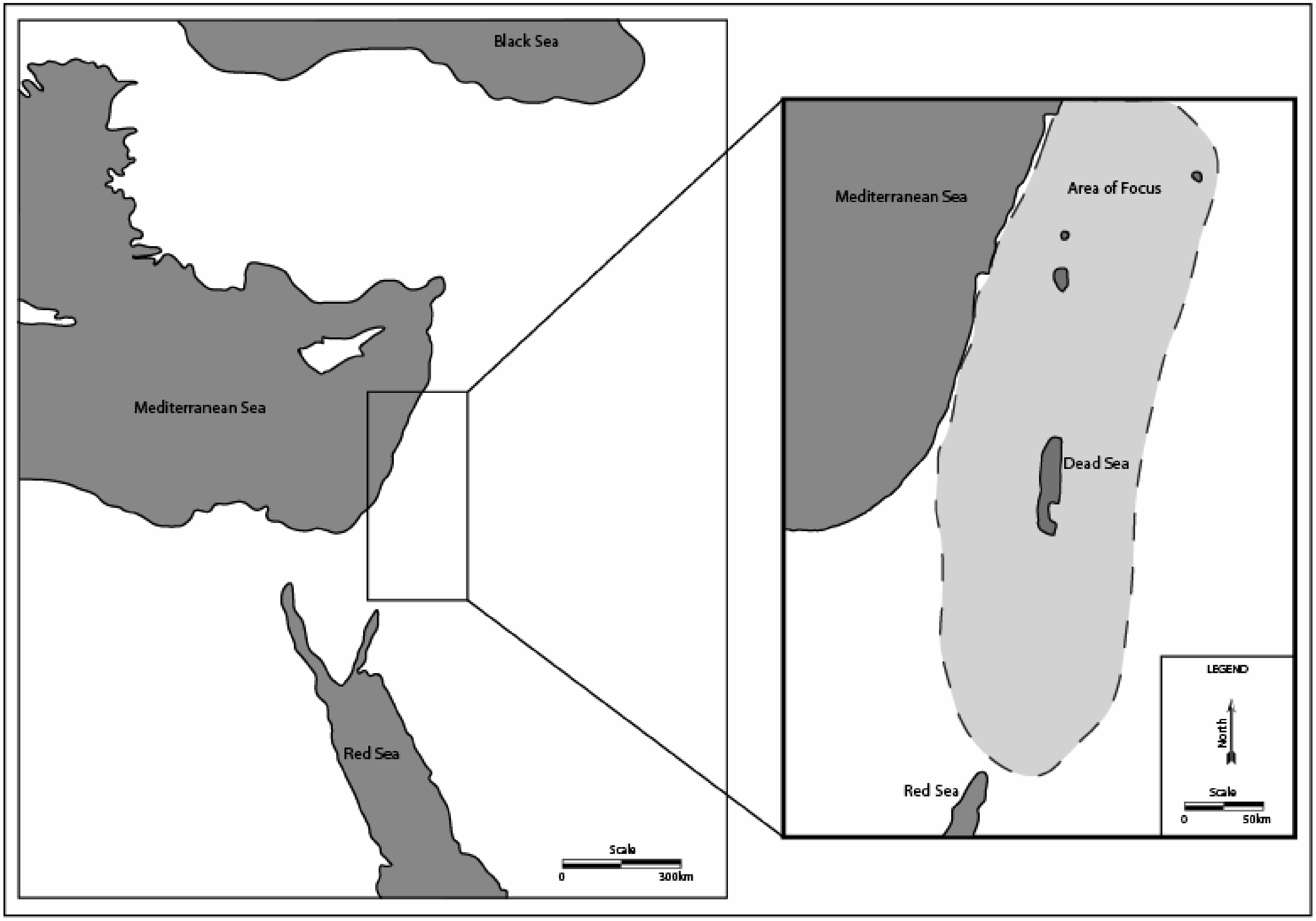

Figure 5.1. The Near East and the Southern Levant as the focus of this research.

Table 5.1. Cultural Chronology of the Near East Transition to Food Production.

Period	Cultural Horizon	Cal. Date Range
Early Epipaleolithic	Kebaran	22,000-18,500
Middle Epipaleolithic	Geometric Kebaran	18,500-14,500
Late Epipaleolithic	Early Natufian	14,500-12,800
	Late Natufian	12,800-11,700
Pre-Pottery Neolithic	Pre-Pottery Neolithic A	11,700-10,500
	Early Pre-Pottery Neolithic B	10,500-10,100
	Middle Pre-Pottery Neolithic B	10,100-9250
	Late Pre-Pottery Neolithic B	9250-8700
	Pre-Pottery Neolithic C	8600-8250

Discussion and research presented here is limited spatially to the southern Levantine region of the Near East for a number of reasons. First, the southern Levant is a well defined geographic area (Figure 5.1) where a number of archaeological investigations have resulted in readily available data useful for estimating population growth. Second, the relationship between people living in the northern and southern Levant during the entire time sequence examined here is not well understood.

Obsidian source analyses suggest some interaction between the northern and southern Levant as early as the Pre-Pottery Neolithic A. Obsidian sourced to present-day Turkey, has been identified in a number of Early Neolithic communities in the southern Levant, although it is not in abundant until fairly late in the sequence. In addition, technological developments such as particular tool types and socioeconomic strategies such as the advent of sedentism occur early in the sequence in both regions, indicating likely early social ties between the north and the south. Current difficulties in understanding this relationship are in part the result of limited excavations in Lebanon and southern Turkey and the complexity of the political climate of these regions. In order to avoid any issues related to geographic separation and potentially different paleodemographic parameters and characteristics in play in each region, I only focus on the southern Levant in this study.

Early Epipaleolithic

Starting with the Early Epipaleolithic from 22,000-18,500 cal BP, the Kebaran culture encompassed a highly mobile residential lifestyle during the Last Glacial Maximum when cold and dry conditions prevailed. Henry (1995) argues that Epipaleolithic groups were transhumant, altering seasonally between different locations where low altitude rockshelters were winter camps and open-air upland sites functioned as summer camps (Figure 5.2). Sites are usually characterized as small in size and shallow in depth; indicative of sites occupied by highly mobile hunter-gatherer. Site sizes range from 12,000 square meters at Wadi Hasa 618 (Clark et al. 1988) to 1000 square meters Ein Aqev (Marks 1976).

Evidence for Early Epipaleolithic structures occur at the site of Ohallo II on the southwestern edge of the Sea of Galilee where tight clustering of huts built of wood and brush were constructed (Nadel and Werker 1999; Nadel et al. 1995, 2006). The excellent preservation of the site allowed the detection of a midden area and high quantities of seeds, fruits and wild grains (Nadel and Werker 1999; Nadel et al. 1995, 2006). The site appears to have been burned upon abandonment and due to its exceptional preservation in a covered lake bog, is very important for our understanding of Early Epipaleolithic lifeways.

Nadel et al. (2006) have provided the most abundant evidence that perishable materials were incorporated into the Early Epipaloelithic life way at Ohallo II. Because of the exceptional preservation of the site, numerous wood objects were recovered, many of which were incised with lines. It is not clear how these items were integrated into the socioeconomic or symbolic systems during this time period, although it does point to the portion of the archaeological record that we are missing in interpreting past life ways.

Sites exhibiting high residential mobility also occur in the Transjordan Plateau extending into Syria, farther north to Lebanon, and as far south as the Sinai Peninsula (Goring-Morris and Belfer-Cohen 1998). Overall, the organization of the Early Epipaleolithic can be characterized as mobile foragers (*sensu* Binford 1980) incorporating a predominantly egalitarian socioeconomic system (Neeley et al. 1998). Central to the arguments presented here, Early Epipaleolithic sites contain no evidence of storage practices, and people most likely practiced an immediate-return subsistence economy shifting diets with seasonal foods (Goring-Morris and Belfer-Cohen 1998).

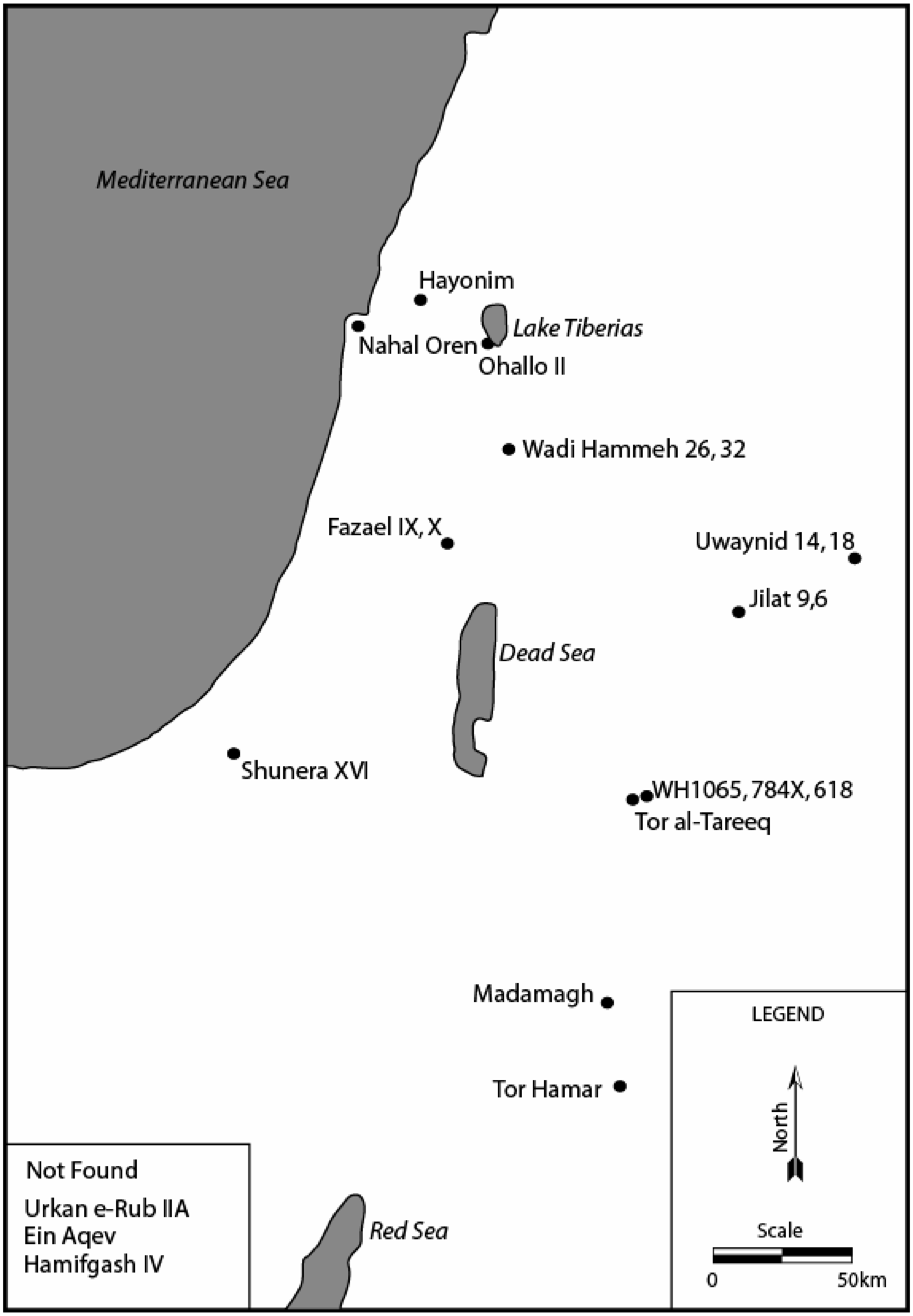

Figure 5.2. Early Epipaleolithic sites with obtainable data for the paleodemographic model presented in Chapter Seven.

Middle Epipaleolithic

The Middle Epipaleolithic (MEP) contains various cultural "entities" (as they are referred to by Goring-Morris and Belfer-Cohen 1998:77-78) that are more or less geographically distinct, defined based on the typological and frequency variants of certain artifacts, specifically microburins. Entities include the Geometric Kebaran, Mushubian, and Ramonian dating from 18,500-14,500 cal BP. During the MEP, Goring Morris and Belfer-Cohen (1998) suggest that with climate improvement and the expansion of lakes and rivers, there was a mass migration and colonization from the southern Sinai to northern Syria (Figure 5.3). This was coupled with an increased carrying capacity of the landscape due to improving climatic conditions (Goring-Morris and Belfer-Cohen 1998).

Excavations at the site of 'Uyun al-Hammam in the Wadi Ziglab of northern Jordan has revealed more than nine individuals in seven burials dating to the MEP, the largest sample of human remains for this period and any previous period in the region (Maher 2007a, b). Based on the complex burial systems and the number of individuals found in graves at 'Uyun al-Hammam and at Kharaneh IV (Maher 2007a, b; Muheisen 1988), Maher (2007a, b) posits that certain sites may have functioned as purposeful cemeteries in the MEP, a trend also seen during the Late Epipaleolithic Natufian period. Additionally, a special relationship between humans and animals may have begun to develop in the MEP, for one burial contained a canine skull (Maher 2007b:198). This may point to the beginnings of dog domestication in the southern Levant much earlier than what was previously thought to have been the case in the Natufian (Kuijt and Goring-Morris 2002).

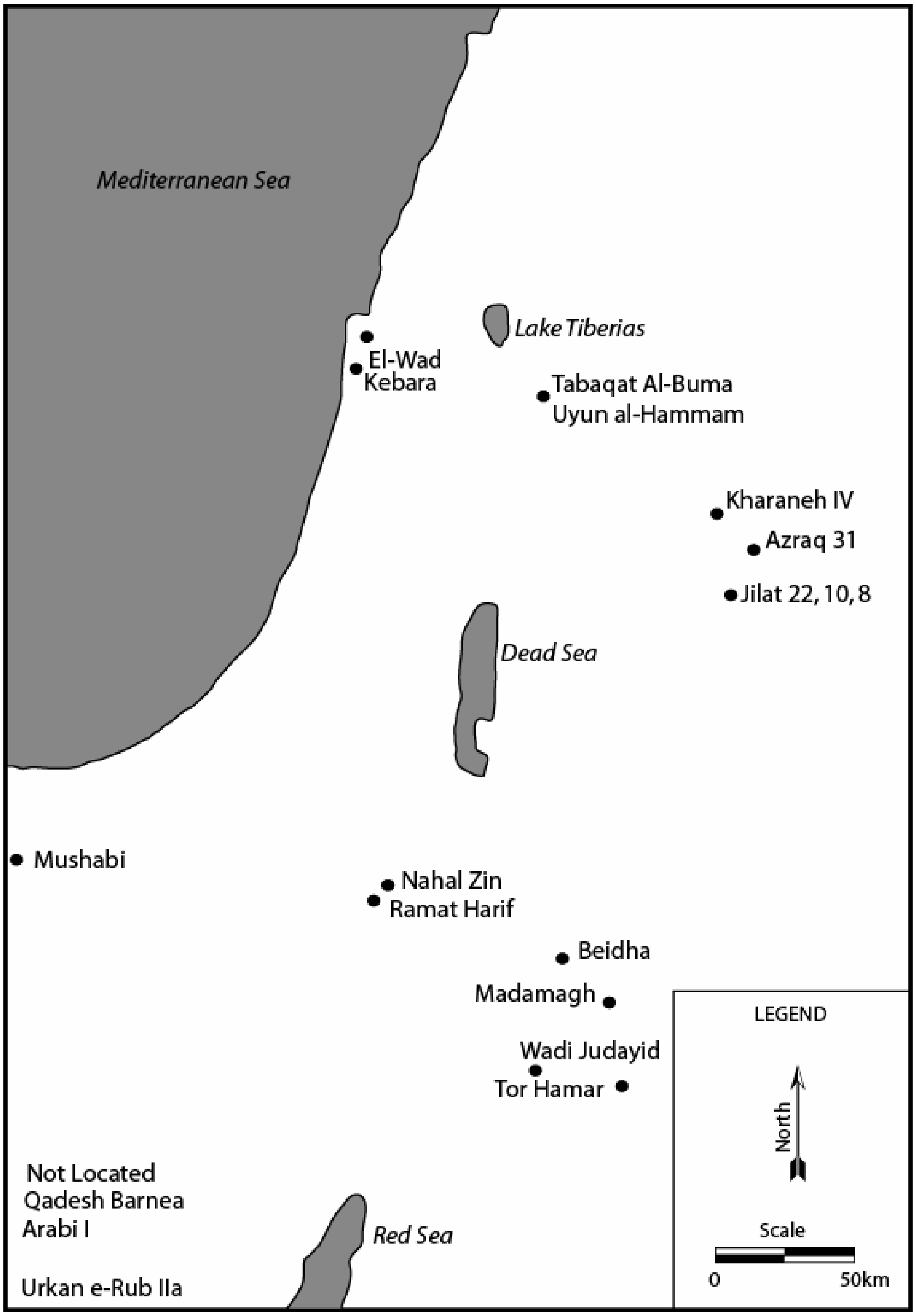

Figure 5.3. Middle Epipaleolithic sites with obtainable data for the paleodemographic model presented in Chapter Seven.

Overall, trends in socioeconomic strategies appear to be very similar to that of the Early Epipaleolithic focused on immediate returns with seasonally available foods (Goring-Morris and Belfer-Cohen 1998). Dietary reconstruction based on fauna and flora analysis indicate in most cases a very broad spectrum of resources was exploited (Bar-Oz 1999; Bar-Oz and Dayan 2002, 2003; Munro 2004; Tchernov 1994). In general, there is also an increased reliance on medium and large mammals including deer, hartebeest, equids, ibex, and gazelle (Maher 2007b). The identification of mortar and pestle indicate the technology to process wild plant foods. While we good evidence to reconstruct diet, the technology to store food was absent from the lives of the Middle Epipaleolithic people.

Late Epipaleolithic

The Late Epipaleolithic (LEP) is characterized by the well documented Natufian culture (Bar-Yosef 1998). The Natufian can be subdivided into two or three phases depending on the scholar. For this discussion I will remain with a two phase distinction as the Early Natufian (14,500-12,800 cal BP) and Late Natufian (12,800-11,500 cal BP). This discussion also covers the Harifian, a southern adaptation in the Negev Desert that appears to be roughly contemporaneous with the Late Natufian (Figure 5.4).

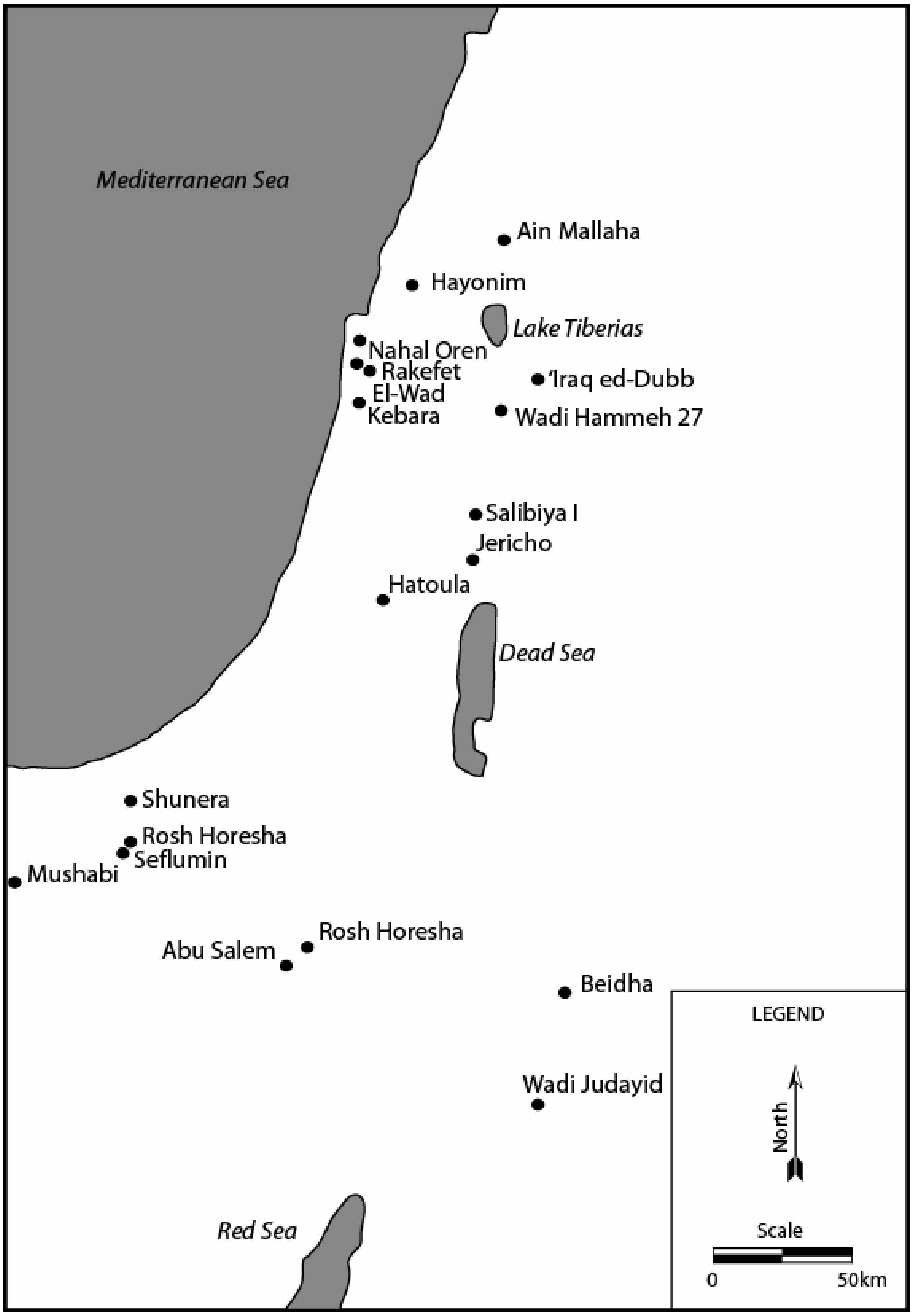

Figure 5.4 Early and Late Natufian sites with obtainable data for the paleodemographic model presented in Chapter Seven.

The Early Natufian

The Early Natufian roughly corresponds with the Bölling Allerød interstadial, a warm wet period directly preceding the Younger Dryas (Bar-Yosef 1998).The Natufian was first defined by Dorothy Garrod (1932) at Shuqbah Cave based on the presence of sickle blades, large mortars and other grinding stones, and what appeared to be high intensity or long-term occupations. Another distinctive feature about the Natufian period is the existence of several large cemeteries. Key sites for the Natufian in the southern Levant include el Wad (Goring-Morris 1996), Hayonim Cave (Bar-Yosef and Goren 1973) and the associated Hayonim Terrace (Henry et al. 1981), Kebara Cave (Bar-Yosef 1992), and Wadi Hammeh 27 (Hardy-Smith and Edwards 2004). Each of these sites demonstrates occupation intensity at a much greater scale than previously known in the region. However, the degree of actual sedentism reflected in Early Natufian settlements has been the subject of recent debate (Boyd 2006).

Sedentism in the Natufian has been largely assumed based on the intensity of occupation at a number of sites evidenced by large amounts of fauna, lithics, and other items documented at several sites in the southern Levant (Garrod 1932). Site types include more ephemeral logistical task oriented sites (Binford 1980) and base camps that reflect far more intensive occupation (Bar-Yosef 1998). It is interesting that during this time such intensive occupations have not been identified out of a small area found in the southern Levant termed the “Natufian Homeland” (Bar-Yosef

1998:162). In areas outside of the homeland, occupations exhibit very high mobility and ephemeral occupations in the Near East (Bar-Yosef 1998).

Other lines of evidence for increased sedentism are suggested by Lieberman (1991, 1993, 1998), whose analysis of gazelle crementum indicates that many of the Natufian base camps may have been year-round residences (Lieberman 1993). Problems may exist with Lieberman's (1993) interpretation due to sample size, dating of sites, and much more importantly, post-depositional effects that produce apatite layers which could be easily interpreted as seasonal cementum growth layers (Boyd 2006).

Another issue that separates the Natufians from later cultural traditions is the absence of systematic refuse disposal (Hardy-Smith and Edwards 2004). The site of Wadi Hammeh 27 has several potential domestic structures; abundant accumulation of garbage totaling nearly 400,000 pieces of lithics, bone and other refuse have been identified in and around the houses (Hardy-Smith and Edwards 2004). It has been suggested that Natufian settlements would have been unsanitary, attracting vermin and disease vectors that might have contributed to greater mobility in the Late Natufian (Belfer-Cohen and Bar-Yosef 2000), However, unsightly messes and unorganized sites may just as easily (and potentially better) be explained by Natufian strategies being much more mobile than currently perceived (Boyd 2006). However, disease may be reflected in the evidence of a reduction in the size of male and female stature potentially caused by illnesses (Belfer-Cohen 1991), although this remains to be confirmed by additional studies.

The Early Natufian demonstrates the appearance of several new tools, including sickle blades and the precursors to early Neolithic heavy utility bifacial tools. Tool kits are dominated by crescent-shaped lunates bearing Helwan retouch (invasive bifacial retouch) and comprise up to 80 percent of tool assemblages at many sites (Henry 1995). The function of lunates remains contested; they may have been used as dart points hafted singly or in pairs (Henry 1995), but there is also evidence for use in sickle harvest (Anderson 1994). There is also an increase in the types and amounts of ground stone tools at Natufian period sites suggesting the intensification on wild cereal exploitation.

Dietary reconstructions for the Natufian have varied greatly. Through the analysis of strontium-calcium ratios reflective of the intensity of plant food intake, Smith et al. (1984) indicate that the human skeletal Sr/Ca signatures from the Mousterian to Natufian sequence at the site of Hayonim fell midway between animal carnivores and herbivores indicating an omnivorous diet. There are potential problems with this analysis, including first that very few studies concerning the use of isotope signatures to reconstruct dietary patterns have been conducted. Second, Smith et al. 1984:126 cite Sillen and Smith (1984) and acknowledge that the Sr/Ca isotopes are similar between animal herbivores and carnivores at the Kabaran site of Ein Gev, suggesting some other contribution of strontium and calcium to the bone such as the local geological conditions.

As discussed in Chapter 4, it is often assumed that Natufians developed storage facilities, but evidence for food storage techniques is absent from the Natufian archaeological record (Boyd 2006; Kuijt 2008a). This causes one to doubt the extent of Natufians intensification of wild cereal exploitation.

> "Despite expectations to the contrary, storage installations are rare in Natufian sites. The few examples include a paved bin in Hayonim Terrace and several plastered pits at Ain Mallaha, which could have served as underground storage facilities."
> Bar-Yosef 1998:163-164.

Even if these hints of storage techniques are evidence of people actually storing foods, there is no evidence that (as defined in Chapter Four) Natufians were intensively storing foods. Thus, the Natufian diet was likely prone to change seasonally based on availability of resources.

Social organization of the Early Natufian appears to be more complex than during earlier times, and this has been argued to be typified as complex hunter-gatherers (Bar-Yosef 2002). Whether or not the Early Natufians exhibited the attributes defined as *complex* hunter-gatherers by Arnold (1996), with ascribed status, and most importantly, control of non-kin labor bases, is moot. Based upon differential distribution of grave goods witnessed in burial data, Wright (1978) argued that there was hierarchical social organization where preferential allocation of grave goods signaled more powerful leaders. In opposition, Belfer-Cohen (1995) countered that this treatment of grave goods was evidence of marked cultural affiliation, or what I assume Belfer-Cohen to infer as burial patterns reflect distinct social groups.

Approximately 8 percent of Early Natufian burials contain grave goods ranging from simplistic to very elaborate. An example of the latter comes from one burial from el-Wad where an intricately produced shell headdress was found on one individual (Bar-Yosef 1998). Examples of the former include other grave goods such as earrings, necklaces and other ornaments made of bone and shell, as well as a bone dagger at Hayonim Cave. Anthropomorphic and zoomorphic figurines have also been recovered from grave contexts (Bar-Yosef 1998).

Other lines of evidence from the Natufian have yet to provide support for complex hunter-gatherer behavior such as intensive storage technology. The lack of intensive storage systems indicates that there is little reason to assume elite control over non-kin labor and any surplus, so it is unlikely that there was complex, at least in terms of Arnold's (1996) definition. Additionally, obtaining a significant conclusion regarding social organization from burials alone is not sufficient; rather there should be other intra-site patterns of possible unequal wealth distribution for contemporaneous households if complex organization was employed (Arnold 2004).

The Late Natufian

The Late Natufian (12,800-11,700/11,500 cal BP) corresponds almost exactly with the timing of the Younger Dryas, a short and abrupt cold spell that had global effects causing the last glacial advance before the onset of Holocene conditions (Bar-Yosef and Meadow 1995). It is widely held that people living during the Late Natufian responded to this climate change by increased residential mobility in reaction to shrinking resource packages, requiring an expansion outside of the original "Natufian Homeland" (Bar-Yosef 1998:162) (Figure 5.4).

Many lines of evidence support this change in settlement pattern as well as significant changes in social structure. First there was a new practice of secondary burials in which skulls were systematically removed. Belfer-Cohen and Bar-Yosef (2000) have argued that this is linked to worship practices within a highly mobile society. Second, lithic assemblages change, particularly a reduction of overall lunate size (Olszewski 1986), which may suggest raw material acquisition patterns changed. Third, most large Early Natufian settlements were abandoned, followed by Late Natufian sites that were much more ephemeral, similar to those of the preceding Early and Middle Epipaleolithic. Fourth, objects of personal adornment cease to be produced and grave goods are completely absent. Lastly, early arguments pointed to the possibility that Natufians exerted sophisticated hunting techniques and specifically culled gazelle for certain characteristics that caused dwarfism in local populations (Cope 1991; Davis 1983; Goring-Morris and Belfer-Cohen 1998). Munro (2004) helps clarify this issue by indicating that while the Early Natufians did not hunt gazelle into extinction, they exerted severe pressure on their populations. In tandem with the poorer climate of the Younger Dryas, subsistence pursuits may have made the Late Natufians revert to higher mobility to shrink group size to cope with changing ecological conditions (Bar-Yosef 1998).

The site of ‘Iraq ed-Dubb contains a Late Natufian occupation in which it appears that the lithic assemblage reflects a high mobility group. Kuijt and Goodale (2009) demonstrate that site structure and use of space was very informal compared with that of the later PPNA occupation. The argument is that less formalized use of space in evident in the Late Natufian deposits and thus, likely highlighting higher mobility and short-term occupation(s) of the site. In contrast, the PPNA deposits indicate more formalized use of space where different areas had different purposes (Kuijt and Goodale 2009).

The Harifian

Briefly, the Harifian of the southern Negev and Sinai is what has been termed a southern Natufian adaptation, mostly contemporaneous with the Late Natufian. The sole difference between Late Natufian and Harifian is the occurrence of the Harif projectile point that may reflect the invention of the bow and arrow (Goring-Morris and Belfer Cohen 1998; Bar-Yosef 1998:168), but this is speculative. In all other aspects, the Harifian is also a mobile adaptation thought to be linked to the Younger Dryas climate deterioration.

Pre-Pottery Neolithic A

The Pre-Pottery Neolithic A (11,700/11,500 – 10,500 cal BP) has been subdivided into two phases: the Khiamian and Sultanian (Bar-Yosef 1998). However, poor understanding of the Khiamian Phase due to the absence of well dated and homogeneous Khiamian PPNA occupations have caused many scholars to debate the actual existence of this as a real cultural subdivision (Finlayson et al. 2003; Garfinkel 1996; Goodale et al. 2002, 2007; Kuijt and Goodale 2006; Sayej 2004). The primary problem is that in every case, a Khiamian assemblage is better explained by site formation processes, notably sediment mixing, rather than an actual cultural affiliation. This is because the sole characteristics of this differentiation are the presence/absence or percentage of different lithic tool types that differentiate the earlier Khiamian phase from the later Sultanian (Bar-Yosef 1998). With the lithic typology basis being the only real distinction, this division sheds little light on any aspect of human behavioral differentiation between these two *entities* (as they are referred to by Bar-Yosef 1998:169). Thus, the actual utility of this distinction is not apparent.

In light of this, my discussion of the PPNA will focus on the entire time period rather than subdividing it. In addition, the variation across the PPNA tool assemblage in the region is so great that several cultural subdivisions could be made through the 1,200 year PPNA period if we were to make divisions solely based on ratios of certain tool types.

The beginnings of the PPNA correspond directly with the onset of Holocene climatic conditions emerging at the end of the Last Glacial Maximum. This period has been regarded for some time as the period when agriculture began an assumption that has only been recently questioned with advances in archeobotanical analysis show evidence of small scale irrigation (Estouti personal communication) but not for fully domesticated plants. The PPNA may be better characterized as the beginig of systematic cultivation. During the PPNA, people were cultivating, harvesting, and processing wild forms of wheat, barley, and other grains (Kuijt and Goring-Morris 2002). Some evidence for the domestic forms of cereal grains have been found at

ZAD 2, a site occupied late in the PPNA, where about a quarter of the recovered grains could be identified as domesticated (Edwards et al. 2004:42) (Figure 5.5). It has also been argued that the actual domesticated forms of these grains do not come about until the EPPNB (although evidence is scanty for this time period; see below) or MPPNB (Verhoeven 2004).

Other subsistence pursuits focused on a broad spectrum of foods including the hunting of medium and small mammals, reptiles, fish, game birds, and an in some sites, an unusual occurrence of birds of prey (Tchernov 1994). It is unknown whether the significance of birds of prey during this time was part of a subsistence strategy as a food item, or if they might have had some other quality related to acquiring certain elements such as the feathers or talons for other purposes. In contrast to the Natufian period when gazelle were a dietary staple constituting up to 95 percent of meat intake (Tchernov 1994:69), in the PPNA there is a significant decrease in the use of gazelle and a widening of the prey spectrum (Henry 1989; Munro 2004; Tchernov 1994). Overall, there appears to be a greater breadth in the diet of people in the PPNA than in the Natufian (Techernov 1994).

The best evidence for the appearance of storage facilities is in PPNA communities, where recent studies indicate that certain structure's had the primary role of storage including Dhra', (Kuijt 2008a; Kuijt and Finlayson n.d.), Netiv Hagdud (Bar-Yosef and Gopher 1997:47); Wadi Faynan 16 (Finlayson and Mithen 2007), and Jericho (Kuijt and Goring-Morris 2002:373) (Figure 5.5). It has become the general consensus that the people of the PPNA were the first to intensively and regularly utilize food storage techniques (Kuijt 2000:80, 2008a) with potential structures and small pits within houses devoted to storage (Twiss 2007). At Dhra' (Finlayson et al. 2003; Goodale et al. 2002; 2008a; Kuijt 2008a; Kuijt and Finlayson n.d.), a number of mud-walled, raised-floor grain storage structures have been identified (Figure 5.6, 5.7 and 5.8). The structures are centrally located within the community, surrounded by stone-walled pithouses and open activity areas, which likely indicates that storage was a communal endeavor rather than a privatized practice (Kuijt 2008a). The Dhra' storage structures represent a very important facet to understanding the significance of cultivation during the PPNA and the best evidence for storage of wild grains. Importantly, the first phase of construction of the granary occurred very early in the Dhra' community, between 11,200 and 11,400 cal BP (Figure 5.7).

Stone-walled pit structures in the PPNA likely functioned as houses and are found at many sites, including Dhra', Netiv Hagdud, Iraq ed-Dubb, Wadi Faynan 16, and others (Goodale et al. 2002; Kuijt and Goodale 2006; In Press; Bar-Yosef and Gopher 1997; Finlayson and Mithen 2007). In the southern Levant there is scanty evidence for non-residential structures except at Jericho where a nine meter tall tower and a massive stone wall were exposed, interpreted as both defense devices and a ceremonial place (Bar-Yosef 1998).

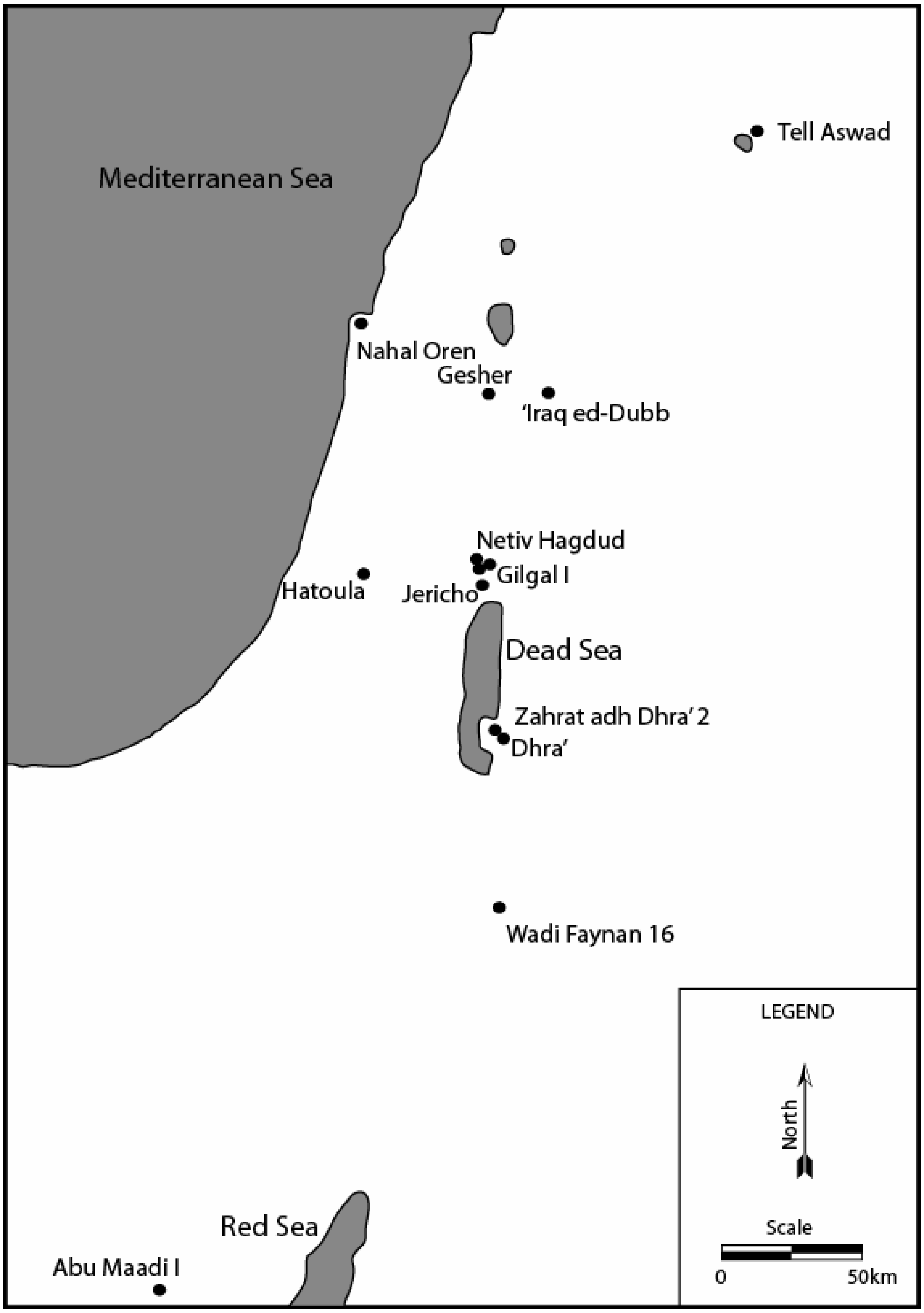

Figure 5.5. Pre-Pottery Neolithic A sites with data available for demographic analysis presented in Chapter Seven.

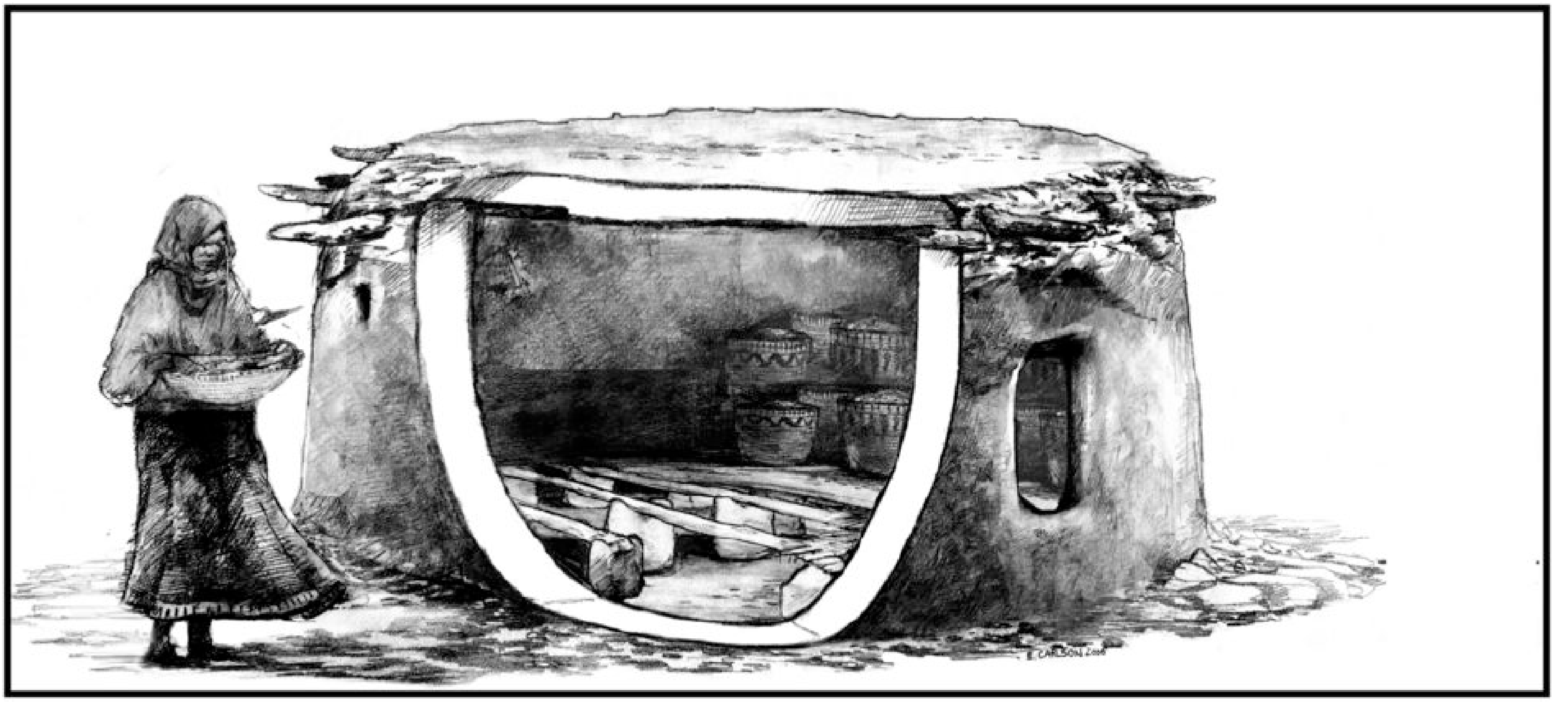

Figure 5.6. Artist reconstruction of the storage structure at Dhra', Jordan. Drawing by Eric Carlson.

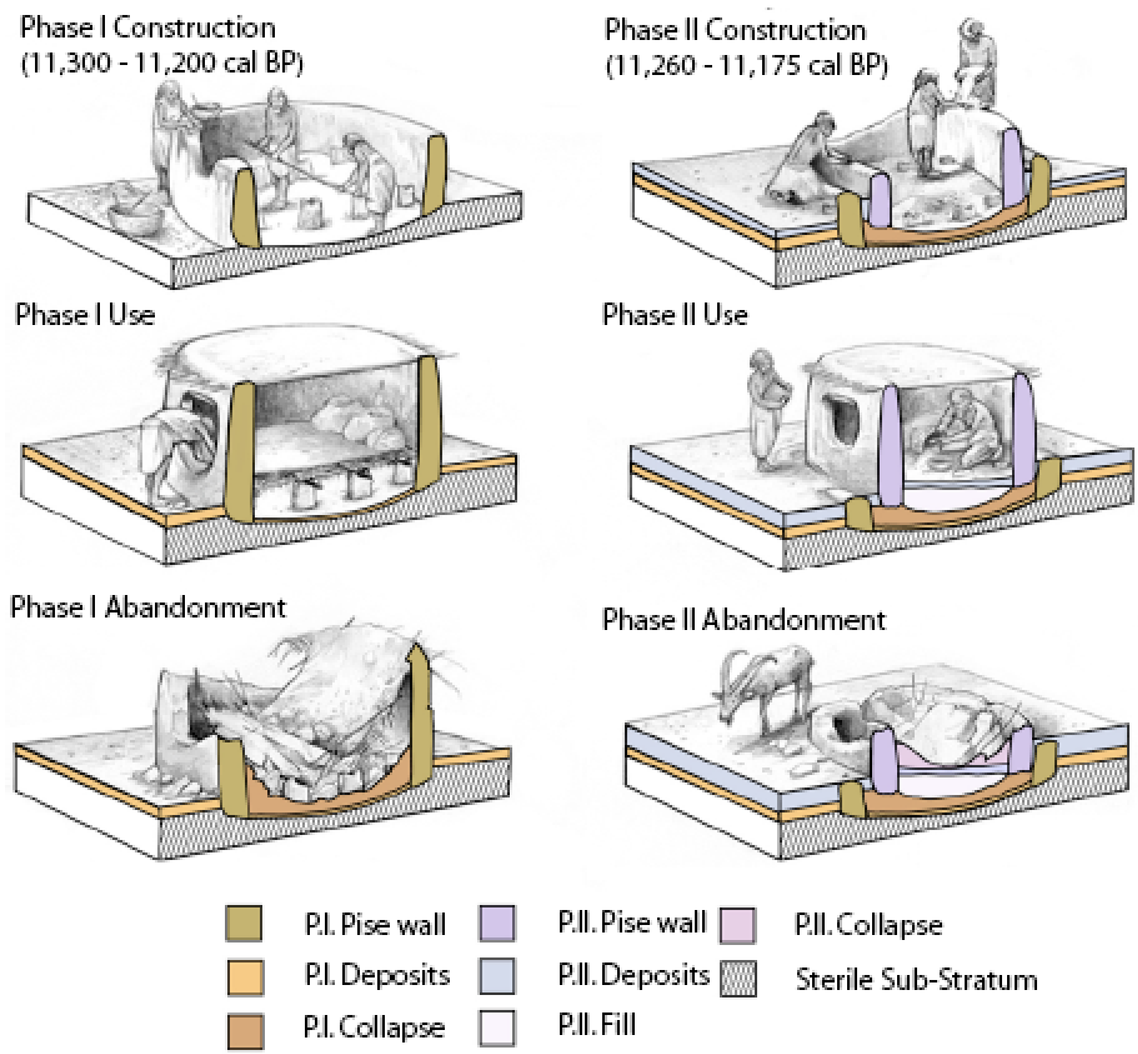

Figure 5.7. Artist's reconstruction of the two phases of construction of one of the storage structures recovered at Dhra', Jordan.

Figure 5.8. Carbonized wild wheat grain recovered from the storage structure at Dhra'.

The greater part of research in the southern Levant has indicated that mortuary practices during the PPNA show continuity with the Late Natufian through secondary burial practices and skull removal (Kuijt and Goring-Morris 2002:376), with little to no associated grave goods. The burial assemblages at Dhra' depict a slightly different picture. Of the seven burials recovered, all are primary internments, suggesting that secondary skull removal was not ubiquitous across the PPNA social landscape. Several also exhibited pestles marking the top of the head (Kuijt and Finlayson n.d.) indicating a particular use of minimal grave goods. Interestingly, the PPNA burials were somewhat standardized for both adults and children, although children have also been found in house contexts, usually within post holes of houses (Kuijt and Goring-Morris 2002).

Technological strategies point to the invention of the notched (projectile?) point (although some see it as related to the development of the Harif Point see Goring-Morris and Belfer-Cohen 1998). Projectile points come in various styles during the PPNA, including the El-Khiam, Salibiya, and Jordan Valley styles. However, it has been demonstrated by Quinn et al. (2008) and Smith (2005) that the invention of the hafted point was not necessarily devised as a hunting armature but instead as a perforating device for soft materials; at least at the site of Dhra'. The evidence comes from replication experiments where the macroscopic breakage patterns are more similar to perforating leather than any other task (Quinn et al. 2008). Additionally, only one el-Khiam out of the nearly 800 recovered from Dhra' has a fracture that could be interpreted as consequence of a high velocity impact (Goodale, analyst observation).

Other new lithic items added to the PPNA tool kit include the Hagdud and Gilgal truncations. These tools may have functioned as arrow barbs or transverse arrow points (Nadel 1997) or as hafted micro scrapers (Sayej 2004). Additional analyses are needed to confirm or refute these hypotheses, including detailed microwear analysis and experimental programs, for these have only been minimally conducted for these tools (Sayej 2004; Smith 2005).

During the PPNA, heavy-use biface tools first seen in Natufian assemblages become more complex in form with large picks, adzes, and axes (Barkai 2005), the last two commonly with transverse blows creating a sharp cutting edge. Sickle blades continue in use and have been found hafted in large bone and wood handles earlier in the Natufian (Edwards 2007). Recent research by Goodale et al. (n.d.) suggest that some of the sickle blades found at Dhra' were intensively utilized on potentially season to multi-season basis. This is based on experimental wheat cutting and quantifying the blade edge within comparison to the amount of harvest time. The sickles from Dhra' also contain polish similar to that produced experimentally by cutting wheat and barley (Unger-Hamilton 1985). Groundstone implements continue to comprise a large percentage of the subsistence processing tool kit in the forms of large to small cup-hole mortars and pestles.

In summary, the PPNA may be characterized as farmer/foragers who likely cultivated wild grains (Kuijt and Goring-Morris 2002:379) but also hunted a variety of wild game. For the first time, economic systems likely had delayed-return benefits. Social organization appears to have been generally egalitarian (Bar-Yosef 1998; Kuijt and Goring-Morris 2002). The PPNA is usually regarded as a major stepping stone in the pathway to the domestication of plants through advances in sedentary village life, storage technology, and formalized village spatial organization.

Early Pre-Pottery Neolithic B

The Early Pre-Pottery Neolithic B (EPPNB) (10,500-10,100 cal BP) is the most poorly documented period of the Pre-Pottery Neolithic and some have questioned it as an actual time stratigraphic unit (Kuijt and Goring-Morris 2002). Most of the evidence for this period has been suggested by Gopher (1994) based on the presence and percentage of different types of projectile points and other lithic items with no associated radiocarbon dates or consideration of other site formation processes (see Edwards et al. 2005 for an overview). This is a similar problem akin to that of the PPNA Khiamian / Sultanian subdivision. Many sites purported to be EPPNB are characterized by lithic remains with no consideration of stratigraphy or site formation processes (i.e. Gopher and Goring-Morris 1998).

One promising site, Motza, has yielded a substantial occupation during the time period considered to be EPPNB (Khalaily 2007) (Figure 5.9). However, Motza is currently the only well-documented site in the southern Levant with numerous radiocarbon dates dating to the EPPNB. In the northern Levant the EPPNB is potentially better documented and it has been argued that the time period shows a mass exodus of people and/or ideas to the southern Levant (Edwards et al. 2004). However, it is possible that the PPNB arose independently in several areas of the Levant (Khalaily 2007). Whatever the case, sites such as Motza contain abundant obsidian, from Anatolia, suggesting that long distance trade networks existed between the northern and southern Levant (Khalaily 2007:33).

EPPNB communities in the northern Levant have also shown domesticated forms of wheat, barley, and lentils where they potentially appear in the southern Levant by the end of the PPNA as evidenced from ZAD 2 discussed earlier (Edwards et al. 2004). EPPNB Motza contains evidence for the first use of the naviform core reduction technique, a highly sophisticated and standardized approach, argued to represent craft artisan support (Khalaily 2007). Burials at Motza are flexed to disarticulated positions and both primary and secondary internments. There are single adult and child burials, but also a grave with a mature male and infant buried together (Khalaily 2007).

Architecture at the site of Motza is represented by curvilinear and rectilinear structures with exterior courtyards and hearths. Motza potentially contains the first archaeological evidence of lime plastered floors in the southern Levant, a characteristic that becomes ubiquitous in the Middle and Late Pre-Pottery Neolithic. Storage technology during the EPPNB may be represented by a series of interior installations (Khalaily 2007). Yet, the complete nature of storage technology during the EPPNB remains unclear due to the limited sites assigned to this period. Additionally, sparse evidence of community organization provides minimal interpretation regarding the social organization of EPPNB communities.

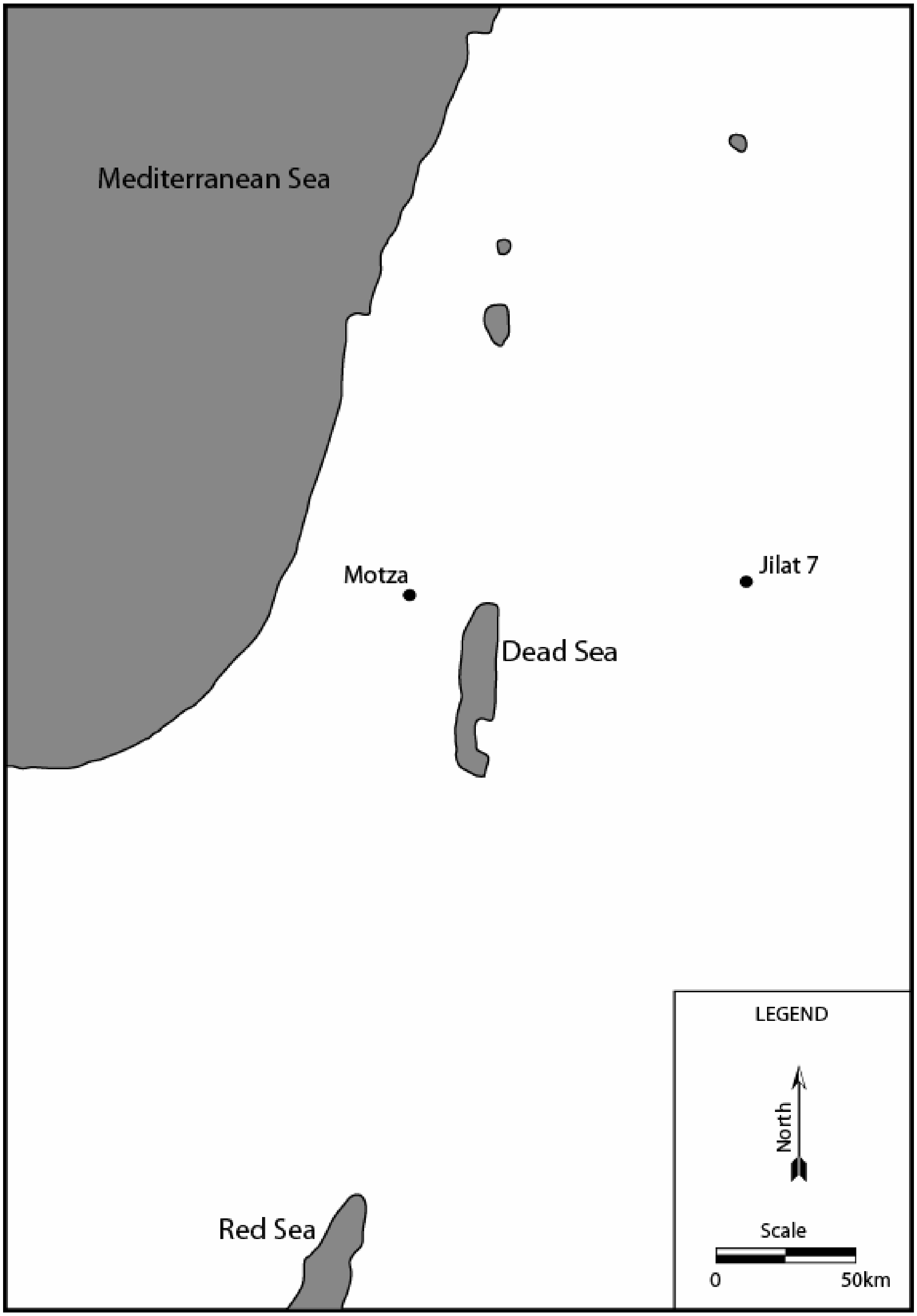

Figure 5.9. Early Pre-Pottery Neolithic B sites with obtainable data for the demographic model.

Middle Pre-Pottery Neolithic B

The Middle Pre-Pottery Neolithic B (MPPNB) (10,100-9,250 cal BP) has a wealth of information to characterize many aspects of socioeconomic systems from sites including Jericho, 'Ain Ghazal, Kfar HaHoresh, Ghwair I, Wadi Shu'eib and Beidha (Figure 5.10). During this time there is the emergence of large communities up to 4-5 hectares in size (Rollefson et al. 1992). The archaeological record of the MPPNB indicates increased population aggregation, complex burial practices with systematic skull removal and re-burial, as well as sophisticated lithic technology that may be representative of craft artisan support (Quintero and Wilke 1995).

MPPNB settlements usually occur in the Mediterranean zone in the Jordan Valley and adjacent areas with desert zone seasonal sites (Kuijt and Goring-Morris 2002). Residential architecture during this time includes rectilinear to sub-rectangular complexes built within close proximity of each other. Early in the MPPNB sequence, posts for supporting roofs are large, 50-60 cm in diameter, but decrease through time suggesting the over exploitation of the environment (Rollefson et al.1992). Buildings always have intensively prepared floors (and often walls) with lime plaster produced by burning lime at high temperatures. At Ain Ghazal and Jericho structures are usually standardized in size and shape with dimensions of 8x4.5m with less than 50cm difference between buildings (Kuijt and Goring-Morris 2002; Rollefson et al. 1992). Other sites such as Kfar HaHoresh and Horvat Galil illustrate the existence of greater size variation and the use of internal partitions and possible special functions sites (Kuijt and Goring-Morris 2002). Non-residential architecture is characterized by sub rectangular to circular structures that are both placed in the center of the village and outside of the village. These structures are found at Beidha, and Kfar HaHoresh (Byrd 1994; Kuijt and Goring-Morris 2002; Rollefson 2004).

Dietary reconstruction through isotope analysis for the MPPNB has suggested that animal protein contributed very little to the human diet during this time (Lösch et al. 2006). While this evidence is from Nevali Çori in southeastern Anatolia, this pattern has not been confirmed in the southern Levant. However, if this were the case, it could indicate that animals were domesticated for purposes other than their meat, potentially for the products that they produce such as wool and milk (Lösch et al. 2006:190). Dietary animal reliance may have been highly variable between communities. Some sites such as Ain Ghazal show that caprines were likely domesticated based on a diminution of size (Köhler-Rollefson et al. 1988). Other sites such as Kfar HaHoresh and Yiftahel yielded no evidence of caprines. MPPNB people subsisted on a wide range of domesticated plants including wheat, barley, peas, lentils, and chickpeas (Kuijt and Goring-Morris 2002:399).

During the MPPNB there is good evidence for large-scale storage practices (Kuijt 2008a:301). Storage techniques demonstrate interior storage facilities within houses (Twiss 2007:29) demonstrated by Garfinkel's (1987) recovery of the remains of a grain storage installation with a domestic structure at Yiftahel. Additionally, the shift from centrally located grain storage structures in the Early Neolithic to within domestic structures in the MPPNB may be indicative of the privatization of food storage.

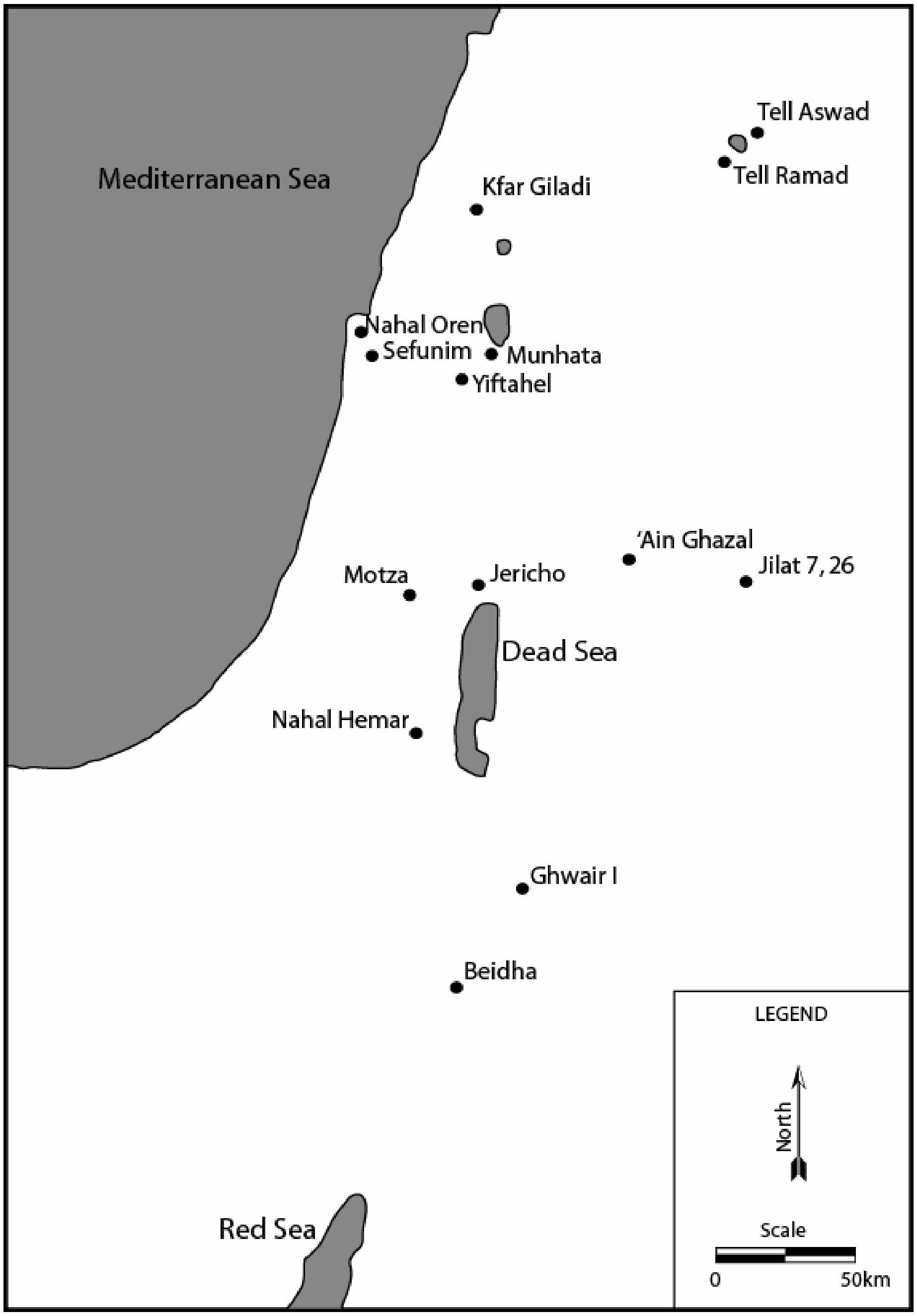

Figure 5.10. Middle Pre-Pottery Neolithic B sites with obtainable data used in the paleodemographic model presented in Chapter Seven.

Burials in the MPPNB are characterized as 1) primary internment of both male and female adults, 2) the internment of infants in single graves, and 3) the secondary removal of some but not all skulls. This has both fascinated and confused archaeologists as to the meanings behind these type of burial practice. As Kuijt (2000) points out, skulls in many instances were reburied in multiples of three. Furthering this argument, Kuijt (2002) suggests that the primary burial within household, or more private areas, represents the initial importance of the ancestor to the household while the secondary removal and reburial of the skull in more public contexts served the purpose to unite different households or the community under more complex social ties (Kuijt 2008b).

In comparison to earlier time periods, the MPPNB shows the advent of systematic realms of symbols, such as a range of face masks, statues, and figurines recovered from Ain Ghazal and Jericho. Other items include clay figurines and at 'Ain Ghazal are a series of killed cattle where flint blades have been stuck into the figurines (Rollefson et al. 1992). This has lead to an interesting aspect of the relationship between wild and domesticated species; Hodder (1990) points out the symbolic depiction of wild rather than domesticated forms in what appears to be ritual contexts and objects.

Social organization for the MPPNB has been discussed and debated for a long time. While most Near East archaeologists would probably agree that there is some evidence for differentiation within Middle and Late PPNB communities, a centralized political authority most likely never existed during that time (Kuijt and Goring-Morris 2002:420). However, there was also likely inter-community integration as evidenced by two-headed statues that have been used to argue that they united members from different communities (see Rollefson et al. 1992). However, many of the other lines of evidence to discuss social organization have not been identified – such as inter and intra-household organization – that will aid in a discussion to adequately assess social organization. Most doubt that the organizational level of a chiefdom was reached during the MPPNB or even the Late Pre-Pottery Neolithic B with a central political authority over many of the large settlements in the southern Levant (Rollefson 2004).

The lithic technology of the MPPNB has been heavily focused on the reduction sequence and greater social importance of the naviform technique (as indicated above, the naviform technique is present at EPPNB Motza) (Quintero and Wilke 1995; Khalailey 2007). The naviform technique was also often utilized on specific raw materials (including pink-purple flint that is available in a few known outcrops in the area; Rollefson et al. 2007). This high quality flint has been found in what has been called specialist workshop areas in a number of sites including 'Ain Ghazal and Wadi Shu'eib (Quintero and Wilke 1995). The naviform technique is a specialized and highly standardized method of core reduction that permits the consistent removal of long straight blades from an opposed platform core (Quintero and Wilke 1995). During this time projectile point types include Jericho and Byblos styles, and other items include long inversely retouched sickle blades and the use of ovate axes (Rollefson et al. 1992).

In summary, the MPPNB represents a very dynamic time in the southern Levant when people established villages on a scale not known in this region before. Domesticated animals as well as plants were in full use, and new symbolic systems were well-developed. The scale and intensity of the number of people in settlements allowed the number of social roles to expand significantly, perhaps enough to support craft artisans. While the MPPNB is a monumental time in the southern Levant, there were tumultuous changes in settlement patterns at the beginning of the Late Pre-Pottery Neolithic B.

Late Pre-Pottery Neolithic B

The transition from the MPPNB to the Late Pre-Pottery Neolithic B (LPPNB) (9,250-8,700 cal BP) includes a drastic change in settlement systems and through an abandonment of villages in the west with the occupation of highly populated villages east of the Jordan Valley (Kuijt and Goring-Morris 2002) (Figure 5.11). It has been suggested that this represents a mass migration of people to the east (Rollefson 2004).

Structures at this time are built in very close proximity to each other, similar to the MPPNB, a potential indication of increasing populations within the community (Kuijt and Goring-Morris 2002). Residential architecture in the form of true two-story structures developed with morphologies and stone work similar to the Pueblos in the American Southwest (Kuijt and Goring-Morris 2002).

Storage technology includes dedicated 1.5-2m^2 rooms for households that lack any domestic artifacts (Kuijt and Goring-Morris 2002:407). Furthermore, two-story buildings have been found in several sites with the first floor as storage with a residential second story (Kuijt 2008a). Nonresidential architecture still appears with special buildings that have unique interior features (inset stones) and little else within them (Rollefson 1998; 2004).

Mortuary practices change in a number of ways from the MPPNB. Differences include the increase of human burial with animals (Kuijt and Goring-Morris 2002:410), and for the first time in the Neolithic there are systematic grave goods including necklaces, shell, pendants, stone beads, bracelets at Ain Ghazal, Basta, Ba'ja, Es-Sifiya (Kuijt and Goring-Morris 2002). Additionally, secondary burials increase dramatically during the MPPNB. Lines of evidence for continuity from the MPPNB is minimal but include burial practices are the presence of stone skull masks at Basta and plastered human skulls at Ramad (Kuijt and Goring-Morris 2002).

Subsistence shows the domestication of animals such as goats, pigs, cattle, and sheep (Köhler-Rollefson et al. 1988; Bar-Yosef and Meadow 1995). Although complete analysis of plant remains from many of the large scale LPPNB villages is yet to happen, small scale projects have demonstrated that people were utilizing a broad range of domesticated plants.

Lithics are very similar to the MPPNB, but Kuijt and Goring-Morris (2002:412) have noted the possible decline in naviform products or potentially becoming less standardized (Quintero and Wilke 1995). Amuq and Byblos points are very prevalent in assemblages along with flint sickle blades and groundstone tools.

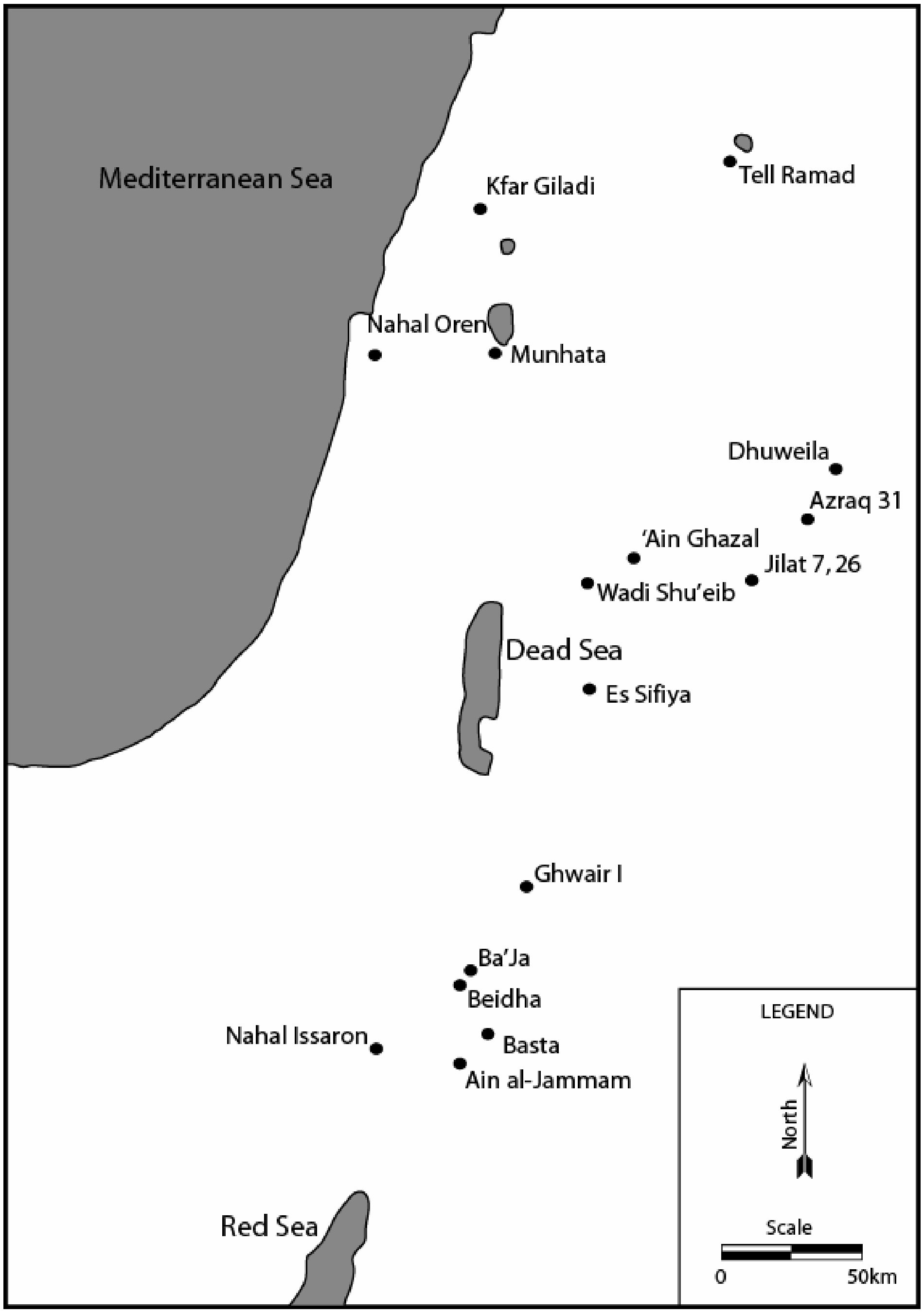

Figure 5.11. Late Pre-Pottery Neolithic sites with obtainable data for the paleodemographic model presented in Chapter Seven.

Overall, the most significant component of the LPPNB is what appears to be an increase of human population numbers, and probably the most intense growth is toward the end of the LPPNB. Along with this we see that the overall importance of domesticated animals had increased substantially, especially with the introduction of domesticated sheep. True two story architecture probably aided in the ability to store foods in order to feed a larger population.

Pre Pottery Neolithic C

The final period of the Pre-Pottery Neolithic, named the Final Pre-Pottery Neolithic B (FPPNB) or more recently called the Pre-Pottery Neolithic C (PPNC) (Rollefson 1990; Rollefson and Simmons 1986) is a fairly new time stratigraphic unit. Until 25 years ago, settlements of this period were unknown. However, as demonstrated by ‘Ain Ghazal, Wadi Sh’eib and other sites, the formally regarded hiatus from the Pre-Pottery Neolithic to the Pottery Neolithic is instead a dramatic shift in settlement patterns (Figure 5.12). This time shows the abandonment of most of the large Pre-Pottery Neolithic villages but some were not abandoned and are characterized by reused PPNB architecture or newly constructed more ephemeral buildings. ‘Ain Ghazal contracted in size and population size probably decline significantly (Rollefson 2000:187).

It has been argued that this period may represent a higher reliance on more nomadic pastoralism. Some have argued that the over-exploitation of local wood for the production of lime plaster had the consequence of damaging the environment to the point where large-scale agricultural communities could no longer be supported. This also indicated a time when lime plastering of house floors and walls decreased completely.

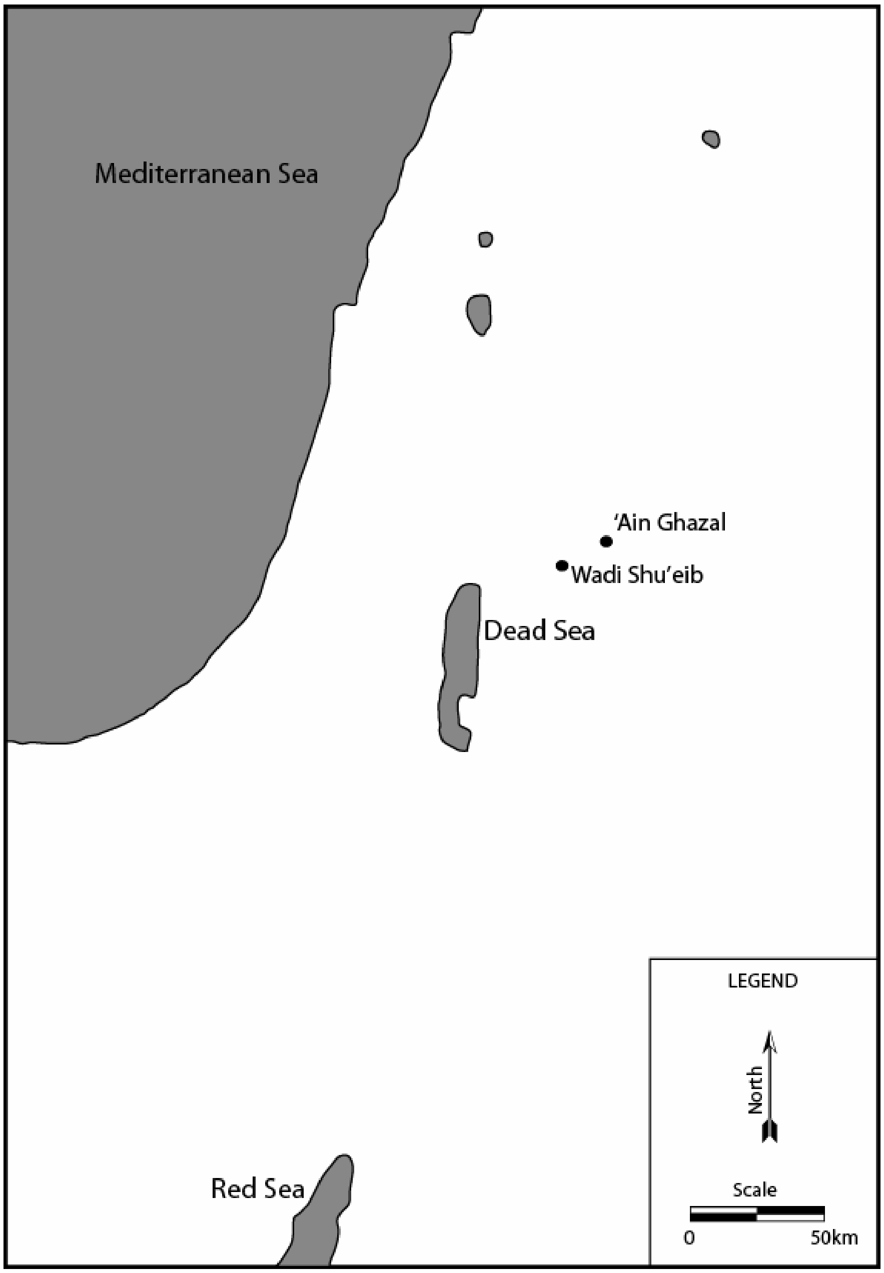

Figure 5.12. Pre-Pottery Neolithic C sites with obtainable data for the paleodemographic model presented in Chapter Seven.

The limited nature of archaeological investigations for this time period has provided little information regarding social organization however, with the major changes in settlement, there was likely a large scale social reorganization. Burials in the PPNC are often in single to multiple individual internments and isolated human bone fragments are quite common which may be representative of disturbed earlier burials (Rollefson 1998). Interestingly, the first known case of tuberculosis has been recovered from PPNC 'Ain Ghazal which el-Najjar et al. (1996) suggest may be a direct indicator of humans interaction with diseased animals. Increased reliance on only a limited number of plant and animal species may be indicated and domesticate caprines comprised about 70 percent of the recovered faunal assemblages where sheep appear to far outweigh goats (Kuijt and Goring-Morris 2002; Kuijt 2008a).

Summary

Through the examination of the prehistory of the southern Levant from the Early Epipaleolithic to the end of the Pre-Pottery Neolithic period, we witness many fascinating trends in the evolutionary history of human societies. These include the appearance of the first sedentary communities; the development of storage technologies; subsistence intensification, which lead to the domestication of plants and animals; the rise of the first town-scale communities; and the ability to potentially support craft artisans. The rich archaeological record of the area, coupled with the abundant data (as well as consistently recorded variables of proxies of human population densities) available in the published literature, make the southern Levant a particularly interesting case study in which a paleodemographic model of the substantial increase in human numbers associated with the NDT can be developed. In the next chapter I cover the methodology utilized to accomplish this task.

CHAPTER SIX

MEASURING POPULATION GROWTH RATES AT THE DAWN OF AGRICULTURE

An important aspect of building an accurate but versatile demographic model from the archaeological record is selecting pertinent and viable data. Foremost, a model must incorporate multiple variables appropriate for population reconstruction. Second, the data must be readily available from archaeological literature from several geographic areas. Importantly, each proxy should be a standard measure that researchers commonly present in site reports as well as in larger discussion pieces regarding changing settlement practices and mobility strategies.

The purpose of this chapter is twofold, first, to outline the proxies of population growth used to interpret population growth rates during the transition to agriculture in the southern Levant, and second, to introduce new analytical techniques of assessing population demography using multiple variables representing population proxies. Importantly, variable proposed has been utilized as a measure of human population density by archaeologists and paleodemographers and is readily available in archaeological literature. The measures presented here include 1) habitation area defined in hectares, 2) depth of deposits in meters, 3) frequency of sites occupied in 50-year increments based on the 95 percent confidence interval of their associated ^{14}C dates and, 4) ^{14}C date frequency expressed as the total frequency of ^{14}C dates occurring in 50-year increments where each date is counted in every 50-year interval that its 95 percent confidence interval spans. In other words, if a date has a calibrated range of 11,400-11,000 calibrated BP, it would be counted in each of the 50-year increments. As specified below, certain criteria were established to determine if specific data could be used based on its integrity in terms of both accuracy (if the date makes sense to the original excavator) and precision (the error range fit within some expectation).

The second section of this chapter covers the analytical technique cross-correlation (or convolution analysis) and its potential utility to directly analyze and compare these variables as proxies of population. The cross-correlation analysis technique is used to examine how well each variable correlates to the others with the hypothesis that if all of these variables are monitoring and tracking the same phenomenon (population growth), then there should be a strong cross-correlation.

Proxies of Population Growth

In this section the proxies utilized in the paleodemographic models demonstrating past population growth are outlined. Each variable is utilized as a proxy of human occupation or in other words, higher values should be reflective of higher numbers of people.

^{14}C Date Frequency

In the past several decades the abundance and precision of ^{14}C dates have enabled archaeologists to examine large-scale spatiotemporal problems (Chamberlain 2006). ^{14}C date distribution has been regularly utilized as a population proxy as a signature of human activity (Anderson and Faught 2000; Barrientos and Perez 2005; Bocquet-Appel and Demars 2000; Brantingham et al. 2004; Fort et al. 2004; Gamble et al. 2004; Goodale et al. 2004, 2008a; Housley et al. 1997; Pettitt 1999; Rick 1987). Rick (1987) argued that radiocarbon date frequency can be representative of human population densities, and their distribution can reflect changing settlement systems or population replacements. ^{14}C dates have been utilized to trace the demise of the last Neanderthals in Europe (Bocquet-Appel and Demars 2000; Pettitt 1999), paleodemography and the transition to resource intensification in the Pacific Northwest of North America (Goodale et al. 2004, 2008a), continental colonization of Europe after the last glacial maximum (Fort et al. 2004; Gamble et al. 2004; Housley et al. 1997) and the Americas (Anderson and Faught 2000) as well as detecting the hiatus of human occupation during the middle Holocene in the Pampas of Argentina (Barrientos and Perez 2005). In all of these studies both the frequency and the distribution of ^{14}C dates is an important parameter in the signal of human activity and population densities.

While temporal frequency distributions have been a common method in order to measure the extent of human activity, the analytical technique has not gone without criticism (Surovell and Brantingham 2007). The basic premise of the critique is that in most instances the frequency distributions of radiocarbon dates as well as sites take the form of a positive curvilinear function (Surovell and Brantingham 2007). In the traditional context, this would indicate that frequency increases as human activity increased; however, this is also the exact outcome if one assumes that taphonomic conditions produce a bias where the constant destruction of sites ensures that as the farther one goes back in time, the weaker the demographic signal (Surovell and Brantingham 2007).

Briefly, in attempt to explore issues of taphonomic bias (Surovell and Brantingham 2007:1874) in these frequency datasets, I first compare the value for $1/\lambda$ (the value to control the rate of drop off in the decaying exponential model) for all of the variables. Second, while Surovell and Brantingham (2007) are correct that the systematic destruction of sites through time should be modeled as a decaying exponential, they do not consider the rate at which sites are added. In order to compensate for this, the final section of Chapter Seven presents a computer simulation taking into account both the rate of site destruction and additions to the archaeological record. The results of both of these analyses suggest that the data utilized to build the population growth rate model are not severely impacted by taphonomic bias. Additionally, as suggested by Surovell and Brantingham (2007:1874) to correct for taphonomic bias, short-term variation (50-year increments in this study) is superimposed over long-term trends (22-8kya). This technique is appropriate because while taphonomic bias will influence the long-term trend, it should be less severe on short-time scales.

I utilize the 95 percent (two σ) confidence interval of each ^{14}C dataset as a proxy for human activity from Early Epipaleolithic to the end of the Pre-Pottery Neolithic 20,000 to 8,000 years ago. As a method of standardization, this period of time was subdivided into 50-year increments. The frequency of ^{14}C dates was calculated for each 50-year time interval for the entire range of the 95 percent confidence interval. It is expected that if ^{14}C dates correlate with population increase, there should be a statistically significant positive correlation through time, even without the affect of taphonomic bias.

^{14}C Dataset

Most of the ^{14}C dates utilized in this study can be found in the C^{14} radiocarbon CONTEXT database (Böhner and Schyle 2006), an online database that is free to download. The database contains a large number of ^{14}C dates and most of the original references where those dates were published from the Near East, Africa and Europe. While this resource is available, it did not provide the dataset utilized in this study. Instead, it served as a reference point, as all data compiled to build the demographic model in this study were pulled from the original literature. While compiling the data for the model, my relationship with the CONTEXT dataset was somewhat of a double-edged-sword. In many instances I found typographical errors in the CONTEXT database, missing references, and data I found that was not included. However, the database did aid in making sure that I could trace back as much data as possible to build the demographic model and make it as precise, detailed, and accurate as possible.

^{14}C dates were included only if a number of criteria could be met. The first criterion for a ^{14}C date to be included in the analysis is that it could be traced back to the original literature. If a date could not be found in the original literature or through personal communication with the principal investigator, the date was not included in the database. The second criterion for a date to be included in the database was that it dated archaeological deposits in the southern Levant, thus, all northern Levant dates were excluded from the analysis. The third criterion for inclusion in the database is related to its stratigraphic integrity. If the literature presenting the ^{14}C date questioned the relationship between the timing of the date in association with the archaeological materials, the date was not included in the analysis. Lastly, if the ^{14}C date has an error range exceeding ± 10 percent of the mean of the date, the date was excluded from the database.

Each ^{14}C date was calibrated with OxCal v.3 to the 95 percent confidence interval. In total, the population of ^{14}C dates utilized in this study is $N = 520$, where the range fell within the time frame of 20,000 to 8,000 cal BP from the Early Epipaleoltihic through to the end of the Pre-Pottery Neolithic.

Habitation Area in Hectares

Habitation area or site size refers to the horizontal extent of archeological deposits. Site size has been considered in relationship to population predominantly to estimate how many people occupy some given amount of space based on ethnographic accounts that are then projected into the past (Adams 1965; Kramer 1978), although the actual ability to do this has been questioned (Kuijt 2000). Kuijt (2000) demonstrates that the figures for estimating how many people actually occupy a defined amount of space vary greatly cross-culturally and through time. Despite this problem, there does appear to be a fairly strong correlation between area occupied and population size in modern Southwest Asia (Kramer 1978). Because of these disparate viewpoints, in this study I do not attempt to place any figure of actual human numbers occupying a defined unit of space and instead only rely on site size as a relative proxy of human population size. The use of the data in this manner is also appropriate for examining long-term trends in population growth and decline, where the densities of humans within a defined area most likely changed dramatically. Thus, one figure of human numbers per defined area is insufficient for this study.

Habitation area is probably the most common variable presented for prehistoric archaeological sites in the southern Levantine literature. Predominantly, habitation area is calculated for the Epipaleolithic in square meters and in hectares for the Neolithic. Site size is normally estimated by the spatial extent of archaeological materials. All data utilized here have been converted into hectares. Habitation size was counted for each 50-year increment that the ^{14}C data indicated the site could have been occupied indicated by the 95 percent confidence interval. In this analysis, the full site size was assigned all of the time periods. In the future, I would probably do this differently by proportioning the amount of site size to the likely hood ratio that the calibrated date fall. Nonetheless, it is expected that if site size is a relatively accurate predictor of increasing populations, there will be a statistically significant positive correlation with time.

Depth of Deposits

Depth of deposit or site volume has been utilized, although rarely, as a proxy of population density. Ammerman et al. (1976) directly attribute the depth of deposits in connection with other lines of evidence including the amount of time that the site was occupied, and the volume of interior house materials in order to estimate the number of houses occupied at any given time. With an assumption of five people per house, Ammerman et al. (1976) then calculate how many people may have occupied the site at a time.

Similar to the issues discussed above concerning habitation area, in this study I do not superimpose any specific numbers of humans in relation to the depth of deposits. Instead, depth of deposits is used as a relative proxy of human population where deeper deposits represent more intense human occupation and thus, a greater number of humans. Similar to site size, depths of deposits were monitored for each 50-year interval that the site could have been occupied indicated by the ^{14}C 95 percent confidence interval. It is expected that if depth of deposits is a relatively accurate predictor of increasing populations, there will be a statistically significant positive correlation with time.

Frequency of Sites Occupied

The frequency of sites occupied at any give time directly relates to the larger regional settlement patterns reflecting the larger use of the landscape (Adams et al. 2001; Waters and Kuehn 1996). While the frequency of sites occupied through time may serve as a proxy for human population, a non-statistically significant positive or even a negative correlation through time may be indicative of population packing events rather than actual increasing population numbers. This would be indicative of increasing population density and humans packing into fewer aggregates. In other words, a signature of population packing should be a non-statistically significant positive correlation or a negative correlation. In opposition, a statistically significant positive correlation would be indicative of not only increasing population but also increasing population density. This is supposes that depth of deposits, site size, and the frequency of ^{14}C are statistically positive, likely signifying increased population growth through time. In this study, the frequency of sites occupied was graphed by the associated ^{14}C date(s) 95 percent confidence interval for every associated 50-year increment.

Analytical Techniques

The data are analyzed with several techniques in Chapter Seven. This includes simple linear regression, a parametric regression analysis technique utilized to predict the outcome of one variable from another. Since regression analysis assumes normality, the raw data values for each variable were transformed into LOG_{10} expressions as all of the datasets were positively skewed. All of the regression analyses were conducted with the computer statistical program SAS v.8. The other analytical technique utilized in Chapter Seven is cross-correlation analysis. As this technique has not been used to my knowledge with archaeological datasets, a detailed discussion of cross-correlation analysis is provided at the end of this chapter. The cross-correlation analysis was conducted with the mathematical computation program, Mathematica v. 7.0.

Summary

While admitting that several variables in use here may be influenced by taphonomic bias or the natural destruction of archaeological deposits, "this is not to say that examining such datasets is a worthless endeavor" (Surovell and Brantingham 2007:1874). Instead, under a cautious approach utilizing several variables as well as analytical techniques to compare the resulting datasets, I hope to circumvent most of the problems of taphonomic bias. The next section provides a detailed overview of the technique, cross-correlation analysis, which will provide a graphical summary to test a series of expectations if the datasets are reliable indicators of population. As noted above, we expect that if each variable is a relatively accurate proxy of the same phenomenon (population growth), we should expect each variable to monitor and track that phenomenon in a similar manner.

Cross-correlation Analysis

Cross-correlation is an alignment algorithm used to find patterns between two datasets (Rockwood et al. 2005). In every case, the researcher takes a pattern (for example DNA sequences, ink chromatograms, or a portion of two images) and then slides it over another pattern that is suspected to match up with it in some manner

(Djozan et al. 2008; Rockwood et al. 2005). For each position in the sliding, the correlation provides one number; and when the numbers are plotted, there will generally be a few peaks; the highest peak demonstrates where the datasets best align.

Cross-correlation Example 1

One way the cross-correlation can be thought of is going down the aisles in a shoe store, trying on a bunch of pairs of shoes sizes 4 through 16+ and giving each a rating. Those you cannot put on, or fall right off, get very low scores; and those that fit your feet generally get a high rating. Producing a plot of rated score versus where you are in the shoe store will provide a view of the topographical landscape; the valleys correspond to shoes of the wrong size or shape, and the peaks (say in the right-sized sandals section) where size and fit are just right for you. In this case, your feet (*a*) are the sliding pattern, the shoes (*b*) in the shoe store are the fixed pattern you're sliding over, and however you rate the comfort of the shoes is the scoring criterion(N) for forming the cross-correlation (Figure 6.1 (A)).

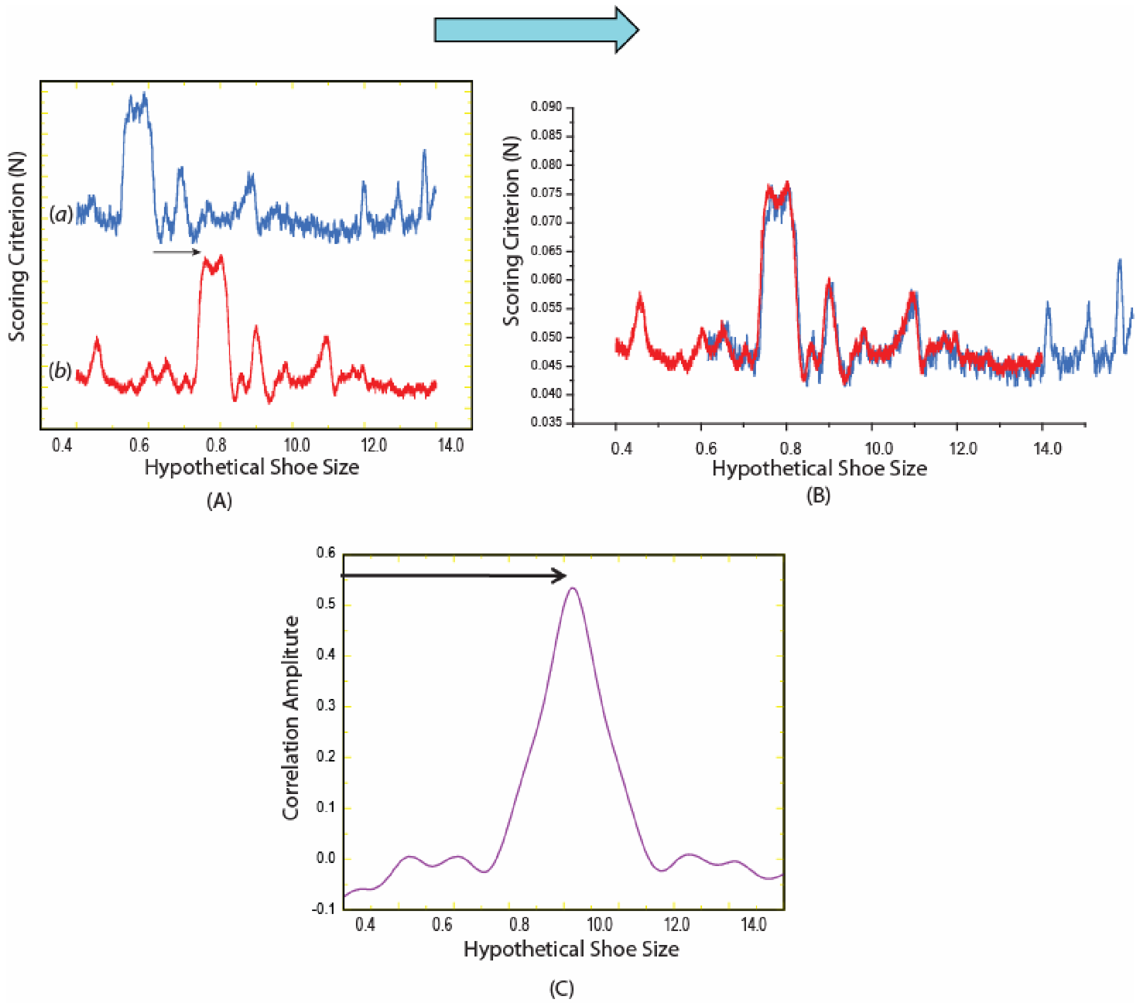

Figure 6.1. A graphic illustration of the cross-correlation procedure where (A) represents the two functions for comparison, (B) represents the shift required to match up the two functions and (C) represents the cross-correlation where the peak is the best fit between the functions.

Thus, wherever the peaks are in the *ab*N numbers, they tell us how far the analyst has to shift, say, *b* to get it to line up the best with *a* (Figure 6.1 (B)); the height of the peak (and in some sense, the narrowness of its width) demonstrates how good the match is between *a* and *b*; and so on. In other words, if *ab*9.5 is by far the highest number in all of the sets that are cross correlated, it indicates that *a* and *b* match up the best at shoe size 9.5 (Figure 6.1 (C)). Furthermore, cross-correlation provides a method where we can examine several datasets, say, where the sizes of different types of shoes fit the best. Thus, we can examine if sandals (c) fit the best in the same size as dress shoes (d), athletic shoes (e) etc. The two types of shoes that fit the best in the same range will score the highest (N) and thus, have the highest cross-correlation.

Cross-correlation Example 2

For humans, picking patterns out from images is remarkably easy, sometimes too easy. We can recognize the faces of long-lost relatives in photographs and paintings, even though we may not have ever seen the person depicted before. We can pick our native written language out of examples of thousands of typeset or even handwritten words, and we can match pieces to gaps in a jigsaw puzzle, despite not being sure of which position or orientation the piece should have. Before computers took over the task of matching fingerprints found at a scene to those residing in a catalog, the task was done by having human investigators look at the found print (called here the target; see Figure 6.2) and turn them this way and that, running them down a row of suspect prints (the template), mentally filling in gaps and deleting ink-blots, and rescaling the target print until they made the best match possible with the template prints.

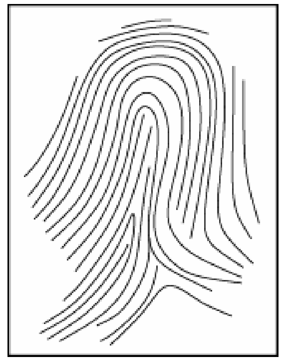

Figure 6.2. A typical target fingerprint.

Having a computer do this is by no means a difficult feat. The heart of almost every pattern-matching program is cross-correlation analysis, which will be illustrated here in example 2 with the task of matching a fingerprint against a catalog of several others (potentially millions). One way in which to have a computer match a finger print against another is to digitize the print in strips, as shown in Figure 6.2. Wherever a ridge (dark on a print) makes a prominent appearance in a given strip, a high number is given to the strip at that location; lower numbers indicate a valley of the print, or no print at all. The computer's task is then to rapidly match each strip of a target print against the millions present in a large repository of template prints.

Figure 6.3b shows the blue trace from 6.3a, and a copy of it that has been shifted to the right, and changed by adding noise to it. This simulates what might happen when the print is lifted under different situations. The challenge is to figure out how much the gray trace (the target) must be moved to line up best with the blue trace (the template). Additionally, we want to come up with a way of quantifying the goodness-of-fit once the best shift has been found. The cross-correlation incorporates this naturally.

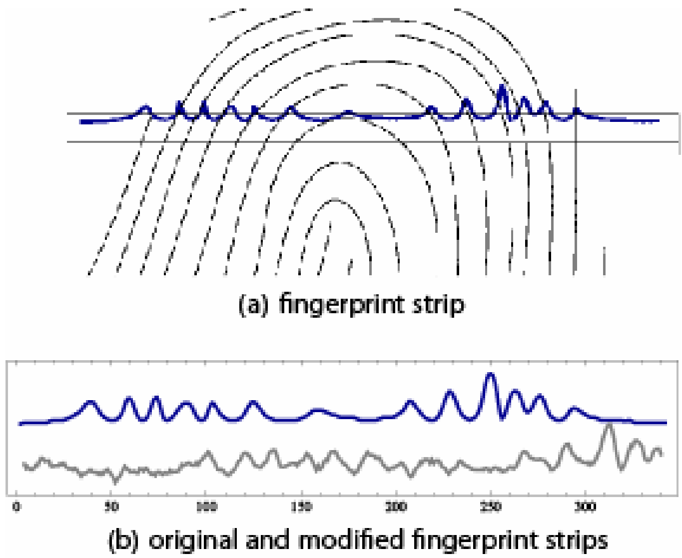

Figure 6.3. (a) A fingerprint, digitized in strips. The blue trace shows the pixel density in a given strip; higher pixel density indicates a ridge at that point in the strip. Sampling the fingerprint under different conditions can lead to changes; **(b)**shows the original strip and a shifted, noisy version.

To start, the target trace is shifted all the way to the left, and both traces are zero-padded (Figure 6.4). Each trace is divided into bins which are one point wide, and the numbers in each corresponding bin are multiplied together. All of the resulting numbers are then added, to give one number (the correlation) corresponding to this fully leftward-shifted position of the target. Because of the zero-padding, those portions of the traces that do not overlap automatically get a value of zero and add nothing to the total.

Table 1 illustrates three steps in a cross-correlation of two small datasets. The resulting data structure can be expressed as

$$\{\ldots,\{j,\sum_{i=1}^{N} tem_i \times tar_{i-j}\},\ldots\},$$ (eq 6.1)

where N is the length of the target and template (*tem*) datasets, and *j* represents the amount of the shift applied to the target (*tar*) set (*j* can run from -N when the target set is shifted all the way to the left, to +N when the target set is shifted all the way to the right).

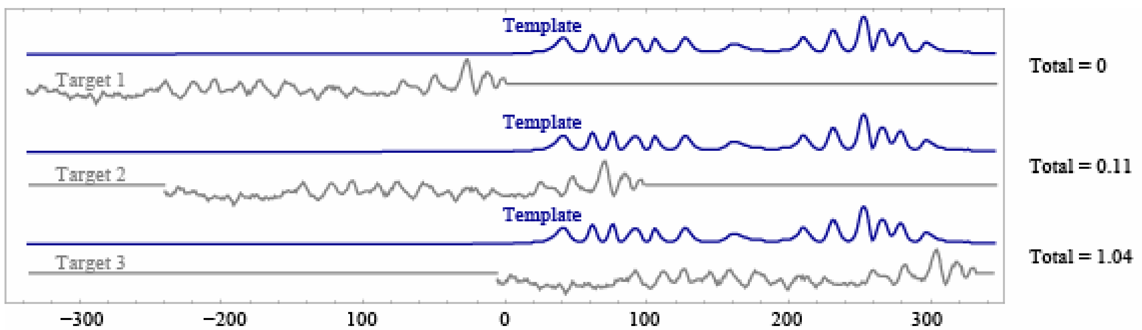

Figure 6.4 A zero-padded template (blue) and a fully left-shifted, zero-padded target (gray) at three different shifts in the cross-correlation process.

Once the set of numbers is compiled for all of the shifts, the computer can look for peaks. These peaks occur when the two datasets have numbers that match up well, so the sums of the products add to large numbers. Note that the sums can be negative if the multiplications give more negative numbers than positive numbers. Negative sums imply that for those shifts, the datasets are generally matching peaks with valleys. The cross-correlation between the two traces in 6.3b is shown in Figure 6.5.

Table 6.1. Three Steps (shifts) During a Cross-Correlation.

O1	O2	O3	O4	O5	O6	Shift #
3.20	3.40	3.10	2.70	2.00	1.50	template shift 2
0.00	0.00	-0.40	0.10	0.14	0.40	target
0.00	0.00	-1.24	0.27	0.28	0.60	S =-0.09
3.20	3.40	3.10	2.70	2.00	1.50	template shift 3
0.00	0.00	0.00	-0.40	0.10	0.14	target
0.00	0.00	0.00	-1.08	0.20	0.21	S =-0.67
3.20	3.40	3.10	2.70	2.00	1.50	template shift 4
0.00	0.00	0.00	0.00	-0.40	0.10	target
0.00	0.00	0.00	0.00	-0.80	0.15	S =-0.65

Note: the template dataset is held constant, while the target dataset is slid alongside it, by one position during each step. The numbers at the same position in the template and target are multiplied, and then the entire result is added up to give a total number for each shift. The resulting cross-correlation would have the structure {…,{2,-0.09}, {3, -0.67}, {4, -0.65},…}.

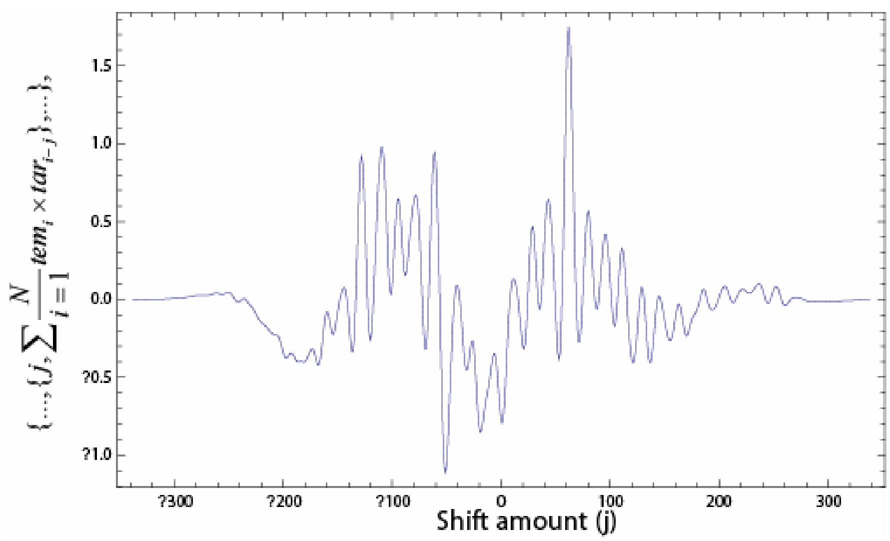

Figure 6.5. The result of the cross-correlation of the two traces in Figure 6.3b. The large peak at a shift of+61 indicates that the target trace (gray) should be shifted 61 positions to the left (alternatively, the blue trace should be shifted 61 places to the right) to match up best.

Summary

There have been a number of ways in which archaeologists have attempted to model past population fluctuations. In this chapter I have presented the variables used to interpret past population growth through the transition to agriculture in the southern Levant. Importantly, each line of evidence to build the cultural model is a standard line of evidence that researchers normally present in site reports as well as in larger discussion pieces regarding changing settlement patterns and mobility strategies (Kuijt and Bar-Yosef 1994). Additionally, each variable has been adopted by archaeologists and paleodemographers as proxies of human population densities. Through utilizing multiple variables in concert with regression and cross-correlation analysis, a number of expectations will tested in order to determine if the data are fairly accurate measures of population and not overly skewed by taphonomic bias. In Chapter Seven, the results of the data analysis are presented as well as the paleodemographic model of the NDT in the southern Levant.

CHAPTER SEVEN

THE NEOLITHIC DEMOGRAPHIC TRANSITION IN THE SOUTHERN LEVANT: A POPULATION GROWTH RATE MODEL

Although a daunting task, archaeologists largely remain fascinated by population size and the remains in the archaeological record that may allow us to estimate past population growth rates. The Neolithic demographic transition, defined as a substantial increase in human numbers, should logically be quantifiable based on archaeological data, apart from paleoanthropological markers in cemeteries (Bocquet-Appel 2002; Bocquet-Appel and Naji 2006). This chapter is dedicated to building a model of population growth rates based on the variables presented in Chapter Six.

I argued in previous chapters that the NDT was a caused by 1) an increase in fertility as a result of certain foods being available on a longer than seasonal basis, and 2) population growth as a result of labor reorganization to in incorporate younger age classes that helped feed larger families. While these points were argued, it is beyond my means to quantify these aspects of the model at this point. Instead, my focus in this study is to present the population growth rate portion of the model and bring all other components of the model together in the concluding chapter.

In order to avoid imposing specific numbers of people in the past for a certain unit of space, we can instead examine proxies of human populations or the intensity of human occupation in some defined space. The population proxy model discussed here attempts to demonstrate 1) that the data should not be overly influenced by taphonomic bias, 2) that each variable demonstrates a statistically significant positive correlation of increasing population densities through time, 3) that each variable has a good cross-correlation with the others, which would indicate that each variable is tracking the same phenomenon (population growth) in a relatively consistent manner, and 4) because results 1-3 indicate that the data should be fairly reliable indicators that are tracking population growth, we should be able to employ the data to examine population growth rates. Finally, the population growth model is compared to a simulation of how population growth should pattern if 1) there is a reasonably consistent growth of population in comparison to 2) differing rates of taphonomic processes that are influencing the destruction of the archaeological record at different rates. Surovell and Brantingham (2007) develop a similar simulation, yet mine differs in that it considers both the rate of addition and subtraction of sites from the record. The simulation demonstrates very similar patterns to increasing population through time with minimal destruction of the archaeological record.

The Data

As covered in Chapter Six, the data utilized here to model population growth rates include the total depth of deposits, the total site area in hectares, the frequency of sites occupied and the frequency of ^{14}C dates occurring in each 50-year increment from 20,000 to 8,000 cal BP. The data analyzed here can be found by site in Appendix A and by time interval in Appendix B. Additionally, all of the references to where the data were obtained are documented in Appendix C. All data are from the southern Levant and gathered from the published literature. Sites were included in the analysis if they were dated using radiocarbon means and if the principal investigator agreed with the dates. In total, I recovered 109 archaeological sites with affiliated and reliable ^{14}C dates spanning this period. I was able to recover information on the depth of deposits and site size for many of the sites, although not all of them as indicated in Appendix A. In some cases below, the raw data was utilized in the analysis, such as with the regression analysis, but were transformed for normality as required by the technique. However, in the population growth rate model, the raw data have been converted to the percentage of the total of each variable occurring in each 50-year increment. This was in order to put each variable on the same scale for comparison.

Decaying Exponentials and Taphonomic Bias

Discussed in Chapter Six, taphonomic bias (Surovell and Brantingham 2007), or the destruction of sites over time, could present problems for accurately estimating past populations. In short, there are three rudimentary issues of taphonomic bias in using archaeological data to reconstruct population size, 1) the visibility of older versus younger sites lending to identification and dating, 2) the validity of older versus younger archaeological deposits as they become more disturbed through time and 3) the destructive processes that have removed sites from the archaeological record consistently through time, thus making older materials less abundant than they originally were.

In order to address the influences of taphonomic bias in the population proxy model for the southern Levantine Neolithic and Epipaleolithic, I examined patterns in the variables of site size and depth of deposits dating from 8000-20,000 calibrated years ago. Best-fit exponential decay models were found for all variables. The exponential decay models are determined by finding a *1/λ* value. *1/λ* controls the rate of exponential decay in the model and can be thought of as the constant rate of site destruction of one site a year, regardless of the number of sites added each year. By presenting the patterns of site size and depth of deposits with a best fit 1/*λ* value, we can estimate how significantly processes of taphonomic bias may be influencing the dataset.

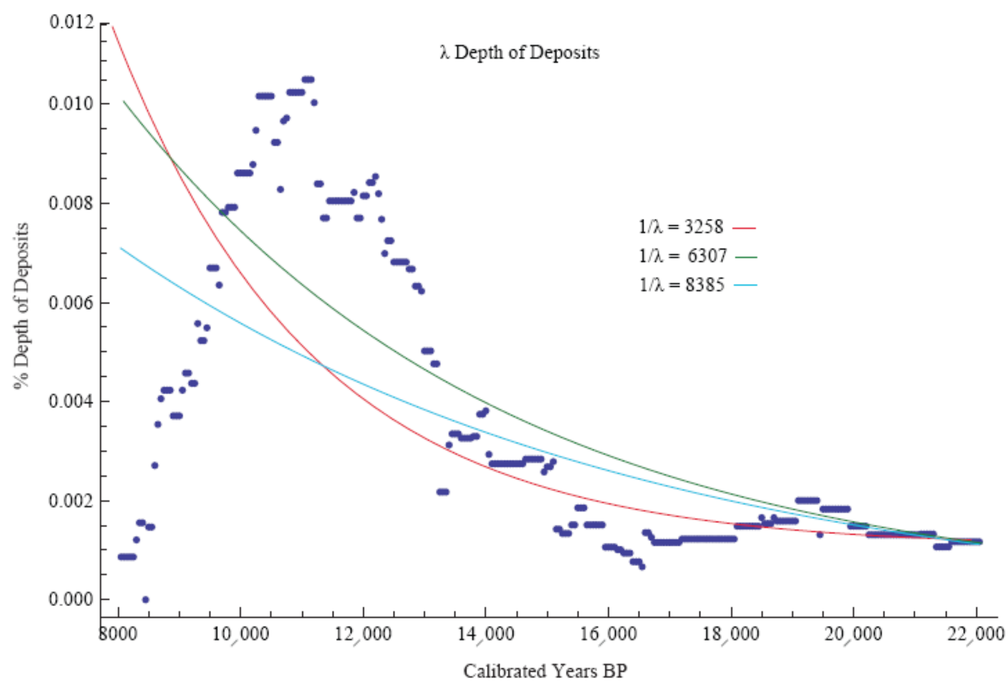

Figure 7.1. 1/λ values for depth o deposits. RED = all data, GREEN = only pre-8650 data, BLUE = only pre-10,500 data.

As noted by Surovell and Brantingham (2007) constant rates of taphonomic bias will influence the frequency of both sites occupied and ^{14}C dates to pattern in an exponential manner. However, they do not postulate how taphonomy may potentially influence site size and depth of deposits. Arguably, if we make the assumption that we have a reliable representation of the largest/smallest sites and the deepest/shallowest sites, we may suggest that these two variables (site size and depth of deposits) may not be largely affected by taphonomy. In this case, if taphonomy is not highly influencing the patterns, we would expect the curves for the frequency ^{14}C dates and frequency of sites occupied to be less steep than those of depth of deposits and site size.

As indicated in Figures 7.1-7.4, this pattern of exponential decay is found within these data. Although the curves are shallower for the frequency of ^{14}C dates and the frequency of sites occupied, the variables suggested by Surovell and Brantingham (2007) can be greatly influenced by tamphonomic destruction. These interesting patterns may suggest that the data used here are not significantly impacted by taphonomic bias.

Due to the somewhat tentative nature of this conclusion, a simulated model is provided at the end of this chapter to compare this frequency data to simulated data that is representative of archaeological sites appearing and disappearing at different rates through time. The simulation further demonstrates that the data pattern in a consistent manner with little influence of taphonomic bias. Next however, we move on to other means of analyzing the frequency datasets and their potential as population proxies.

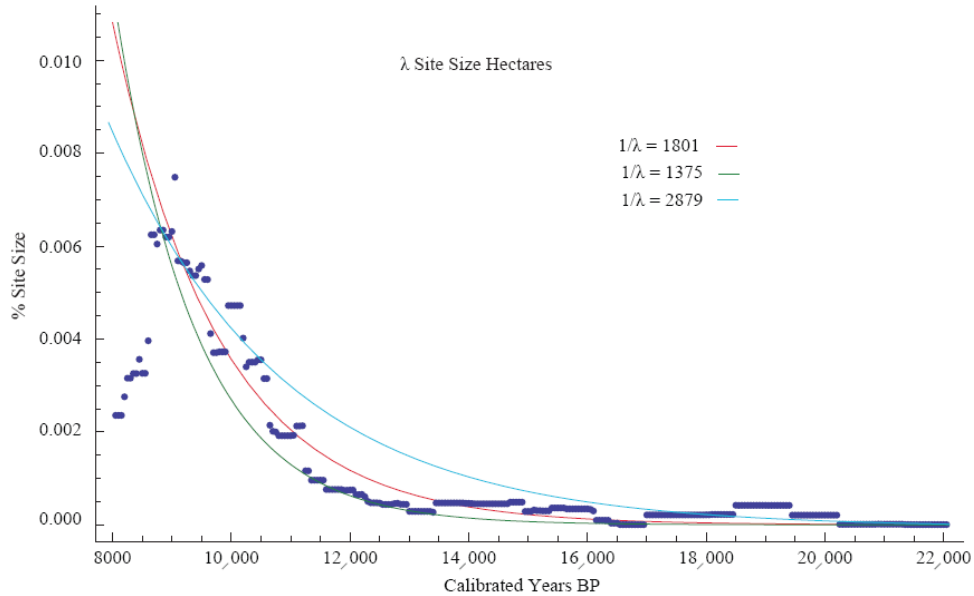

Figure 7.2. 1/λ values for site size. RED = all data, GREEN = only pre-8650 data, BLUE = only pre-10,500 data.

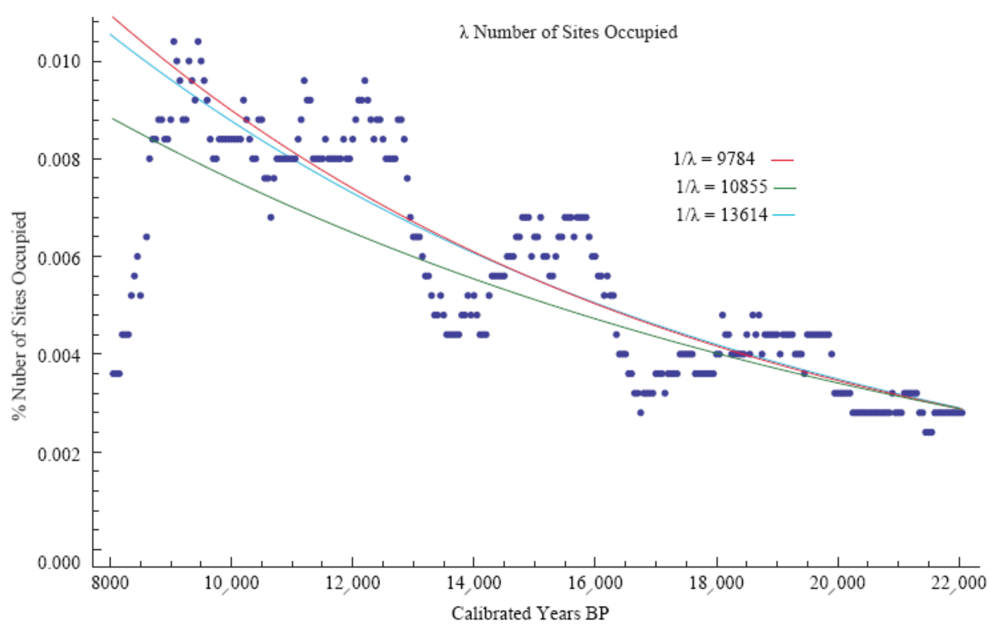

Figure 7.3. 1/λ values for number of sites occupied. RED = all data, GREEN = only pre-8650 data, BLUE = only pre-10,500 data.

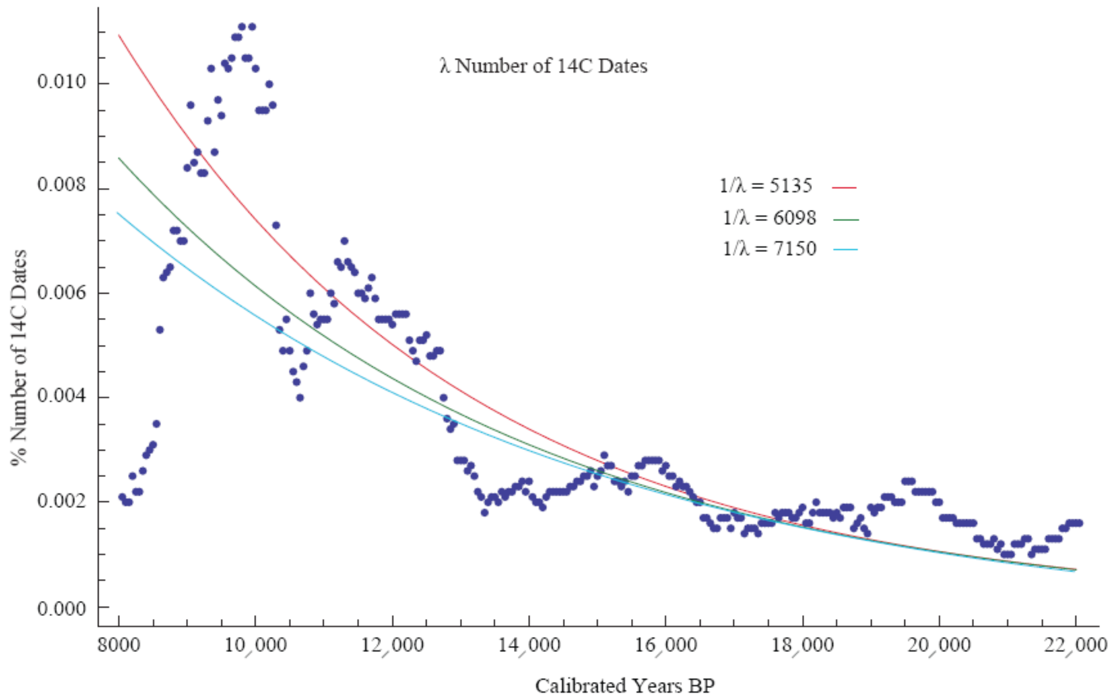

Figure 7.4. 1/λ values for number of sites occupied. RED = all data, GREEN = only pre-8650 data, BLUE = only pre-10,500 data

Cross-correlation Analysis: The Best Fit

This section presents the results of the cross-correlation analysis which enables a graphical representation of both when and how well each population proxy correlates with the others. This allows a comparison of which variables may match up most closely with each other, providing a topographic landscape of the entire time from 22,000-8,000 cal BP. This analysis is important because if each variable is a viable proxy for population growth, each of them should monitor and track the phenomenon in a similar manner.

Cross-correlation analysis provides an additional tool for examining datasets that should be following the same phenomenon in similar manners. More importantly, it provides the ability to test how well each variable measures the phenomenon in relationship to all of the other variables. In this analysis, the data were scaled to the percent of the data occurring in each 50-year increment. In other words, as indicated in Appendix B, the 50-year increment of 9900-9950 cal BP contains a total of 47.195 meters of deposits which is .0146 percent of the total. This was done in order to compare different measures on the same scale such as site size in hectares to depth of deposits in meters.

In Figures 7.5 – 7.10, each dataset is cross correlated with all of the others. Depicted in each figure is the raw data shift as well as the final cross-correlation. In the final cross-correlation we see 1) where the peaks, or best fits, occur and 2) how far each dataset has to be shifted in order to produce the best fit cross-correlation. The hypothesis states that the better the cross-correlation between two variables, the sharper and better defined the peak and where the peak forms is expressed in how many years the data have to be shifted in order to achieve the best fit. If the variables are proxies of population growth, they should require relatively little shifting while forming well defined peaks, the idea being that as proxies of population growth, all variables should correlate more or less with each other.

Depth of deposits to Frequency of Occupied Sites

The cross-correlation between the total depth of deposits versus the frequency of occupied sites demonstrates a very good correlation with zero shift and a well defined peak (Figure 7.5). This suggests that the total depth of deposits and the frequency of occupied sites as proxies of population growth are tracking the phenomenon in a very similar manner.

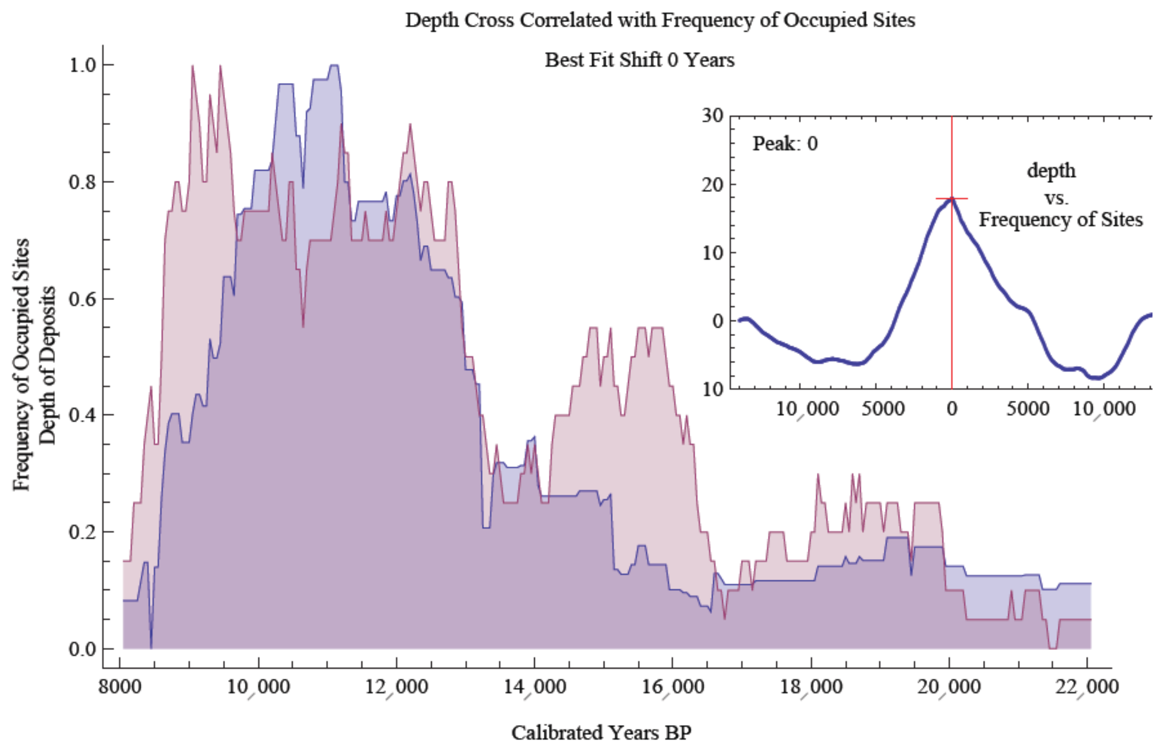

Figure 7.5. Cross-correlation of depth of deposits versus frequency of occupied sites from 22,000 to 8,000 calibrated years ago. Blue = Depth of Deposits and Red = Frequency of Sites Occupied.

Frequency of Sites Occupied to the Frequency of ^{14}C Dates

The cross-correlation between the frequency of sites occupied and the frequency of ^{14}C dates is also very good (Figure 7.6). To form the best fit cross-correlation, zero shift is required and a well developed peak forms. Thus, the frequency of sites occupied to the frequency of ^{14}C dates as proxies of population growth appear to track the phenomenon of population growth in a similar manner.

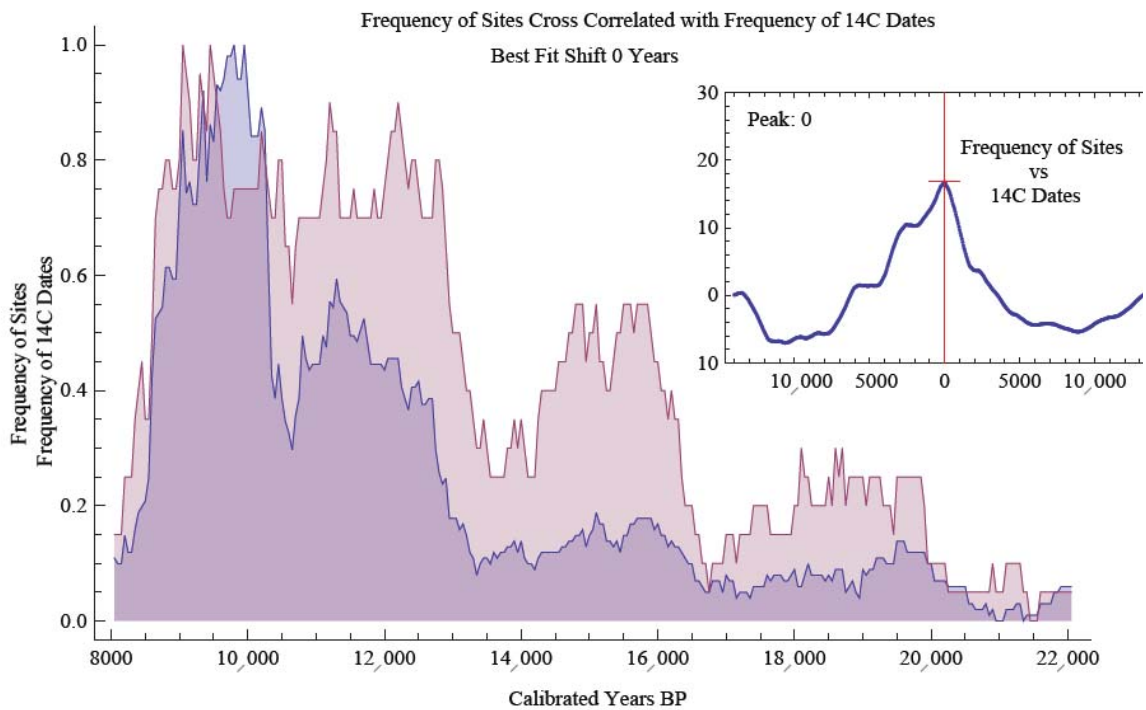

Figure 7.6. Cross-correlation of frequency of occupied sites versus frequency of ^{14}C dates from 22,000 to 8,000 calibrated years ago. Blue = Frequency of ^{14}C Dates and Red = Frequency of Sites Occupied.

Site Size to the Frequency of Sites Occupied

The cross-correlation between site size and the frequency of sites occupied is also a good correlation (Figure 7.7). This is highlighted by a defined peak (although not as well defined as those above) and a minimal shift of 100 years. This amount of shift in an archaeological sense is probably inconsequential in terms of how well each line of evidence is monitoring population growth.

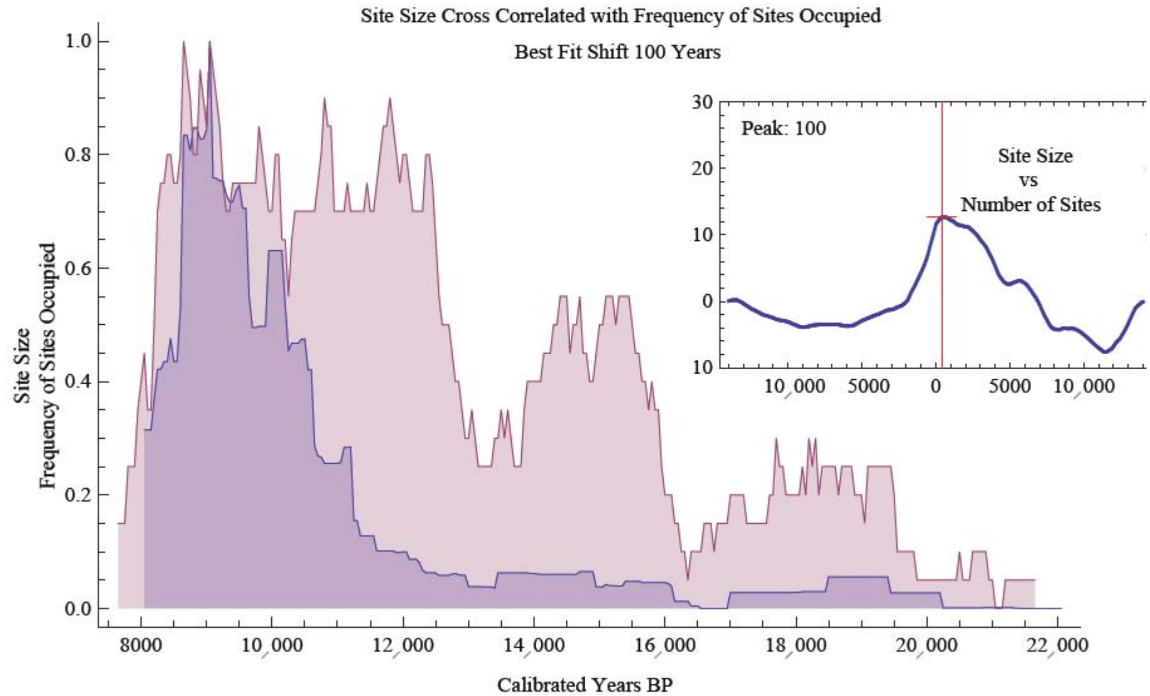

Figure 7.7. Cross-correlation of site size versus frequency of occupied sites from 22,000 to 8,000 calibrated years ago. Blue = Site Size and Red = Frequency of Sites Occupied.

Site Size to Frequency of ^{14}C Dates

The cross-correlation between site size and the frequency of ^{14}C dates is also moderate to good (Figure 7.8). There is a well formed peak but to obtain this, a shift of 250 years is required. While this shift is greater than all of the others presented thus far, my overall interpretation of this is that on an archaeological time scale, a shift of 250 years is fairly inconsequential. Thus, I would argue that these two variables are monitoring and tracking population growth fairly consistently in comparison to each other.

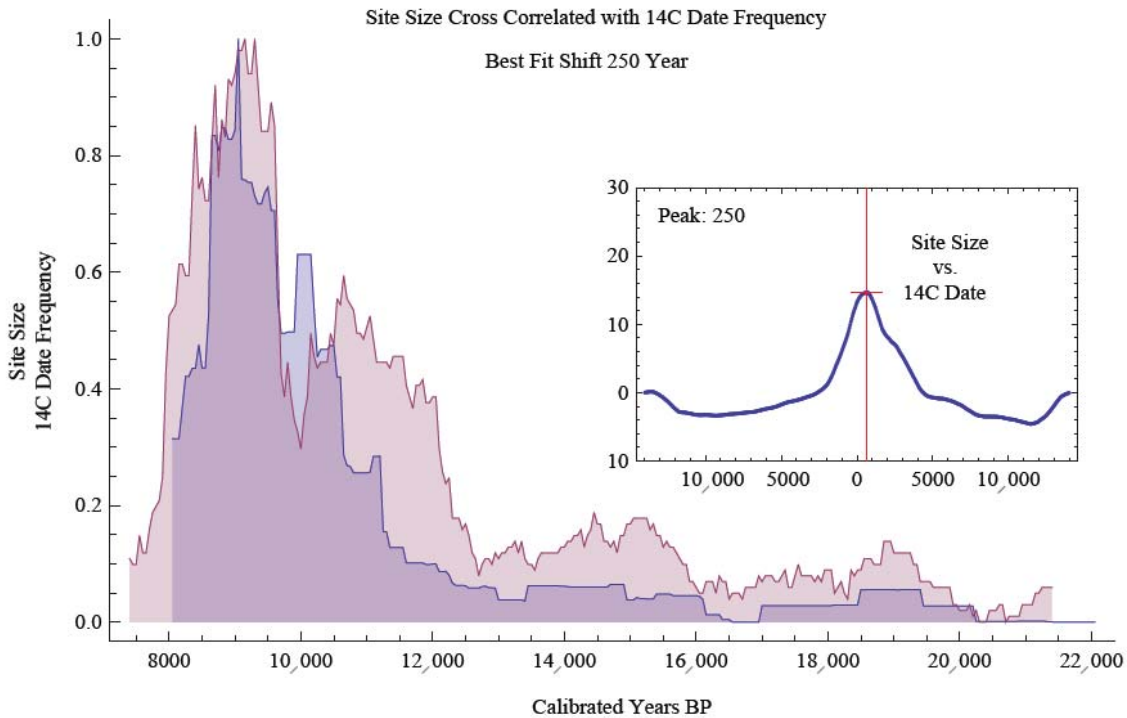

Figure 7.8. Cross-correlation of site size versus frequency of ^{14}C dates from 22,000 to 8,000 calibrated years ago. Blue = Site Size and Red = Frequency of ^{14}C Dates.

Depth of Deposits to the Frequency of ^{14}C Dates

The cross-correlation between the total depth of deposits and the frequency of ^{14}C dates demonstrates a good cross-correlation with a well defined peak. but a shift of 900 years is required before the best fit occurs (Figure 7.9). A potential explanation for this result is the nature of the settlement strategies specifically during the Early Natufian. As noted in Chapter Five, Early Natufian settlements are commonly in caves where depth of deposits will become deeper due to the horizontal restriction that the caves impose. Thus, we expect that depth may be the hardest variable to cross correlate with the others. However, because site size is restricted during this time, when all of the variables are utilized to examine population growth rates in the final section, other variables such as site size should circumvent any deleterious effects that depth of deposits impose on the model. Thus I argue that while depth of deposits is not well correlated most likely due to this change in settlement patterns, it is still an important parameter for modeling population growth.

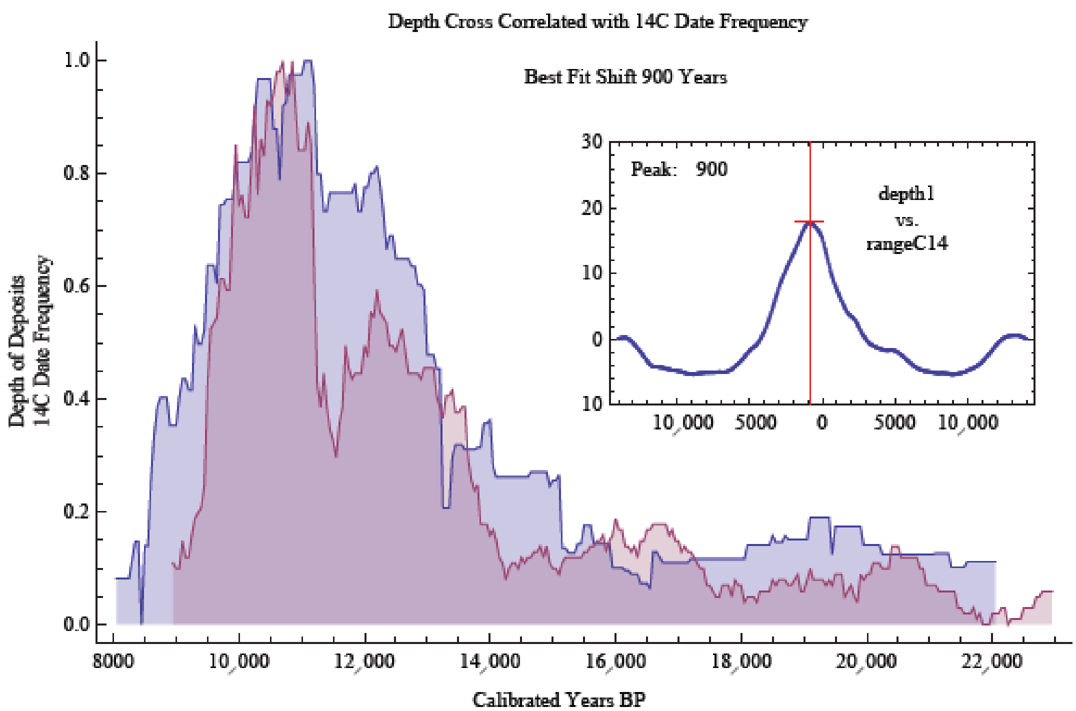

Figure 7.9. Cross-correlation of depth of deposits versus frequency of ^{14}C dates from 22,000 to 8,000 calibrated years ago. Blue = Depth of Deposits and Red = Frequency of ^{14}C Dates.

Depth of Deposits to Site Size

The cross-correlation between depth of deposits with site size is similar to that of depth of deposits to the frequency of ^{14}C dates with a fairly well defined peak but a required shift of 1650 years (Figure 7.10). For the reasons noted above associated with Early Natufian settlement patterns, I will argue below that the other variables consistent cross-correlation should circumvent most deleterious effects of depth of deposits on the overall model of population growth.

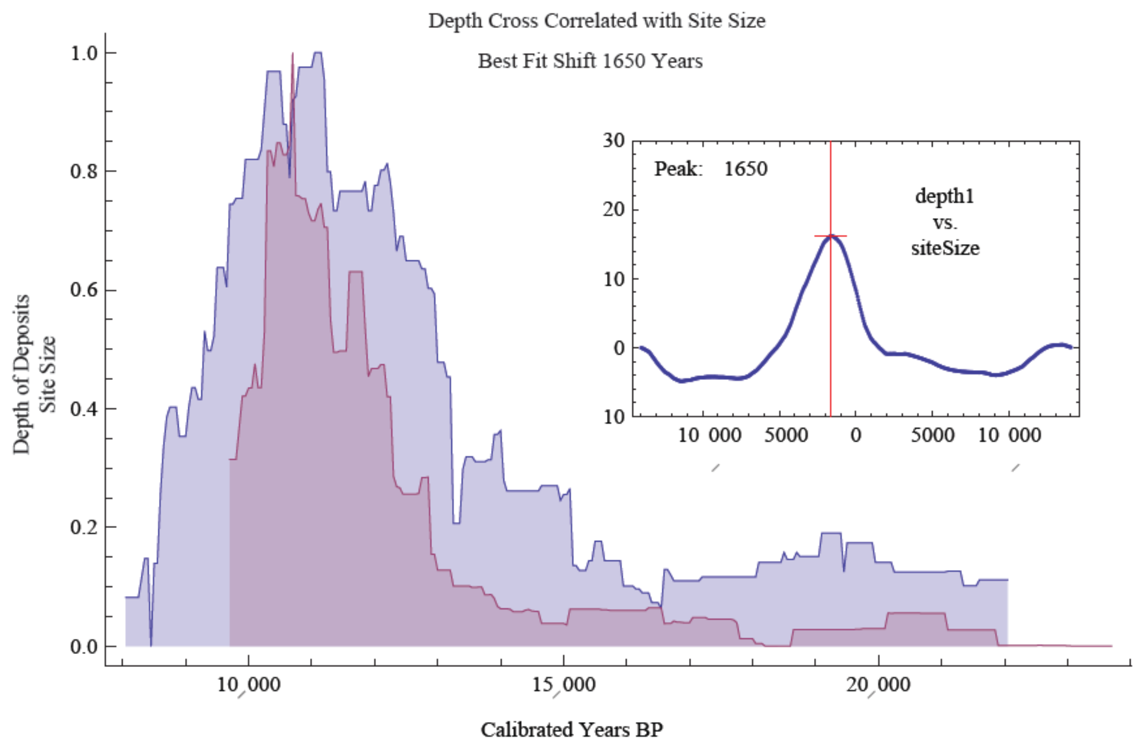

Figure 7.10. Cross-correlation of depth of deposits versus site size from 22,000 to 8,000 calibrated years ago. Blue = Depth of Deposits and Red = Site Size.

Overall Trends in the Cross-correlation

The purpose of the cross-correlation analysis is to utilize a technique designed to measure how well certain related variables reflect a single phenomenon in comparison to each other. Most of the measures fit well with each other with little to minimal shifting required that develop well defined peaks. However, depth of deposits compared to site size and ^{14}C date frequency were the weakest measures. I believe that there is an archaeological correlate to explain this result that involves Early Natufian settlement patterns. Interestingly, the Early Natufian period is regarded to be on the order of about 1700 years (Table 5.1). As an amazing coincidence or something that can substantiate my argument, the biggest shift that has to be made is 1650 years for the correlation between depth of deposits and site size (the two variables largely affected by the intensive use of caves during the Early Natufian). As a result, with the good cross-correlation between the other variables, they should combine to minimize deleterious effects on the model caused by the variable "depth of deposits." Furthermore, because "depth of deposits" is likely showing this change in settlement during the Early Natufian, I believe that it is an important parameter to keep in the model. This may also help to answer the long standing question if population grew during the Early Natufian.

Regression Analysis: Population Growth through Time

The goal of this section is to provide a more robust statistical evaluation of the data that I have argued thus far are 1) not overly influenced by taphonomic bias and 2) appear to be monitoring and tracking the same phenomenon (population growth) in a consistent manner. To achieve statistical verification, a series of regression analyses is used to examine the overall significance of the model and also how reliably each of the population proxy variables is predicted by the dependent variable – time. All analyses utilized the raw data transformed for normality with Log_{10}.

Multiple linear regression is a common parametric analysis used to predict the outcome of one dependent variable through a series of predictors or independent variables. In this case the dependent variable is time and the predictor variables are the frequency of ^{14}C dates, the frequency of sites occupied, depth of deposits, and site size. The results indicate that the overall model is statistically significant and positively correlated (f=254.95; df=4; p =<.0001; r^2=.7870). The high r^2 value also indicates that together, the variables are reliable predictors of time.

Simple linear regression analysis is a common parametric statistical test utilized to examine patterns in archaeological data. Specifically, I use regression analysis here to examine the dependent variable – time as calibrated radiocarbon years BP - with the population proxy variables including: depth of deposits, frequency of ^{14}C dates, frequency of sites occupied, and the total site size occurring in each 50-year increment. By running pair-wise regression tests we gain a more detailed understanding of each datasets relationship with time and thus, population growth.

Regression analysis was conducted using SAS v.8 statistical software with the proc reg function. For each case, the regression analysis was run twice with time as the dependent variable. The first run included all of the data compiled from 22,000 to 8,000 calibrated years BP. Due to a substantial decrease in available data representative of population at the end of the Late Pre-Pottery Neolithic B (LPPNB), the second regression analysis was conducted with only data pre-8650, as this is the date regularly regarded as the end of the LPPNB (Kuijt and Goring-Morris 2002) (limited data post-8650 may be due to changing settlement systems or large scale population decline post-8650 during the PPNC; see Chapter Four).

Table 7.1. Results of the Pair-Wise Regression Analysis.

Variable	Dataset	*f*	*df*	*p*	r^2
Freq ^{14}C	All	640.24	1	<.0001	.6965
	Pre-8650	1142.48	1	<.0001	.8106
Freq Sites Occ	All	623.42	1	<.0001	.6908
	Pre-8650	1364.05	1	<.0001	.8363
Depth of Dep	All	270.36	1	<.0001	.4921
	Pre-8650	650.41	1	<.0001	.7090
Site Size	All	656.79	1	<.0001	.7019
	Pre-8650	586.10	1	<.0001	.6870

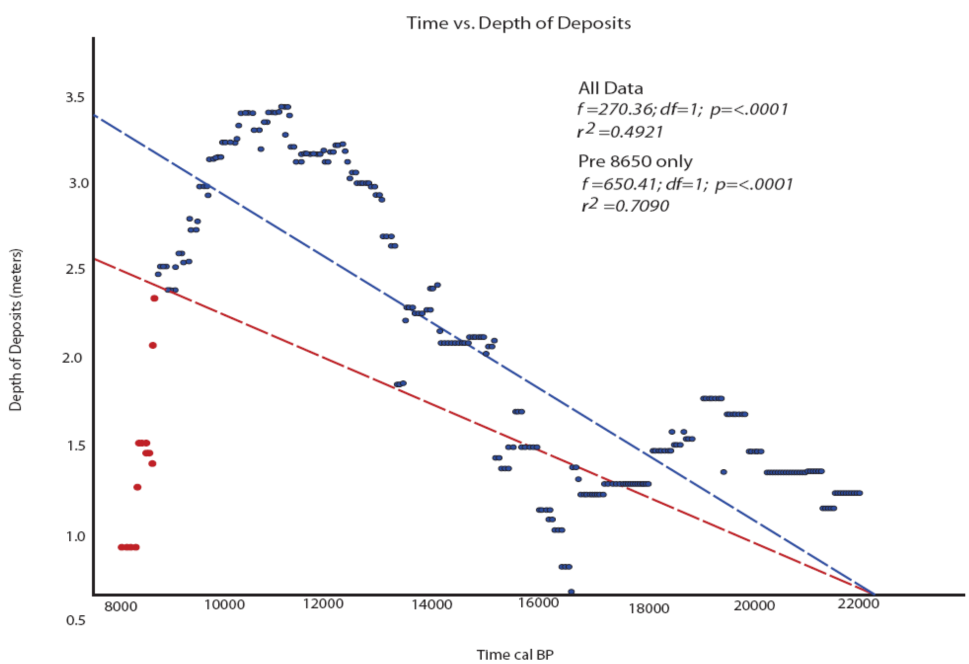

Figure 7.11. Linear regression of depth of deposits to time (calibrated BP). Regression line in RED reflects that of all data and regression line in BLUE reflects that of only data pre-8650. Data points in RED are those dating to post-8650 cal BP.

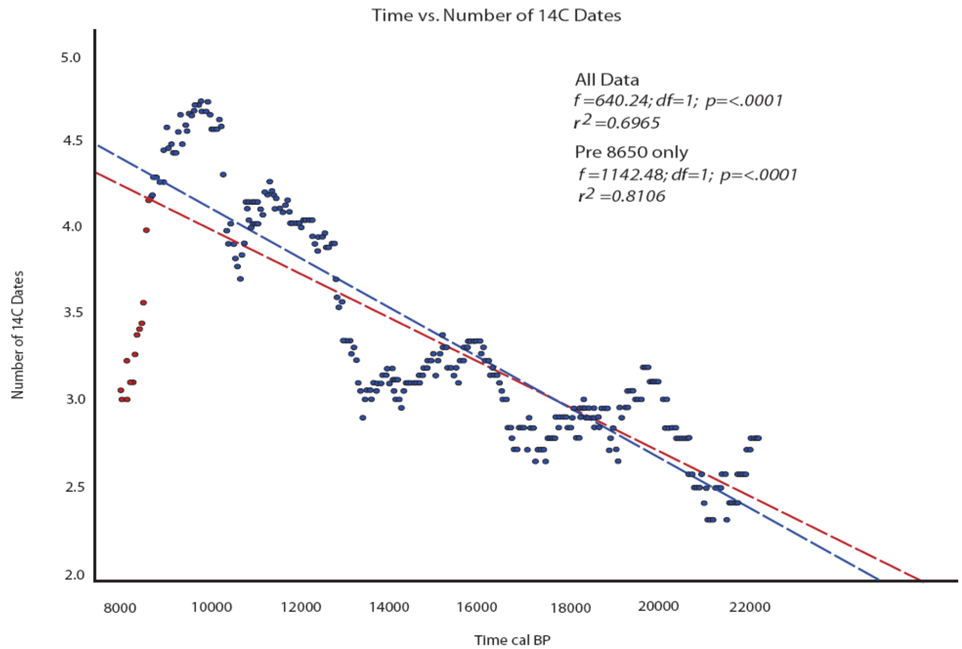

Figure 7.12. Linear regression of the frequency of [14]C dates to time (calibrated BP). Regression line in RED reflects that of all data and regression line in BLUE reflects that of only data pre-8650. Data points in RED are those dating to post-8650 cal BP.

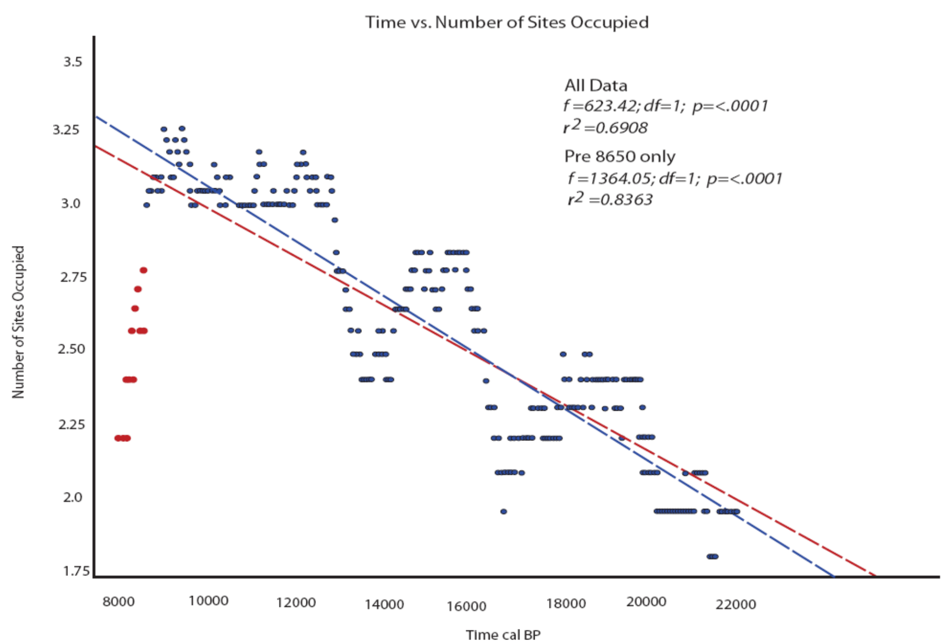

Figure 7.13. Linear regression of the frequency sites occupied to time (calibrated BP). Regression line in RED reflects that of all data and regression line in BLUE reflects that of only data pre-8650. Data points in RED are those dating to post-8650 cal BP.

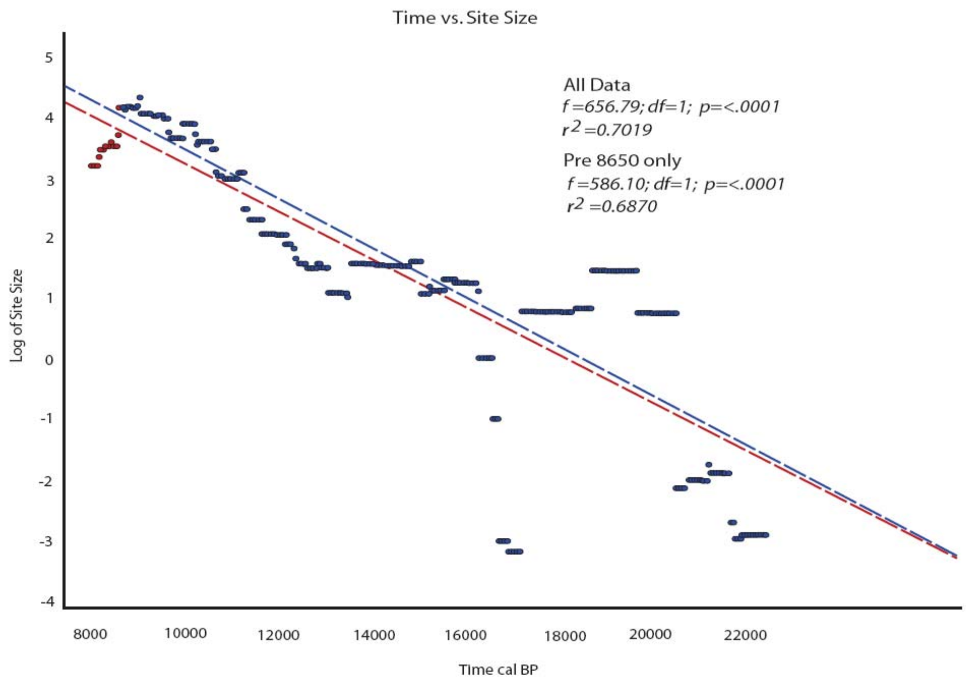

Figure 7.14. Linear regression of site size to time (calibrated BP). Regression line in RED reflects all data and regression line in BLUE reflects that of only data pre-8650. Data points in RED are those dating to post-8650 cal BP.

Results depict an overall trend that each variable positively and significantly increased through time (likely indicating that population increased through time); however, there are different levels of prediction indicated by the r^2 values (Table 7.1 and Figures 7.11-7.14).

Having argued that taphonomic biases have not significantly influenced the data of the southern Levant used here (and verified by computer simulation later), we can assume each variable with both significant *p* values as well as high r^2 values (ca. > .60 but the higher the better) is a reliable predictor of population growth through time. Thus, as each variable examined here has both significant *p* values as well as r^2 values >.60, (excluding time versus depth of deposits all inclusive data r^2 .4921) indicating these should be relatively good predictors of population growth through time (Table 7.1). Importantly, because the regression of time versus depth of deposits including all data from 22,000-8,000 cal BP may not be a reliable predictor (due to the low r^2 value), all following analyses utilize only data from pre-8650 for all variables.

Population Growth Rates

The ability to measure population growth rates over long time periods allows us to understand human behavior better as well as the major transitions in our evolutionary history. While we will never know exactly how many people are represented in each 50-year period, I posit that we can produce an overall model of population growth based on these particular proxies.

Figure 7.15 shows all of the proxies of patterned population proxies through time. Each variable has been scaled to the percentage for each 50-year increment in order to have a directly scaled comparison. The overall trend in Figure 7.15 demonstrates an increase in all of the population proxies through time until 8700 cal BP. By taking all of these variables we can add all of their percentage values for each 50-year increment and calculate the percent change or growth rate from one period to the next by $(Time_1 \times Time_2)/50$, obtaining growth rates from one period to the next. The result is depicted in Figure 7.16.

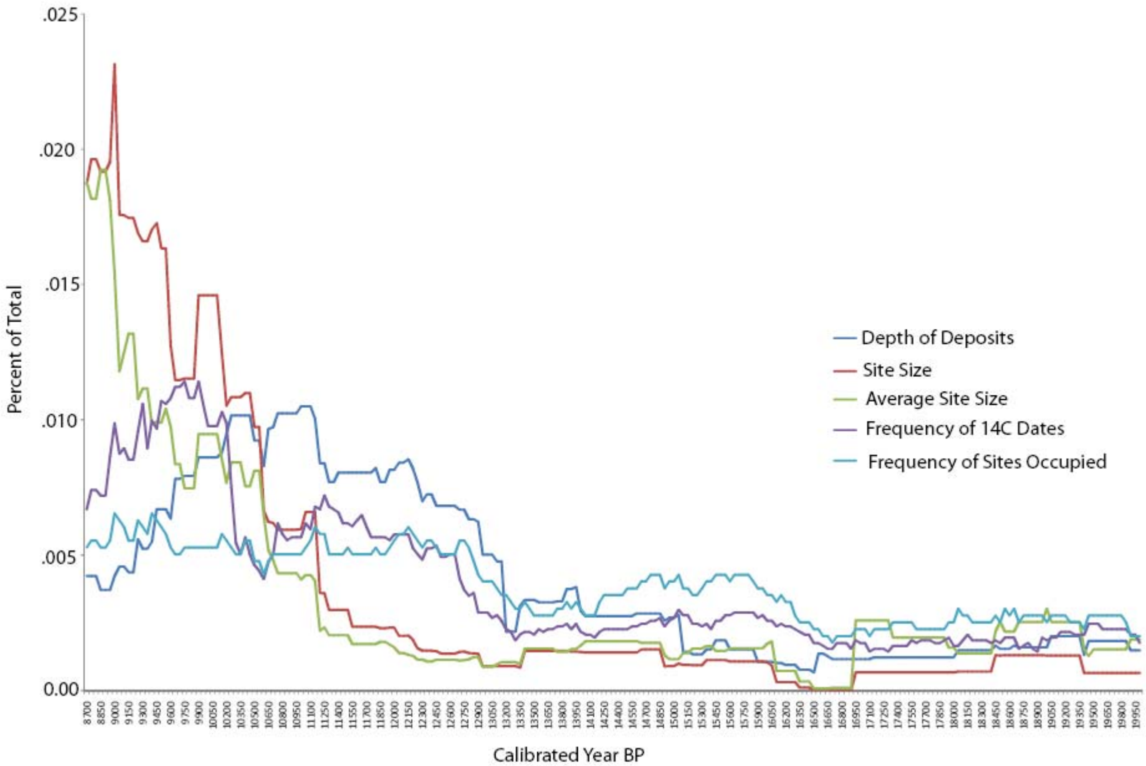

Figure 7.15. The overall trends in the data from 20,000 to 8650 cal BP of all the variables utilized in the population proxy model.

Figure 7.16 demonstrates the positive and negative growth rates for each 50-year increment through the sequence of 8,650-22,000 calibrated years ago. There are several interesting patterns within the graph. First, note that the growth rates were very small throughout the Epipaleolithic, probably mimicking essentially zero-growth rates. This is emphasized by similar frequency and scaled negative growth rates with their positive counter part growth rates.

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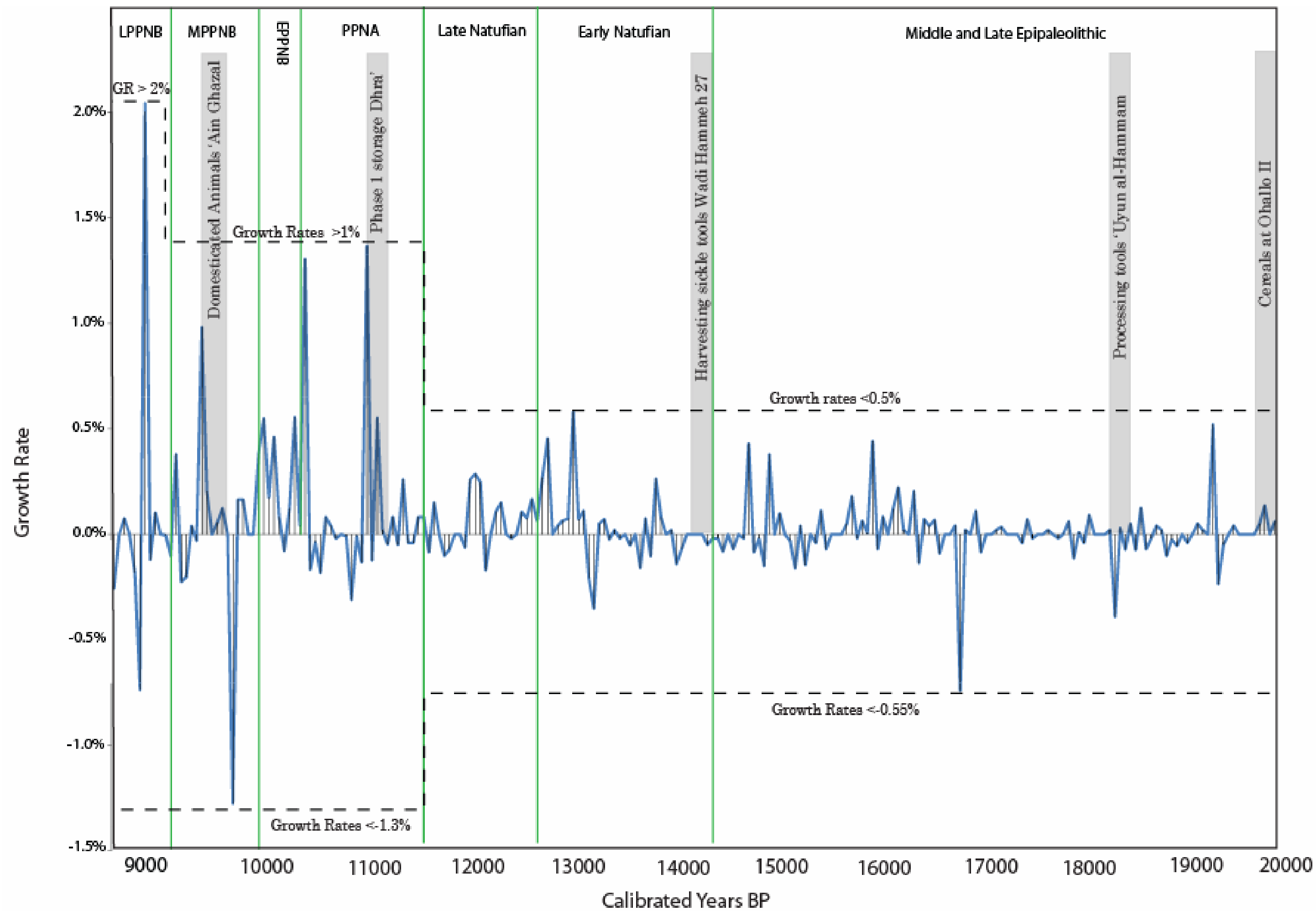


Figure 7.16. Changing growth rates through the sequence. Note that the dashed line tracks the growth rates and the significant increase during times of population growth after the first well documented case of intensive food storage.

If we revisit arguments made above with the cross-correlation analysis regarding the potentially deleterious effects that deeply stratified Early Natufian sites may impose on the model, it is clear that growth rates in the Early Natufian were on the order of the rest of the Epipaleolithic despite the early increase in this variable. This may help clarify some of the arguments regarding population growth during the Early Natufian (Goring-Morris and Belfer-Cohen 1998; Boyd 2006; Henry 1989) for this model indicates that their populations likely remained on the same order of magnitude as other Epipaleolithic populations.

Another interesting pattern that occurs during the Epipaleolithic including the Natufian is the seemingly minor impact that technological inventions had on increasing population growth rates. Through the model presented in Chapter Four, I argued that a significant increase in population growth would not occur until all of the fundamental elements were in place including storage technology. The logic is that food storage provides a stabilized diet of foods associated with increased fertility. The model presented in Figure 7.16 suggests that there is significant credibility to the hypothesis that these early inventions of technology that aided in harvesting and processing efficiency did not overly influence population growth.

Perhaps the most significant contribution of the model is the suggestion that the first population growth rate event that is higher than those of the Epipaleolithic, occurs in the Early Neolithic during the Pre-Pottery Neolithic A (Figure 7.16). This event is congruent with the first evidence of intensive storage in the form of grain storage structures at Dhra', Jordan (Kuijt 2008a; Kuijt and Finlayson n.d.). This suggests a strong correlation between food storage and population increase.

Interestingly, each sharp increase in population growth rates only occurs during one 50-year interval. The same is true for negative growth rates, hinting that population increases and decreases happened over short periods of time (cf. Rollefson and Pine n.d.). Also note that the negative growth rates follow a pattern similar to positive growth rates in terms of scale and frequency. That is, once populations start grew at a high rate, negative growth rates also occur more dramatically. This may indicate stressful periods, where shortfalls in crop failure may have had more catastrophic effects on population size as noted in Chapter Four under delayed-return food economies. Alternatively, short-term positive growth rates may sometimes be indicative of the addition of resource bases that may raised some theoretical carrying capacity and, at the same time, influenced fertility. This may be evidenced by the occurrence of domesticated animals when we see a likely *in situ* domestication of goats at 'Ain Ghazal during the MPPNB (Savard et al. 2006) and the dairy products that they would have provided also associated with increasing fertility.

While most of the other spikes in population growth seem to have strong correlates with the addition of resource bases, the final and largest growth rate spike during the LPPNB between 8950-9000 cal BP is probably associated with the mass movement of people from the sites in the west to inhabit villages east the Jordan Valley (Kuijt and Goring-Morris 2002; Rollefson 2004). This too appears that it was a very rapid shift that occured in less than ca. 50 years.

Finally, the model demonstrates that population growth rates with the transition to agriculture likely never exceeded 2 percent per year, arguably a very conservative estimate. Support for this view are the similar findings that Bocquet-Appel (2002:647) suggests for the NDT in Europe. The model also suggests that the largest growth of human population likely occurred in the Late Pre-Pottery Neolithic B with other significant growth events in the Middle Pre-Pottery Neolithic B and in the Pre-Pottery Neolithic A.

Simulating the Effects of Taphonomic Bias

Through a simple simulation model, we can compare these results with the expected destruction of sites promoted by Surovell and Brantingham (2007). We can demonstrate this model very easily through a simple decaying exponential function; however, what their model fails to specifically address is the relationship between the frequency of sites that were added in relation to the number that were destroyed. The following exercise provides an example where we can control the rate of sites being added and subtracted from the archaeological record through an easily explainable analogy. This simulation produces a plot comparable to Figure 7.16 and the behavior of the data based on different rates of adding and subtracting archaeological sites from the record. This approach allows further justification for the conclusion that the dataset utilized here may not be significantly affected by taphonomic bias.

Random Destruction

Pretend you are at the carnival or country fair. The life sized doll of Richard Simmons has caught your eye, and the only way to win it is to pop balloons stapled to a board by throwing darts at them. You've bought the Super-Mega-Family packet of tickets, so you can throw as many darts as you'd like at the board. The objective of the game is to pop all of the balloons, where the balloons are analogous to archaeological sites and the board analogous to some defined geographic area. Your aim is random and you consistently hit the board somewhere, but other than that, the darts go all over. At first you break balloons quite often, but later fewer and fewer dart-throws break balloons, and the last several seem to take forever to pop. The reason for this is simple: with random throws, you're more likely to break a balloon when there are lots of balloons to break; later on, when there are fewer balloons left on the board, breaking one by chance takes longer. In fact, the probability to break a balloon on any particular throw, because you can't aim any better than to hit the board, is simply the area covered by unpopped balloons, divided by the total area of the board. In other words, as archaeological sites become less and less frequent due to their age, the less probable it will be to destroy those few remaining sites defined as:

$$P(destroy) = \frac{b \times area_{site}}{area_{geography}}, \qquad (7.1)$$

where $area_{site}$ is the area covered by a single archaeological site (*d*), and *b* is the frequency of sites in the defined geographic area. The rate of the site destruction (that is, how many sites are destroyed in a given interval of time) is directly proportional to this probability:

$$\frac{db}{dt} = -k \times P(destroy) \text{ with } k > 0, \qquad (7.2)$$

Note that $\frac{db}{dt}$ is necessarily a negative quantity, the balloon number *b* doesn't increase with time. Also, *P*(*destroy*) is positive; I simply choose the proportionality constant *k* to be positive, so that there must be a negative sign out in front. Rewriting Equation (7.2) to include Equation (7.11) gives

$$\frac{db}{dt} = -kb \qquad (7.3)$$

where the constant $area_{site}$ $=area_{geography}$ has been absorbed into the constant *k*, because the product of a bunch of constants is still a constant. Equation (7.3) is the simplest non-boring differential equation imaginable. It says that how fast something changes (*b* here, the number of sites left to destroy) is proportional to how much of that something is present. It's commonly referred to as the heat equation, because it describes how fast (for example) a cup of coffee will cool down. It can be solved by integrating both sides, or by remembering that the exponential function has the interesting property that its slope is proportional to its value at all points. In other words, the solution to Equation (3) is

$$b(t) = b(0)e^{-kt}, \qquad (7.4)$$

where *b*(0) is the value of *b* when t = 0. A plot of this is shown in Figure 7.17.

Note that if you take the derivative of Equation (4), you get

$$\frac{db}{dt} = -k \times b(0)e^{-kt} \qquad (7.5)$$

but the last part of this equation, $-k \times b(0)e^{-kt}$, is just the same as Equation (7.4), so that Equation (7.5) is really just $\frac{db}{dt} = -kb$.

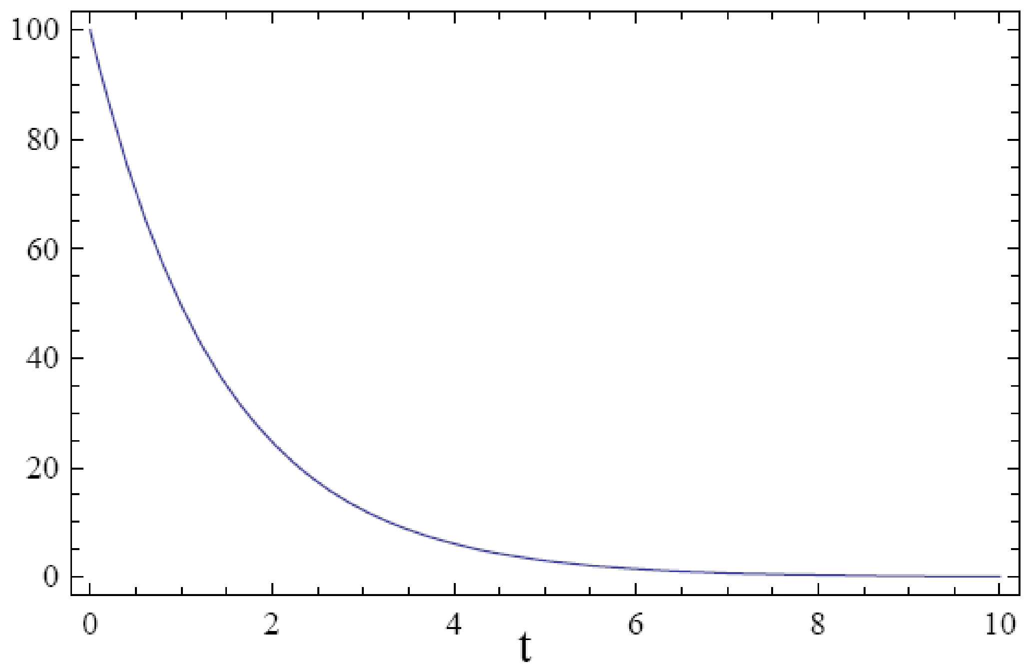


Figure 7.17. A typical exponential decay curve. In this case, the curve's equation is $100e^{-7/10t}$ Note that the curve starts at 100; and after any given interval of length 1, the curve loses about 70 percent $(100 \times 7/10)$ of the value it had at the start of the interval.

It is relatively easy to simulate the dart-throwing and the expected outcome. The board chosen for the simulation has 8 rows of 7 sections where each section is divided up into 9 squares and any or all of the squares starts out with a balloon stapled to it. The computer then throws darts randomly at the board, hitting somewhere in the $8 \times 7 \times 9 = 504$ squares, and keeps track of whether it hits a balloon (thus removing it from the board) or hits an empty space (so nothing happens). The simulation for a given board continues until all of the balloons are popped. Figures 7.18, 7.19, and 7.20 show three simulations with different starting numbers of balloons. We can imagine these boards with balloons as defined geographic space with some N number of sites.

By having the computer keep track of how many balloons were on the board at each step, we can see the rate of balloon pop. Of course, the starting number is set by the analyst, but after that, the randomness of the dart throws means that the number of balloons is only described approximately by Equation (7.4). Sometimes, the numbers deviate wildly from what is predicted on the average. Figure 7.21 illustrates the results of a number of dart games, with different numbers of starting balloons. Even though it seems that the games with larger numbers of balloons are more accurately predicted by Equation (7.4), this is only because the scales on the plots have been changed to show the full results. If one looks at the tails of the records in Figure 7.21b and 7.21c, they are just as jagged and unpredictable as the records in Figure 7.21a. In fact, this is guaranteed by the nature of the process we are dealing with: the balloons on the board do not have any knowledge of what number of darts have been thrown at them, nor whether their neighbors have been popped or not. This means that we can take the case of the boards which start with 504 balloons, throw darts, and wait until there are only 56 balloons left, and then count those as though we have just started throwing darts at the boards. The entire game has the same rate constant, *k*, which means that any portion of any of the dart games has to look, on average, just like any other portion.

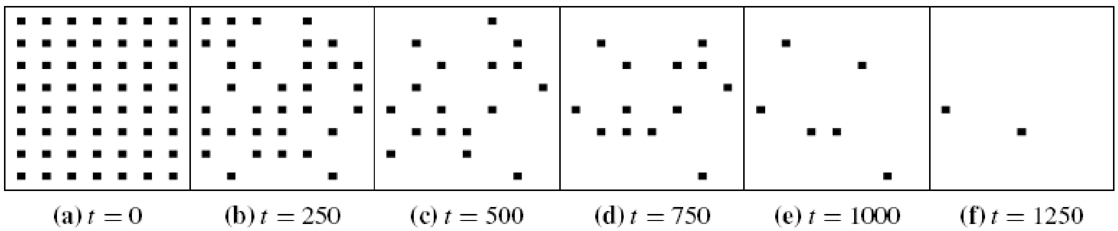


Figure 7.18. The board at different steps in the simulation. Black squares represent balloons left on the board. The simulation starts with 54 balloons on the board.

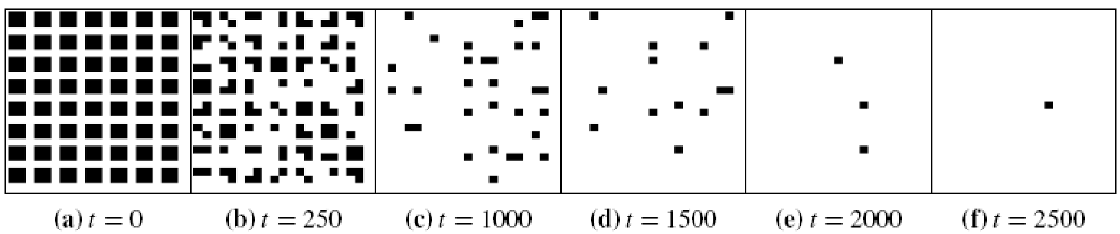


Figure 7.19. The board at different steps in the simulation. The simulation starts with 216 balloons on the board.

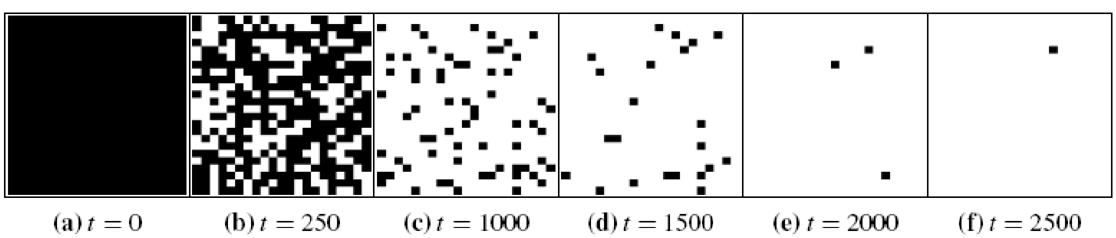
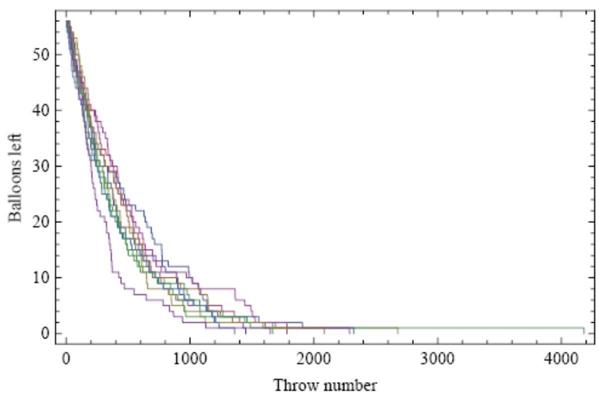
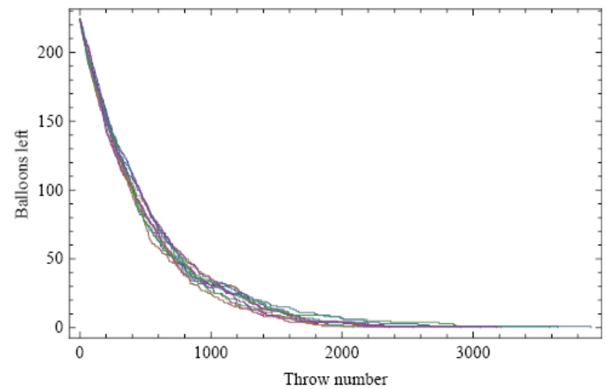


Figure 7.20. The board at different steps in the simulation. The simulation starts with the board fully covered: 504 balloons are on the board.

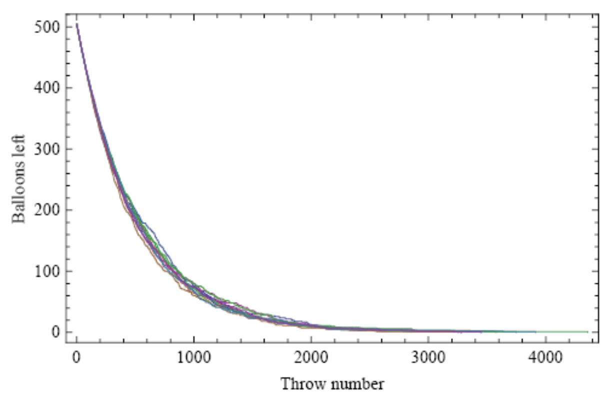
This simulation is very similar to that provided by Surovell and Brantingham (2007) for the destruction of archaeological sites and decaying exponential expectations. The limiting factor to this is the absence for considering the rate of addition to the record. In this simple explanation this would equate to a *sneaky operator* adding balloons to the board when you were not looking. In our real example of measuring population growth rates during the NDT, the "sneaky operators" are the people of the past, consistently (but not necessarily constantly) adding new sites to the record. Here is a simulation to account for this problem.



(a) Ten boards, starting with 56 balloons.



(b) Ten boards, starting with 226 balloons.



(c) Ten boards, starting with 504 balloons.

Figure 7.21. The total number of balloons left on the board, after a number of throws. The different subfigures show results for boards starting with 56, 226, and 504 balloons, respectively.

Sneaky Operator and Taphonomy

Suppose that the operator of the dart boards is sneaky, and every once in a while, if your back is turned, he quickly staples a new balloon to the board. This modifies the rate of the balloon disappearance, and the original differential equation, Equation (3), gets an added term:

$$\frac{db}{dt} = -kb + a \, , \qquad (7.6)$$

where *a* is the rate at which the operator sneaks new balloons onto the board or in our case study, the rate at which people are adding sites. Perhaps it is once every throw (if you're very distracted—in this case, you don't have a hope of winning), or perhaps it is only once every 100 throws. The solution to this equation is nearly as simple as the original. It is

$$b(t) = \frac{a}{k} + ce^{-kt} \qquad (7.7)$$

Here, we have abandoned the notation of $b(0)$ because at time $t = 0$, note that the starting population is, in fact, $a/k + c$ (*c* is the coefficient in front of the time dependent term). The only term which changes with time is the one containing *t*, this one goes to zero as $t \to \infty$ but the population never quite reaches zero. It asymptotically approaches the value a/k, because the operator keeps adding a balloon once in a while. When the probability of the operator adding a balloon equals the probability of you popping one, then the population of balloons reaches a static value. Figure 7.22 contains several curves showing what should happen if the operator adds balloons at different rates to an initial population of 100. Notice that some of the curves actually increase (the operator adds balloons slightly faster than you remove them, but eventually your removal rate catches up with his adding rate, because the density of balloons on the board increases). One of the curves stays level, at the value a/k, because the addition rate happens to just balance the removal rate for that curve.

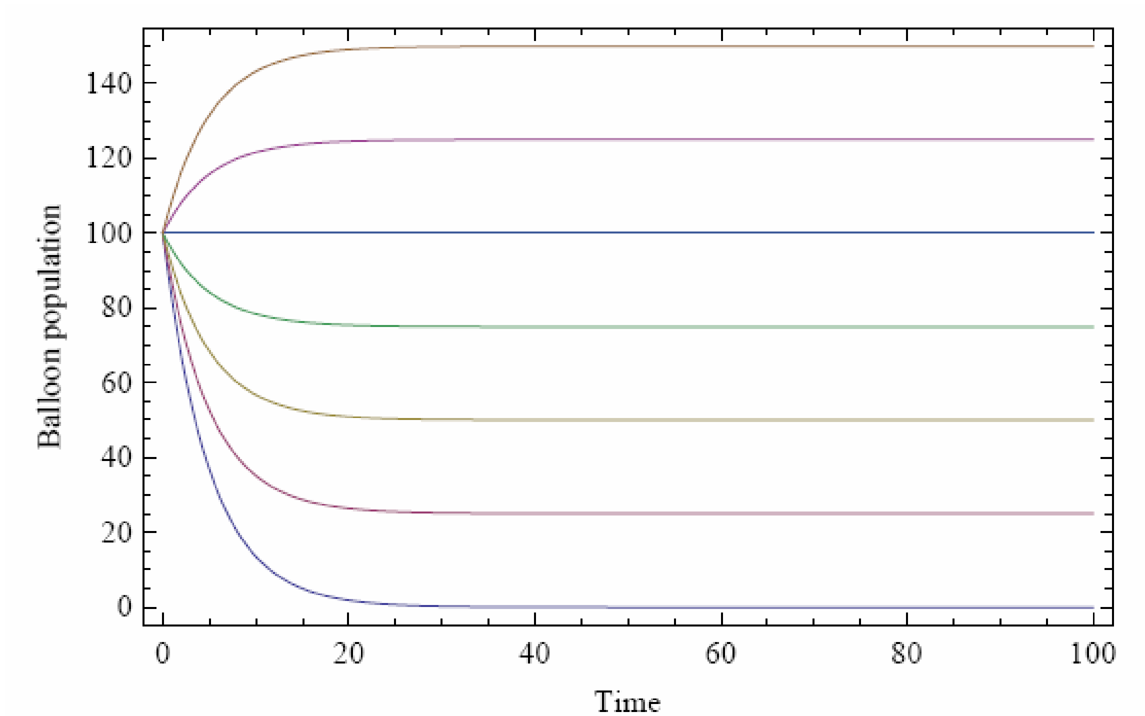


Figure 7.22. Balloon populations vs. time, with a cheating operator. Only the lowermost curve has no interference from the operator; all of the other curves have the operator adding balloons at some constant rate (in an archaeological sense the cheating operator would act as a nondestructive force).

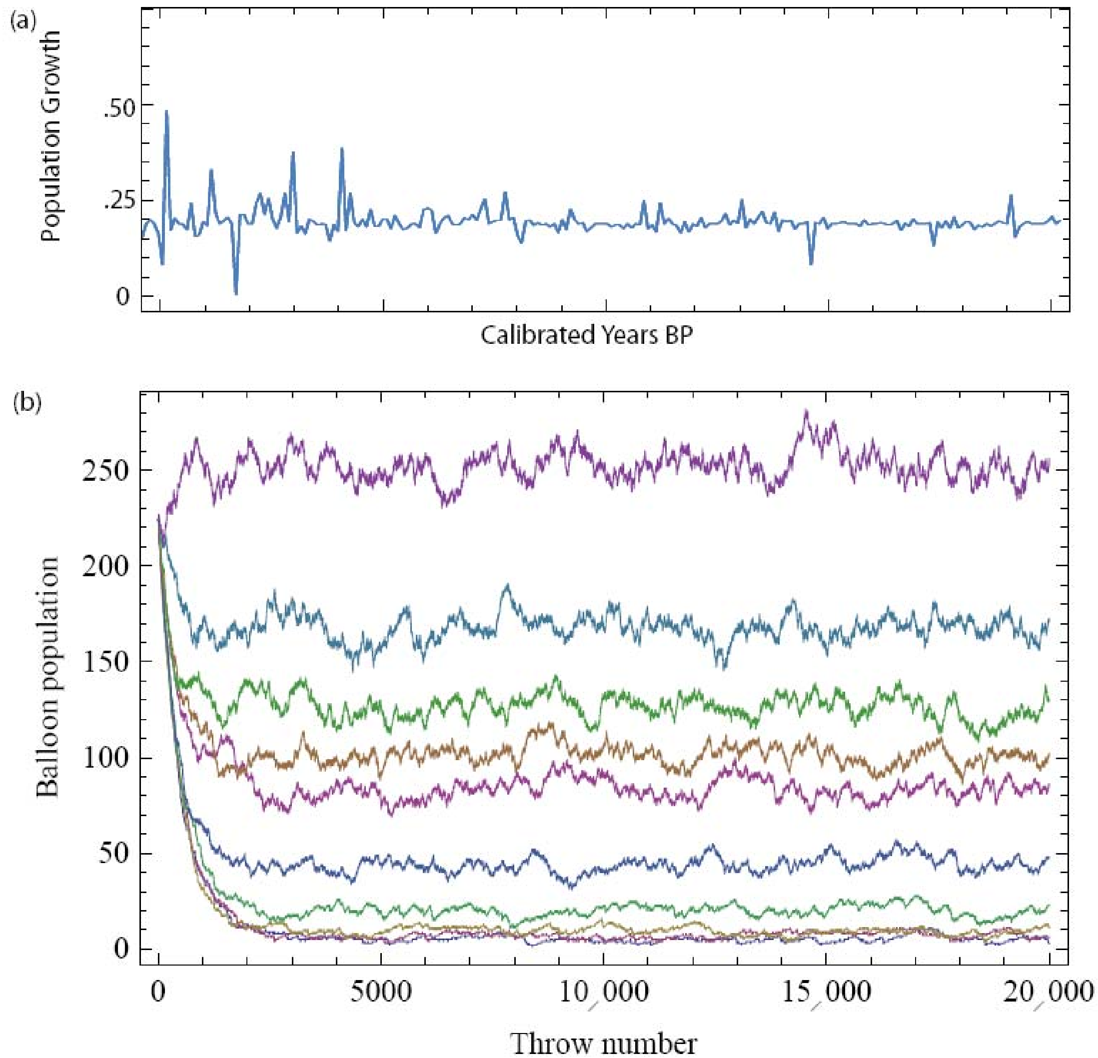


Figure 7.23. (a) the population growth rates presented earlier scaled to compare to the sneaky operator simulation. Note that the archaeological data take the form most similar to the second line from the top indicating a fast sneaky operator or in our case, slow taphonomic destruction. This line also takes the form most similar to this line at the end of the sequence where there is minimal logistical growth. (b) Balloon populations vs. time, with a cheating operator, as simulated on the computer. The board started with 216 balloons. The lowermost curve has a balloon added every 100 throws; the uppermost curve has a balloon added every throw.

One can also simulate this situation. For every time step, the dart hit the board in a random spot, similar to a site being randomly destroyed by some event (the board started out with 216 balloons, as in Figure 7.19(a)); if it hit a balloon, that balloon was removed. The sneaky operator would add a dart every 100, 50, or 10, throws. The total number of balloons was tracked for several different addition rates; the result is shown in Figure 7.23. In each case, the curves level out to the value predicted in the long-time-limit from Equation (7): a/k.

In this case, the parallels with taphonomy in archaeology should be apparent, except that the cheating operator in the balloon game are our friends in prehistory; as people add sites, natural processes destroy sites. The trick here is if sites are getting added at a faster rate than they are getting destroyed, growth rates should produce very noisy plots, such as that in Figure 7.16 for our estimates of growth rates in the southern Levant. Not only should the plots be very noisy, they should also have very little logistic growth towards the end of the sequence, also similar to Figure 7.16.

Figure 7.23 contains only random taphonomic destruction (which works at a well-defined rate) and an addition to the population (which also works at a well-defined and very constant rate), yet they compete to give pretty jagged curves. Most likely, the conclusion that we can draw from this simulation is that the addition and destruction rates going on in the archaeological data are much less controlled than here, and so one would expect even spikier curves if taphonomic bias was not a significant influencing factor. Moreover, the results of population growth during the interval of 22,000-8650 years ago are very jagged presented in Figure 7.23a. These are comparable to the simulated effects of one balloon (archaeological site) added at a high rate, similar to a fast rather than a slow sneaky operator. In other words, the data suggest that as population grows through time, the signal should become stronger even though a jagged signal suggests that destruction rates should be low. This simulation and observation lends additional support that the population growth model reflects actual population trends through the transition to agriculture and while not completely free of taphonomic bias, we can at least suggest that it is an insignificant factor.

Summary

This chapter has accomplished several tasks. First I have argued that the variables utilized here as population proxies do not appear to be largely affected by tamphonomic bias. This was first accomplished by comparing the exponential decay curves of those variables that are the most prone to taphonomic bias to those variables that should not be impacted by taphonomic bias. Second, a simulation was conducted to examine the destruction of sites through time in relation to how fast they are added to the record. Both of these exercises suggest that the data used here as population proxies are not significantly impacted by taphonomic bias.

Through cross-correlation analysis I have argued that the data are all tracking and monitoring the same phenomenon (population growth) in a similar manner. Additionally, all of the datasets have a statistically significant positive correlation with time. Because of the results of both the cross-correlation and regression analyses, I constructed a population growth rate model with all of the variables to examine population growth rates from 22,000 to 8,650 cal BP in the Near East. This provided a detailed model of the Neolithic demographic transition that highlighted a number of interesting facets of the transition including: the relatively few but rapid population growth rate increase and decrease in under 50 years; the seemingly little effect that technological inventions had on increasing fertility until storage was adopted; the first substantial population growth rate increase appears to co-occur with the first signs of intensive food storage in the PPNA; the subsequent population growth rates co-occurring with the addition of other resources bases; and finally, detecting the potential mass migration of people during the LPPNB.

CHAPTER EIGHT

CONVERGENCE IN THE NEOLITHIC: HUMAN POPULATION GROWTH AT THE DAWN OF AGRICULTURE

It is widely held that the origins of agriculture incorporated a significant demographic transition in the form of a substantial increase in human numbers (Bocquet-Appel 2002). The results of this study support this argument. I believe, however, that the question that is necessary to ask is why did population growth rates mimic zero-growth throughout most of the southern Levantine prehistory, only to increase at a specific point in time? By posing this question we can begin to understand the potential factors that combined to produce this change when it happened, and not before. Further, by understanding the influencing factors, specifically the diachronic relationship between zero-growth rates for much of human history punctuated by periods of exponential growth, will aid in our future endeavors to model human population history, ultimately leading to a better appreciation of significant transitions in our evolutionary past.

Evolution and the NDT

The case study presented here highlights the flexibility of human nature to negotiate the constraints of resources (or lack thereof) and the ability of humans to shift food economies and adjust not only to bearing and investing in more offspring, but also the potential to shift resource focus to enhance fertility. However, this shift does not occur overnight; instead it was part of a long and gradual process. The flexibility of human behavior involved a number of factors, including how humans interact with their social and natural environments.

Natural selection has favored a human phenotype that is behaviorally and cognitively flexible (Flinn 1996) where we are aware of strategies that produce diminishing marginal returns on investment (Kaplan and Lancaster 2000). As a result of these propensities, humans can alternate strategies toward specific goals as social and environmental circumstances fluctuate (Kaplan and Lancaster 2000). The cost–benefit structure of engaging in any economic activity is shaped by the requirements of involvement and competitiveness in a particular context (Kaplan and Lancaster 2000). This structure helps negotiate whether an individual engages in the production of a food resource or spends time and energy in other arenas that may have greater effects on fitness. Linked to this is the availability of resources in the environment, the quality of the resources available, and the number of other individuals already engaged in the enterprise. The balance of these three conditions affects the number of people engaged in harvesting and processing a particular resource into a usable end product. While the traditional focus of Human Behavioral Ecology is on food quantity in relation to some caloric benefit, I have argued that there is a very strong link to quality, specifically in relation to nutrient content.

If competition is intense for high quality and low quantity resources, costs will theoretically be high to engage in the economic activity, which will lead to fewer individuals participating in production and consumption. As a result, population growth should be constrained if other available resources are not associated with increasing fertility (such as protein from red meat). However, if competition is low and the resources can have significantly positive impact on fertility, population growth will not be constrained, although this is predicated on the assumption that there are no consistent population regulating practices in place (such as infanticide). As a result, population should grow and expand across the landscape, producing larger communities and denser populations through time. Linked to this is the integration of additional age brackets into the work force by younger non-dependent offspring (Kramer and Boone 2002), a common characteristic in ethnographic contexts around the world. Since researchers can estimate nutrient content of the foods that were harvested, processed, and eaten during the NDT, we can examine the potential effects of these foods on fertility. While not directly tested in this study, I expect a focus of my future research on this question will directly test this hypothesis.

When resource quality is low, and availability of resources is low, one should expect that the resource will have a low impact on fertility. Poor-quality resources provide little in terms of nutritional value and may be hard to manipulate into their edible form; however, resources of this nature are commonly utilized, for example, sago palms in highland New Guinea (Diamond 1997). Exploitation of a specific resource, of course, is highly dependent upon what other resources are available and if the resource is even targeted.

Strongly linked to resource quality is the duration of available resources, regardless of their nutritional quality in terms of their potential effects on fertility. In other words, if a resource is associated with increased fertility, yet is only consumed sporadically or even seasonally, the positive effects on fertility may be very minimal (Chavarro et al. 2008). Thus, under circumstances of inconsistent or seasonally shifting diets, one would expect fertility, and therefore population growth, to be constrained.

Why did Fertility Increase?

Our current understanding of the NDT proposes that there was a substantial increase in human fertility at the start of the transition (Bocquet-Appel 2002). What we lack is a detailed discussion and link to potential explanations as to why there was a significant increase in fertility at this specific point in time. Bocquet-Appel (2002:647) provides one hypothesis that incorporates the change in diet between the Mesolithic and Neolithic in Europe. I have argued here that there is a strong link to this hypothesis; however, there is more to this than just a dietary shift. One would expect that if dietary changes were the sole catalyst for increasing fertility, then populations would have started to grow much earlier, perhaps during the Natufian in the southern Levant as evidenced by a greater reliance on the foods that would ultimately increase fertility millennia after. Yet as the model suggests here, Natufian populations likely remained at the magnitude of those during the Early and Middle Epipaleolithic.

Instead of only a dietary shift influencing increased fertility, I argue the issue is much more complex. In short, increased fertility is likely associated with a stabilized diet of specific foods (Chavarro et al. 2008), something that only occurred when storage technology was invented. The foods that people had access to in the southern Levant for a number of years (at least 23,000 years ago according to Savard et al. 2006), namely cereal grains are strongly linked to increasing fertility (Chavaro et al. 2008).

Why did Population Increase?

While not directly tested by this model other than with providing evidence that populations did increase during the transition to agriculture, I have argued that population increased largely because of the introduction of younger non-dependent offspring into the work force. As frequently documented in the ethnographic record, people practicing cultivation consistently incorporate younger offspring into the labor force than do people practicing hunting and gathering strategies (Kramer and Boone 2002). Kramer and Boone (2002) document that females in groups that cultivate plants provide net subsistence as early as 12 years of age, where hunter-gatherers females produce net subsistence much later, perhaps not until they are 20+ years of age. There is a similar trend in males as well, boys will produce net production in cultivating societies around the age of 17, but in hunter-gatherer societies net production may be as late as 22 (Kramer and Boone 2002).

The link to incorporating younger offspring into the workforce with population growth and cultivation comes down to this simple explanation: just because you can have more children does not mean that parents can or will invest in raising more children. In this case, children were enhancing their parents' reproductive success, helping to provide subsistence to feed not only themselves but also their younger, dependent siblings, basically underwriting the cost of larger families (Kramer and Boone 2002).

Convergence in the Neolithic

Until now we have only been able to speculate why fertility increased at the dawn of agriculture. Bocquet-Appel (2002) suggests that increased fertility is linked to food nutrition, but he does not suggest exactly what that relationship entails. In this study I have argued for a convergence of a number of factors that ultimately laid the foundation for increased fertility. These include the availability of particular foods associated with the fertility diet, human interaction with those resources, with subsequent human actions creating of a series of technological inventions (Figure 8.1) that increased efficiency such as processing and harvesting tools. Although increasing efficiency, tools may help provide more food at certain times of the year; however, they have minimal effect on fertility because they don't necessarily ensure a consistent and stable diet for a longer period of time than the harvest season. I believe, much like Testart (1982), that the development of storage technology was probably the most significant invention in human prehistory. Storage technology provided the means for stabilized diets and along with fertility-enhancing foods, enabled the Neolithic demographic transition to occur.

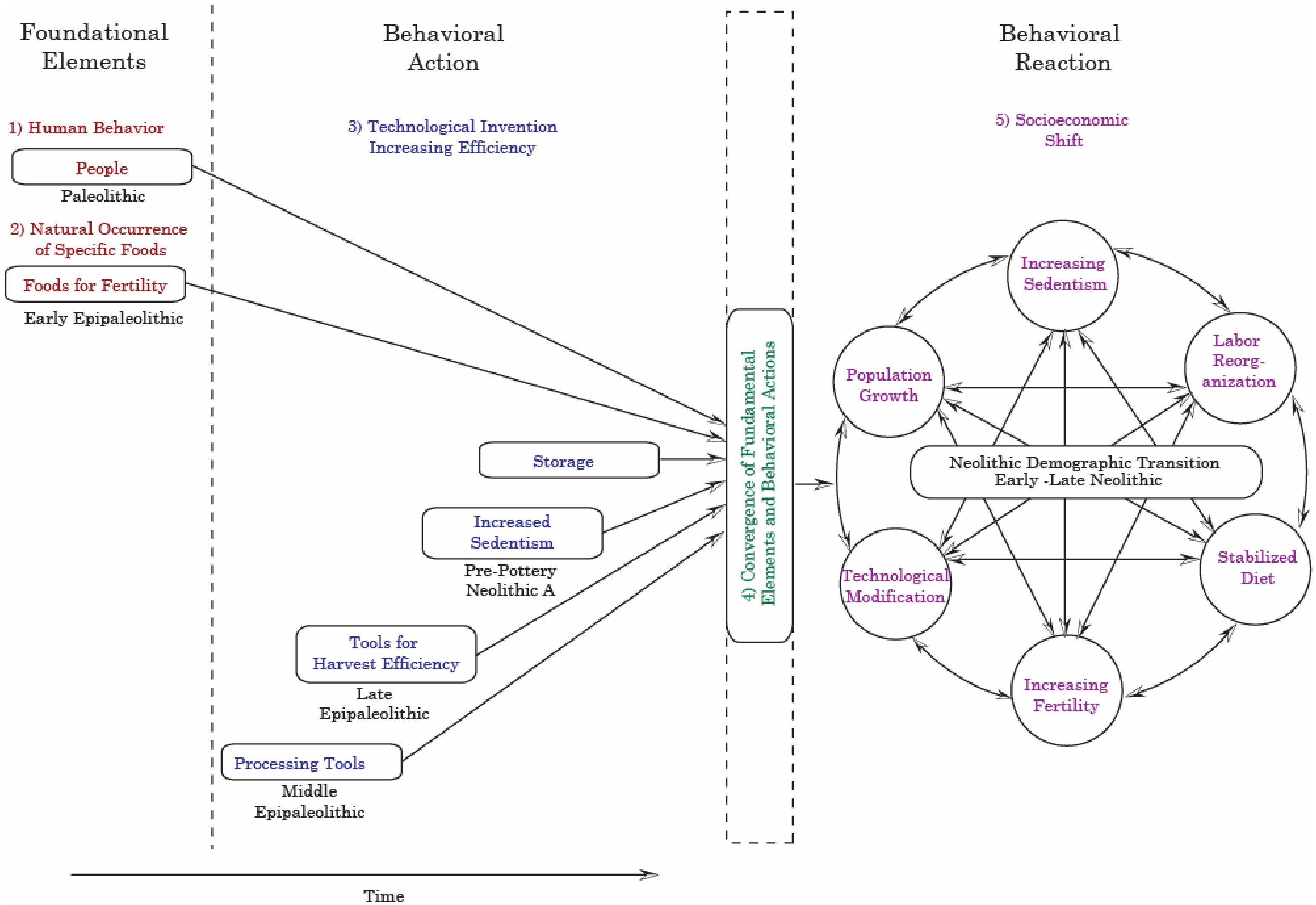


Figure 8.1. A theoretical model of converging natural occurrences and behavioral actions to produce the NDT and subsequent behavioral reactions in socioeconomic systems. Note the time periods where we see the *first* archaeological correlates.

Modeling Population Growth

One general development in this study is the consideration of the flexibility of human nature in negotiating the specific attributes that may enhance fertility. I have identified four specific variables, food nutritional content, technological development, exercise intensity and duration, and labor organization, which merge to circumvent problems associated with increased fertility and thus, population growth. I have argued that these are fundamental elements, and without them in place, a Neolithic demographic transition would not have occurred.

I have argued that there are basic elements (modern human behavior and foods for fertility) that prompt behavioral action (the invention of technologies to harvest, process and store those foods) that become fundamental to the NDT (Figure 8.1). During the NDT population growth was largely a consequence of increased fertility, increased sedentism, stabilized diets and labor reorganization, where technological modifications allowed continued efficiency in procuring, processing and storing resources which ultimately fed more people. It is important to note that I do not suggest this was technological invention out of necessity, rather that the hallmarks of a new socioeconomic system were already in place before and not after population growth rates began to increase. This is in direct opposition of the long held assertion that the origin of food production was an outcome of population pressure (Cohen 1977b). As demonstrated by the population model (Figure 7.16), population growth rates appear to have remained below .005 percent until all of the basic elements (Figure 8.1) were in place, which I argue, coalesced to allow fertility to increase and resulted in an NDT in the southern Levant starting around 11,250 cal BP.

A second important development of this study is an additional methodological technique to detect the timing and rate of an NDT. This method is unique because it utilizes data largely available within the published literature. This offers a means to circumvent issues of other methods, specifically, data availability (Bocquet-Appel 2002; Ammerman and Cavalli-Sforza 1984), and more generally methodological concerns of best fit lines that demonstrate structures within the data (Bocquet-Appel 2002). Although there is probably considerable room for improvement in the analytical procedures I have used, I submit that utilized with other methods, they can only significantly enhance our understanding of population growth and decline as a consequence of the origins of agriculture.

The model presented here improves our ability to understand population growth in the NDT in several ways. First, we can specifically address how accurately each variable tracks population growth and decline based on an objective determination of the best fit cross-correlation among all of the variables. This is critical to the formulation of a model based on frequency data because while multiple variables as proxies of population growth will aid in building better models, each variable needs to monitor the same phenomenon (population growth) in a similar manner. Second, because this model is based on accessible quantitative data, models can be derived for other areas of the world where an NDT occurred. The ability to examine the NDT in many parts of the world allows a greater understanding of the nature and tempo of the NDT and is especially rewarding when comparing the NDT in areas where agriculture was independently invented with regions where it spread through migration and knowledge transmission.

Bocquet-Appel (2002) and others recognize that in areas where cultivation was independently invented, the characteristics of full-scale agricultural villages developed much more slowly than those where food cultivation was introduced from outside areas. As an example, Kuijt (2008a) acknowledges the relatively slow development of plant domestication in the Near East and the subsequent rapid spread throughout Europe as demonstrated by Bocquet-Appel (2002).

The Near East NDT is a good example of the long process to domestication. This is clearly demonstrated by the fact that the foods associated with fertility (specifically cereal grains) were available in the Near East by at least 23,000 years ago (Savard et al. 2006). Moreover, cereals have been recovered in early archaeological contexts, suggesting that people were utilizing these resources. However, even though people exploited these foods, components related to human behavior specifically certain technological inventions, did not appear to have significantly influenced population growth. This would not occur until much later and may be a signature of several converging byproducts of human behavior.

This convergence sequence can be seen in Figure 8.1 and Figure 7.16 with cereal grains found in archaeological contexts at Ohallo II around 23,000 calibrated years ago (Savard et al. 2006), ground stone processing tools in the Middle

Epipaleolithic at various sites (Maher 2007a, b), and new harvest tools in the form of sickle blades hafted into wooden handles during the Late Epipaleolithic Early Natufian tradition (Edwards 2007). All of these factors contributed to exploitation of resources in a more efficient manner. However, they did not aid in increasing fertility or population growth. Instead, the first sign of intensive storage technology appears to be associated with the first population growth rate that was significantly greater than those of the preceding Epipaleolithic. This finding is perhaps one of the most significant of the study.

The NDT in the Pacific Northwest NA

Another example relating population increase and storage technology comes from the Interior Pacific Northwest. Goodale et al. (2004; 2008a) have correlated a significant increase in human numbers after the invention of storage, semi-permanent to permanent residential architecture, and other technological inventions. The area has evidence of human occupation for the past 5800 cal BP, but populations do not appear to grow markedly until 3500 cal BP. This post-dates the invention of storage and increased sedentism by nearly 300 years, a similar time frame for the first big rise in population growth and the evidence of intensive storage in the Near East model (Figure 7.16)

In this area of the world people subsisted on predictable and abundant salmon containing high quantities of Omega 3 fatty acids. There are also correlates of new technology to process high quantities of camas root, which provides plant protein, iron, and is a slow burning carbohydrate. All of these qualities, as noted in Chapter Four, are important features that enhance fertility (Chavarro et al. 2008). What changes, however, is that the hallmarks of the new socioeconomic system are in place including food storage before population starts to rise (Figure 8.2), similar to our southern Levantine example. While these resources in the North American Interior Northwest were never specifically domesticated in prehistory, they have the characteristics of domesticated foods as largely predictable, and when in season, they are usually very abundant (Andrefsky et al. 2000).

While this case study also provides a link between food nutrition and storage technology to population growth, one very important point that this study provides is the replicability in any region of the world where ample archaeological data are available to use as population proxies thus relieving the restrictions that datasets such as human skeletal remains may impose. The variables, however; might not be exactly the same as those utilized here, but instead they should be tailored to the archaeological record and the history of the study area.

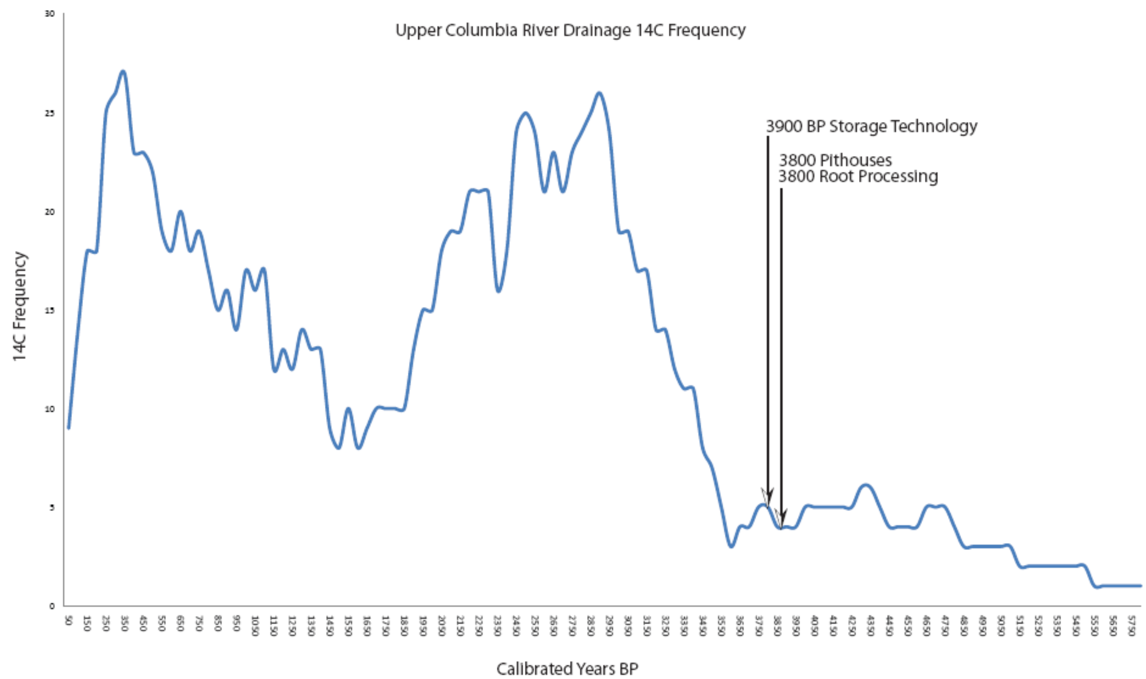


Figure 8.2. A population proxy model for the Interior Northwest of North America in the Upper Columbia Tributaries. The graph is drawn from the data presented in Goodale 2001: Appendix A.

Concluding Remarks

The big picture question discussed and analyzed in this dissertation can be summed up as the following: why was there a substantial increase in the numbers of humans that ultimately characterizes much of what we call the Neolithic? The answer to this question is complex; nevertheless, there are some specific correlates among resource availability, human behavior, and technological inventions that converge at a specific point in time. I have argued that this convergence is the foundation of the Neolithic demographic transition.

Population modeling allows us to test these assertions directly and to examine the timing and rate of technological inventions in correlation to human behavior. Importantly, the database (Chavarro et al. 2008) that has provided the information to address about food nutrition and fertility can provide the potential means to see how much this aspect could have influenced population growth. In the future this will allow an examination of fertility rates and successful birth rates, providing an estimation of how much population grew among the sample of 300,000 modern women. Subsequently, a direct comparison can be made to the population growth model presented here, providing us an estimation of how much nutrition and storage may have contributed to the Neolithic demographic transition. Ultimately, this will provide a more detailed reasoning as to why there was a significant increase in human numbers at the dawn of agriculture.

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APPENDIX A

POPULATION PROXY DATA

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Abu Madi I	8640	120	10150-9400	Pta-3635	1.5	0.18
	9790	100	11650-10750	Pta-4572		
	9790	100	11650-10750	Pta-4551		
	9870	100	11800-11100	Pta4577		
	9880	80	11700-11150	Pta-4580		
	9970	120	12000-11150	Pta-4568		
	9920	80	11750-11200	Pta-4552		
	10110	100	12100-11250	Pta-2699		
Abu Salem	10230 1	50	12650-11250	I-5500	0.75	0.09
	10230	150	12650-11250	I-5499		
	10140	80	12100-11350	Pta-3291		
	10300	100	12650-11650	Pta-3289		
	10340	90	12650-11800	Pta-3290		
	10420	100	12700-11950	Pta-3293		
	10550	90	12850-12150	Pta-3292		
‘Ain Ghazal	7670	100	8650-8210	AA-5196		4.5 MPPNB
	7726	73	8640-8380	KN-4880		10 LPPNB
	7809	74	9000-8400	KN-4882		12 PPNC
	7820	240	9450-8150	AA-1165		
	7825	65	9000-8400	GrN-17494		
	7857	74	9000-8450	KN-4884		
	7880	82	9000-8520	KN-4881		
	7895	95	9050-8450	AA-5205		
	7910	60	8990-8590	AA-25427		
	7910	60	8990-8590	AA-25428		
	7915	95	9020-8540	GrN-17495		
	7939	87	9020-8580	KN-4885		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
'Ain Ghazal	7952	77	9010-8600	KN-4879		
	7960	75	9010-8600	AA-5198		
	7980	55	9010-8640	AA-25429		
	7990	80	9030-8590	AA-5206		
	8030	65	9090-8640	AA-25424		
	8070	230	9550-8350	UCR-1722		
	8080	65	9250-8700	AA-25425		
	8083	47	9140-8770	KN-5056		
	8090	75	9300-8700	AA-5197		
	8162	62	9310-8990	KN-5055		
	8165	50	9270-9000	GrN-12972		
	8200	75	9410-9000	AA-5203		
	8205	65	9410-9010	AA-25426		
	8208	77	9410-9000	KN-4877		
	8230	76	9420-9020	KN-4883		
	8236	81	9430-9020	KN-5054		
	8253	76	9430-9020	KN-4878		
	8270	75	9450-9030	AA-5199		
	8310	250	9950-8550	GrN-14259		
	8310	70	9480-9090	AA-5202		
	8325	70	9490-9120	AA-5201		
	8460	90	9610-9240	GrN-12971		
	8515	50	9550-9440	KN-5188		
	8520	110	9900-9250	Beta-19907		
	8570	180	10250-9050	AA-1167		
	8570	80	9770-9420	GrN-14257		
	8620	320	10550-8750	UCR-1721		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
	8650	200	10250-9150	GrN-12970		
	8660	80	9910-9500	OxA-1472		
	8680	190	10250-9300	GrN-12962		
	8700	80	10150 9500	OxA-1743		
	8775	75	10150 9550	AA-25037		
	8780	70	10150 9550	AA-5200		
	8810	160	10250 9500	GrN-14258		
	8810	80	10200 9600	GrN-12969		
	8930	80	10240 9760	GrN-12967		
	8930	60	10230 9790	GrN-12961		
	8950	390	11250 9050	AA-1166		
	8970	150	10500 9600	Beta-19906		
	8970	110	10400 9650	GrN-12968		
	8970	80	10260 9780	GrN-12963		
	8970	80	10260 9780	GrN-12964		
	9000	90	10400 9750	GrN-12959		
	9030	80	10410 9900	GrN-12960		
	9050	80	10500 9900	GrN-12965		
	9100	140	10700 9750	AA-1164		
	9200	110	10670 10180	GrN-12966		
Ain Mallaha	11,590	540	15150-12150	Ly-1660	1	0.2
	11,740	570	15350-12350	Ly-1661		
Arabi I	14500	190	18150-16650	SMU-2373	N/A	N/A
Ashkelon	7630	65	8560-8330	OxA7881	1	1
	7995	50	9250-8550	OxA-7995		
	8000	110	9250-8550	OxA-7883		
	7990	90	9090-8590	OxA-7882		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Ashkelon	7935	50	8990-8620	OxA-7916		
Atlit Yam	7550	80	8520-8180	PITT-622	N/A	6
	7610	90	8590-8200	RT-944C		
	7670	85	8630-8330	RT944A		
	8000	90	9150-8550	Pta-3950		
	8140	120	9450-8650	RT-707		
Ayn Abu Nukhayla	8509	64	9600-9400	N/A	0.75	1.2
Ayn Jammam	8030	120	9300-8550	N/A	3	7
	8520	190	10150-8950	N/A		
Azraq 31	8350	120	9550-9000	OxA-870	N/A	0.43
	8275	80	9460-9030	OxA-2412		
	13260	200	16450-15050	N/A	0.3	N/A
Baaz	10470	121	12800-12000	KIA-11576	0.75	0.0006
	10667	97	12860-12390	KIA-11578		
	10942	65	13030-12820	KIA-11577		
Baja	7887	43	8980-8580	Bln-5053	0.6	1.2
	7910	44	8980-8590	Bln-5036		
	8100	33	9130-8990	Bln-5123		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Basta	8155	50	9270-9000	GrN14538	1	10
	8380	100	9540-9120	GrN-14537		
Beidha	8550	160	10150-9050	K-1085	3(PPNB)	2(PPNB)
	8545	100	9800-9250	P-1379	0.4 (Nat)	1(Nat)
	8640	160	10200-9300	K-1083		
	8790	200	10400-9400	BM-111		
	8720	150	10200-9450	K-1412		
	8730	160	10200-9450	K-1084		
	8715	130	10200-9500	P-1378		
	8765	100	10200-9500	P-1381		
	8770	150	10200-9500	K-1411		
	8770	160	10250-9500	K-1082		
	8640	50	9740-9520	GrN-5063		
	8940	160	10450-9550	K-1086		
	8850	100	10200-9600	K-1410		
	8890	115	10250-9600	P-1382		
	8810	50	10160-9670	GrN-5136		
	9130	105	10600-9900	P-1380		
	9030	50	10270-9930	GrN-5062		
	10910	520	13850-11150	AA-1462		
	12130	190	14850-13550	AA-1464		
	12450	170	15150-13950	AA-1465		
	12910	250	16050-14250	AA-1463		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Burqu 27	7270	80	8310-7940	OxA-2764	N/A	N/A
	7350	80	8350-8000	OxA-2765		
	7930	80	9010-8590	OxA-2766		
Buruqu 35	8140	90	9450-8750	OxA-2768	N/A	N/A
	8180	80	9420-8980	OxA-2769		
Buruqu 37	8270	80	9450-9030	OxA-2770	N/A	N/A
Dhra’	9610	170	11400-10400	ISGS-3277	1	2
	9940	180	12150-10750	ISGS-3278		
	9835	65	11410-11120	ISGS-A0246ams		
	9960	110	12000-11150	ISGS-2898		
	9835	59	11400-11160	ISGS-A0248ams		
	9984	67	11750-11200	AA-38143		
	10000	68	11800-11250	AA-38144		
	10031	69	11850-11250	AA-38141ams		
	10059	73	12000-11250	AA-38142ams		
Dhuweila	7030	90	8010-7680	OxA-1636		
	7140	90	8170-7780	OxA-1728		
	7450	90	8410-8040	OxA-1729		
	8190	60	9400-9000	BM-2349		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Dhuweila	8350	100	9530-9090	OxA-1637	N/A	N/A
Ein Aqev	17520	790	22650-19050	I-5495	1.2	1.01
	16900	250	20550-19450	I-5494		
	17390	560	22150-19450	SMU-8		
	17890	600	22650-19850	SMU-6		
	19980	1200	25000-21226	SMU-5		
El-Wad	11475	650	15250-11550	N/A	N/A	0.1
	11,920	660	15950-12350	N/A		
	10680	190	13000-12000	Pta 1376		
	10740	200	13100-12100	N/A		
	12620	120	15200-14200	Pta-5435		
	12950	200	16050-14550	RT-1368		
Es-Sifiya	7930	70	9000-8600	N/A		
Fazael IX	17,660	160	21350-20400	OxA-2871		
Fazael X	15,450	130	18960-18590	OxA-2870		
Gesher	9790	140	11750-10700	RT-868b		
	9820	140	11800-10750	RT-868a		
	9870	80	11700-11150	Pta-4595		
	10020	100	12000-11200	Pta-4553		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Ghoraife'	6940	190	8200-7450	Gif-3371	N/A	N/A
	8150	190	9500-8550	Gif-3372		
	8400	190	9950-8750	Gif-3374		
	8460	190	10150-8950	Gif-3375		
	8710	190	10250-9300	Gif-3376		
Ghuwayr I	8755	311	10650-8950	DRI 3255	N/A	1.2
	8530	100	9770-9280	ISGS 4365		
	8390	50	9520-9290	Beta 140757		
	8528	89	9710-9300	Hd 17221-17359		
	8659	178	10200-9300	DRI 3254		
	8510	70	9630-9320	ISGS 4331		
	8570	100	9900-9400	ISGS 4365		
	8570	70	9700-9440	ISGS 4332		
	8590	70	9740-9460	ISGS 4325		
	8620	70	9790-9470	ISGS 4333		
	8610	50	9690-9500	Beta 140759		
	8620	50	9700-9510	Beta 140758		
	8627	46	9690-9520	Hd 17220-17550		
	8690	70	9910-9530	ISGS 4364		
	8754	50	9950-9550	DRI 3256		
	8806	52	10200-9600	DRI 3251		
	8812	61	10200-9600	Hd 17219-17541		
	8880	117	10250-9600	DRI 3252		
	8870	70	10200-9700	ISGS 4330		
	9027	116	10500-9700	DRI 3253		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Gilgal I	9900	220	12250-10650	RT-777	2	0.3
	9710	70	11250-10780	Pta-4585		
	9830	80	11650-11050	Pta-4583		
	9950	150	12150-11050	RT-777		
	9950	150	12150-11050	RT-777		
	9920	70	11700-11200	Pta-4588		
Hamifgash IV	16230	200	19850-19000	OxA-2143	N/A	N/A
Hatoula	8890	120	10250-9600	GifA-91138	0.25	0.2
	10030	140	12100-11200	GifA-91360		
	10170	120	12450-11250	GifA-91139		
	11020	180	13300-12700	GifA-91141		
Hayonim Cave	12010	180	14450-13350	OaX-743	3	0.023
	12360	160	15050-13850	OaX-742		
	16240	640	20850-17950	Hv-2675		
Hayonim Terrace	10100	160	12450-11150	OxA-2573	0.55	0.06
	10000	100	12000-11200	OxA-1899		
	11220	110	13290-12910	OxA-2569		
	11460	110	13570-13110	OxA-2572		
	11720	120	13810-13310	OxA-2977		
	11790	120	13900-13350	OxA-2975		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Hayonim Terrace	11820	120	13950-13400	OxA-2570		
	11920	90	14000-13570	SMU-231		
Hilazon Tachtit	10750	50	12860-12700	N/A	0.09	N/A
Horvat Galil	8950	100	10300-9650	RT-1396	N/A	1
	9340	70	10730-10290	RT-1397		
Iraq ed-Dubb	9592	64	11170-10730	AA-38140	1.5	0.045
	9959	100	11850-11200	OxA-2567		
	9941	72	11710-11210	AA-38145		
	10785	285	13350-11750	GX-17399		
	11175	400	13950-12050	GX-17398		
	10657	82	12850-12390	AA-38278		
	10723	68	12870-12640	AA-38279		
	11145	120	13250-12870	GX-17077		
Jebel Naja	7430	100	8410-8030	OxA-375	0.25	N/A
Jericho	7300	200	8550-7650	GL-46	4(LPPNB)	4
	7800	160	9100-8300	GL-38	7.5(MPPNB)	
	8200	200	9550-8600	GL-28		
	8390	200	9950-8750	GL-36		
	8660	260	10450-8950	BM-1771		
	8700	200	10250-9300	GL-42		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Jericho	8670	150	10200-9400	GL-41		
	8540	65	9660-9430	BM-1320		
	8660	100	10150-9450	P-381		
	8660	130	10200-9450	BM-1793		
	8690	150	10200-9450	GL-40		
	8710	150	10200-9450	BM-253		
	8610	75	9790-9460	P-380		
	8730	80	10150-9500	BM-1773		
	8700	110	10200-9500	BM-1769		
	8770	150	10200-9500	GL-39		
	8895	150	10300-9500	GL-43		
	8680	70	9900-9530	BM-1770		
	8810	100	10200-9550	BM-1772		
	8955	105	10300-9650	P-382		
	9170	200	11150-9650	BM-115		
	9025	100	10500-9750	GrN-963		
	9230	220	11150-9750	BM-1326		
	9140	70	10500-10190	GrN-942		
	9320	150	11100-10200	BM-252		
	9200	70	10560-10230	BM-1789		
	9230	80	10590-10230	BM-1321		
	9280	100	10710-10240	BM-1787		
	9380	85	11100-10250	BM-1322		
	9380	85	11100-10250	BM-1323		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Jericho	9390	150	11150-10250	BM-251		
	9430	85	11100-10400	BM-1324		
	9800	240	12150-10450	GL-72		
	9850	240	12250-10550	GL-69		
	10300	500	13150-10550	BM-250		
	9580	90	11200-10650	P-377		
	9560	65	11160-10690	BM-1327		
	9655	85	11220-10740	P-379		
	9775	110	11650-10750	P-378		
	10180	200	12650-11150	BM-110		
	10250	200	12750-11250	BM-105		
	10300	200	12750-11250	BM-106		
	10800	180	13150-12150	GL-70		
	11090	90	13170-12870	BM-1407		
	11166	107	13250-12890	P-376		
Jilat 10	12700	300	15850-13950	OxA-918	0.2	N/A
	13120	180	16150-14950	OxA-1000		
	14790	200	18650-17150	OxA-520		
Jilat 13	7830	90	9000-8400	UB-3642	N/A	0.08
	7870	100	9000-8450	OxA-1801		
	7920	100	9050-8450	OxA-1800		
	7900	80	9000-8550	OxA-2411		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Jilat 22	12840	140	15700-14650	OxA-1772	0.275	0.35
	13040	180	16050-14850	OxA-1771		
	13490	110	16550-15550	OxA-2409		
	13540	120	16600-15600	OxA-2410		
Jilat 25	8020	80	9130-8630	OxA-2408	N/A	0.32
Jilat 26	8370	100	9540-9120	N/A	N/A	0.78
	8690	110	10150-9450	OxA-1802		
	8720	100	10200-9500	OxA-2407		
	8740	110	10200-9500	OxA-2969		
Jilat 6	15520	200	19250-18450	OxA-524	0.5	1.975
	15470	130	18970-18600	AA-5492		
	16010	200	19550-18850	OxA-525		
	16575	120	19950-19470	AA-5491		
	16695	120	20100-19500	AA-5493		
	16700	140	20150-19500	AA-5494		
Jilat 7	8390	80	9540-9140	OxA-2413	N/A	0.225
	8520	110	9900-9250	OxA-527		
	8810	110	10200-9550	OxA-526		
Jilat 8	13310	120	16300-15300	OxA-521	0.5	0.63

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Kebara	12470	180	15150-13950	OxA-2798	0.25	0.52
	11150	400	13950-11950	N/A		
Kfar Gilad	8905	320	11150-9050	N/A	N/A	N/A
Kharaneh IV	15200	450	19350-16950	KN-4192	2	2.1
	15700	160	19300-18700	KN-4193		
Khirbet Hammam	8120	60	9280-8780	GrN-26146	N/A	3
	8370	40	9490-9290	GrN-26147		
Labwe	7850	140	9050-8350	K-1429 N/A		N/A
	7860	140	9050-8350	K-1428		
	7990	140	9300-8450	K-1430		
Maaleh Ramon East	10430	80	12700-12050	Pta-3483	N/A	0.02
	10530	100	12800-12100	Pta-3371		
Maaleh Ramon West	10000	200	12450-10750	RT-1068N	N/A	0.02
	10400	100	12700-11950	Pta-3483		
Madamagh	14300	650	18850-15450	KN-3593	1	0.01
	15300	600	19850-16750	KN-3594		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Mezad Mazal	8070	75	9300-8650	KN-2443	N/A	N/A
	8240	75	9430-9020	HV-9106		
	8330	75	9500-9120	HV-9107		
	8350	75	9500-9130	KN-2444		
	8440	80	95509260	HV-9108		
	8480	70	9560-9300	B-2737		
	8995	35	10240-9940	RTT-4753		
	9080	30	10265-10195	RTT-4865		
	9100	30	10300-10200	RTT-4751		
	9130	30	10390-10220	RTT-4749		
	9150	35	10410-10230	RTT-4866		
	9200	40	10500-10240	RTT-4867		
	9210	25	10490-10260	RTT-4752		
	9310	30	10590-10410	RTT-4750		
Motza	8995	35	10240-9940	RTT-4753	2	10
	9080	30	10265-10195	RTT-4865		
	9100	30	10300-10200	RTT-4751		
	9130	30	10390-10220	RTT-4749		
	9150	35	10410-10230	RTT-4866		
	9200	40	10500-10240	RTT-4867		
	9210	25	10490-10260	RTT-4752		
	9310	30	10590-10410	RTT-4750		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Munhata	7370	400	9150-7350	M-1792	N/A	N/A
	9160	500	12050-8950	M-1793		
Mushabi I	13310	100	16250-15350	SMU-117	N/A	N/A
Mushabi V	12700	90	15350-14500	Pta-2157	N/A	N/A
	12990	110	15800-15000	SMU-171		
Mushabi XIV	12900	235	15950-14250	QC-202	N/A	N/A
	13260	200	16450-15050	MC-992		
	13830	490	18050-15050	RT-447D		
	13750	285	17250-15450	QC-201		
	13900	400	17950-15450	RT-417		
	13690	150	16850-15750	MC-991		
	13800	150	17050-15850	RT-473A		
	13800	130	16950-15950	SMU-225		
	14330	120	17750-16550	SMU-226		
	14500	100	17950-16950	RT-473B		
	13060	220	16250-14750	RT-447C		
Mushabi XVII	14170	480	18550-15650	SMU-661	N/A	N/A
Mushabi XVIII	13930	110	17050-16150	SMU-217	N/A	N/A

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Nahal Divishon	8170	180	9500-8600	Tx-1125	0.405	2.5
	8620	140	10200-9300	I-5501		
	8900	180	10450-9500	SMU-3		
Nahal Hemar	8100	100	9350-8600	RT-650 N/A		N/A
	8500	220	10250-8950	OxA-1015		
	8250	70	9430-9030	BM-2298		
	8270	80	9450-9030	Pta-3650		
	8600	120	10150-9300	OxA-1014		
	8810	120	10200-9550	OxA-1016		
	9210	300	11250-9550	BM-2298		
	8850	90	10200-9600	Pta-3625		
Nahal Issaron	7100	70	8050-7740	RT-1691	0.75	0.04
	7135	95	8180-7760	RT-1640		
	7460	95	8420-8040	RT-1516		
	7600	110	8600-8180	RT-1665		
	7620	80	8590-8210	RT-1508		
	7950	110	9150-8500	RT-1700		
	7870	55	8980-8540	RT-1509		
	8050	80	9250-8600	Pta-3376		
	8080	90	9300-8600	RT-1507		
	7990	55	9010-8640	RT-1520		
	8120	80	9400-8700	RT-1511		
	8590	240	10250-8950	RT-1699		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Nahal Issaron	8180	80	9420-8980	Pta-3377		
	8200	90	9450-8980	RT-1514		
	8265	80	9440-9020	RT-1638		
	8290	80	9470-9030	RT-1701		
	8330	100	9530-9030	RT-1664		
	8350	75	9500-9130	RT-1522		
	8390	95	9540-9130	RT-1521		
	8430	80	9550-9250	Pta-3000		
	8650	85	9910-9480	RT-1512		
	8685	70	9900-9530	RT-1609		
	8785	80	10200-9550	RT-1515		
	9100	85	10550-9900	RT-1510		
	9195	70	10550-10230	RT-1607		
Nahal Oren V	10046	318	12750-10650	BM-764	1	0.02
Nahal Oren	15800	300	19750-18550	UCLA-1776a	N/A	N/A
	16880	340	20850-19350	UCLA-1776b		
	18250	320	22450-20750	UCLA-1776c		
Nahal Reu'el	8550	60	9660-9440	Pta-3202	N/A	0.04
	8620	60	9740-9490	Pta-3137		
	8670	60	9890-9530	Pta-2848		
Nahal Sekher	12200	150	14850-13750	OxA-2137	0.1	.0001

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Nahal Zin D5	13530	144	16650-15550	SMU-268	0.03	0.008
	13170	230	16350-14950	I-5497		
Netiv Hagdud	9790	380	12650-10150	RT-502A	3.5	1.5
	9400	180	11200-10200	RT-762D		
	9600	170	11400-10400	RT-762B		
	9680	140	11400-10550	RT-762A		
	9700	150	11650-10550	OxA-744		
	9780	150	11750-10650	RT-762F		
	9750	90	11350-10750	Pta-4555		
	9780	90	11500-10750	Pta-4557		
	9660	70	11210-10770	Pta-4556		
	9700	80	11250-10770	Pta-4590		
	10180	300	12850-11050	RT-502C		
	9970	150	12100-11100	RT-762C		
Neve David	12610	130	15250-14200	OxA-892	N/A	N/A
	13400	180	16550-15250	OxA-859		
Ohallo II	15550	130	19020-18650	RT-1246	0.35	0.04
	17500	200	21250-20150	RT-1297		
	18210	240	22250-20850	RT-1623		
	18360	230	22450-21050	RT-1244		
	18600	220	22650-21350	RT-1343		
	18900	400	23750-21350	RT-1252		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Ohallo II	18680	180	22650-21550	OxA-2564		
	18700	180	22650-21750	RT-1617		
	19100	390	23950-21750	OxA-2566		
	18760	180	22700-21900	RT-1358		
	19250	400	24050-22050	RT-1250		
	19000	190	23250-22150	RT-1251		
	19220	180	23550-22350	RT-1618		
	19600	400	24450-22350	Pta-5386		
	19310	190	23650-22450	OxA-2565		
	19400	220	23750-22450	Pta-5374		
	19500	170	23850-22550	RT-1342		
	19800	360	24550-22550	RT-1248		
	19590	150	23850-22650	RT-1616		
	20100	440	25450-22750	Pta-5387		
	19860	190	24350-23050	RT-1619		
	20070	270	24850-23150	RT-1621		
	20190	170	24650-23700	RT-1622		
	20840	290	25000-24250	RT-1624		
	20830	180	25550-24450	RT-1620		
	21050	330	25000-24510	RT-1625		
Qadesh Barnea	13930	120	17050-16100	Pta-2159	N/A	N/A
	14130	160	17550-16250	Pta-2158		
Qadesh Barnea 3	7350	80	8350-8000	Pta-3662	N/A	N/A
	7530	100	8550-8160	SMU-662		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Qadesh Barnea 3	10580	140	12850-12100	I-7030		
Rakefet Cave	10980	260	13450-12150	I-7032	N/A	N/A
Ramad	7880	55	8980-8550	GrN-4823	N/A	N/A
	7900	50	8980-8590	GrN-4822		
	7920	50	8980-8600	GrN-4427		
	8090	50	9250-8770	GrN-4821		
	8200	80	9410-9000	GrN-4428		
	8210	50	9400-9010	GrN-4426		
Ramat Harif	10100	100	12050-11250	Pta-3286	N/A	N/A
	10250	100	12650-11350	Pta-3288		
	10300	100	12650-11650	Pta-3001		
	10380	100	12700-11800	Pta-3284		
	10390	100	12700-11800	Pta-3285		
	10500	100	12800-12100	Pta-3009		
Ras Shamra	7185	85	8180-7840	P-457	N/A	N/A
	7480	90	8430-8040	Pta-100		
	7685	110	8800-8200	P-458		
	8000	115	9250-8550	Pta-113		
	8140	100	9450-8700	P-459		
	9030	400	11250-9050	Gif-102		
	8365	100	9540-9090	P-460		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Rosh Horesha	10490	430	13250-11050	SMU-9	N/A	N/A
	10880	280	13350-11950	SMU-10		
Saflulim	10930	130	13130-12710	OxA-2136	N/A	N/A
	11150	100	13230-12890	OxA-2869		
Salibiya I	11530	550	15050-12050	RT-505A	0.12	0.95
Sefunim Layer 7	7730	115	9000-8300	Hv 2597	N/A	N/A
	9120	85	10600-10150	KN-I 366		
	9395	130	11100-10250	Hv 3368		
Shunera VI Dune	9500	130	11200-10400	N/A	N/A	0.02
Shunera XVI	15800	160	19400-18750	Pta-3702	N/A	N/A
	16100	150	19550-18950	Pta-3403		
	16200	170	19800-19000	Rt-227		
Tabaqat al-Buma	14850	160	18650-17350	TO-991	0.015	N/A
Tell Aswad	8540	110	9900-9250	Gif-2369		
	8720	75	10150-9500	GrN-6677		
	8650	55	9770-9520	GrN-6676		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Tell Aswad	8865	60	10190-9730	GrN-8865	N/A	2
	8875	55	10190-9740	GrN-6678		
	9270	120	10800-10200	Gif-2371		
	9340	120	11100-10200	Gif-2370		
	9640	120	11250-10600	Gif-2372		
	9730	120	11500-10650	Gif 2633		
Tor al-Tareeq	9010	100	10450-9750	Beta-57898	0.3	0.05
	11280	290	13850-12750	Beta-57899		
	15860	430	19950-18050	UA-4394	N/A	0.08
	15580	250	1945018150	UA-4392		
	16570	380	20450-18950	UA-4390		
	16900	500	21250-18950	UA-4391		
	16790	340	20750-19150	UA-4393		
	16670	270	20450-19250	Beta-57900		
Tor Hamar	12683	323	15850-13850	SMU-1399	1.3	N/A
Ujrat El-Mehed	8220	80	9420-9010	Pta-2703	0.03	0.5
Urkan e-Rub IIa	14440	150	17950-16750	OxA-1503	N/A	N/A
	14650	120	18150-16950	OxA-2837		
	14800	130	18650-17350	OxA-2839		
	14860	130	18650-17550	OxA-2836		
	14980	200	18850-17550	OxA-2842		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Urkan e-Rub IIa	14880	120	18650-17650	OxA-2840		
	15050	160	18800-17900	OxA-2838		
	15190	130	18800-18050	OxA-2835		
	15730	130	19230-18750	OxA-2841		
Uwaynid 14	18400	250	22450-21050	OxA-866	0.04	N/A
	18900	250	23450-21850	OxA-865		
Uwaynid 18	23200	400	24050-22350	OxA-867	0.15	0.088
	19500	250	23950-22450	OxA-868		
	19800	350	24550-22550	OxA-864		
Wadi Faynan 16	9180	60	10500-10230	Beta-135110	1.5	1
	9400	60	10800-10400	Beta-120207		
	9420	50	10780-10500	Beta-120206		
	9690	50	11230-10790	Beta-12205		
	9890	50	11600-11200	Beta-120211		
	10220	60	12200-11600	Beta-120210		
	10220	60	12200-11600	Beta-135111		
	19500	600	24950-21550	SUA-2101		
Wadi Hammeh 27	11920	150	14100-13400	OxA-393	0.65	2
	11950	160	14200-13400	OxA-507		
	12200	160	14850-13650	OxA-394		

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Wadi Hammeh 31	16740	220	20350-19450	ANU-4655	N/A	N/A
Wadi Hammeh 32	19480	500	24550-22050	ANU-4653	N/A	.0025
Wadi Hasa 1065	15860	430	19950-18050	AA-4394	0.75	0.0812
	15580	250	19450-18150	AA-4392		
	16570	380	20450-18950	AA-4390		
	16900	500	21250-18950	AA-4391		
	16790	340	20750-19150	AA-4393		
Wadi Hasa 618	20300	600	25750-22650	AA-4395	N/A	1.2
Wadi Judayid	12090	800	16450-12150	SMU-805	0.35	0.04
	12784	650	16850-13350	SMU-803		
Wadi Shu'eib	7810	340	9550-7950	Bta-35088	10	5
	7660	210	9000-8000	Bta-35084		
	8120	280	9650-8350	Bta-35085		
	8500	160	9950-8950	Bta-35086		
	8670	210	10250-9150	Bta-35082		
	8600	100	9920-9420	Bta-35081		
	9160	190	11150-9650	Bta-35089		
Wadi Tbeik	10350	100	12650-11800	Pta-2700	0.5	N/A

Site	^{14}C Date	+/-	Calibrated Range 2σ	LabNo	DOD(M)	Site Size(H)
Yiftahel	7460	210	8800-7800	RT-702b	2	1.5
	8570	130	10150-9250	RT-736a		
	8720	70	10150-9500	Pta-4245		
	8740	140	10200-9500	Ly-3938		
	8940	140	10400-9550	Ly-3939		
	8890	120	10250-9600	RT-736b		
	8870	90	10250-9650	Pta-4242		
Zahrat edh-Dhra'2	9323	59	10700-10290	WK 9444	2	1.5
	9440	50	11100-10500	OZE 606		
	9470	50	11070-10570	OZE 607		
	9490	50	11080-10580	OZE 605		
	9528	61	11150-10600	WK 9570		
	9552	59	11140-10690	WK 9445		
	9623	91	11210-10710	WK 9568		
	9603	59	11170-10740	WK 9447		
	9635	59	11190-10770	WK 9633		

APPENDIX B

POPULATION PROXY SUMMARY DATA

Time	DOD	DOD%	SSH	SSH%	F14C	F14C%	FSO	FSO%
8000	23.564	0.0073	2.5	0.0009	21	0.0022	9	0.0023
8050	23.564	0.0073	2.5	0.0009	20	0.0021	9	0.0023
8100	23.564	0.0073	2.5	0.0009	20	0.0021	9	0.0023
8150	27.564	0.0085	2.5	0.0009	25	0.0026	11	0.0028
8200	31.564	0.0098	2.5	0.0009	22	0.0023	11	0.0028
8250	31.564	0.0098	3.5	0.0012	22	0.0023	11	0.0028
8300	32.564	0.0101	4.5	0.0016	26	0.0027	13	0.0033
8350	32.564	0.0101	4.5	0.0016	29	0.0030	14	0.0035
8400	35.62	0.0110	4.5	0.0000	30	0.0031	15	0.0038
8450	32.62	0.0101	4.25	0.0015	31	0.0032	13	0.0033
8500	32.62	0.0101	4.25	0.0015	35	0.0036	13	0.0033
8550	39.62	0.0123	7.85	0.0027	53	0.0054	16	0.0040
8600	62.44	0.0193	10.255	0.0035	63	0.0065	20	0.0050
8650	62.44	0.0187	11.755	0.0042	64	0.0067	21	0.0053
8700	60.44	0.0196	12.255	0.0042	65	0.0074	21	0.0055
8750	63.44	0.0196	12.255	0.0042	72	0.0074	22	0.0055
8800	63.44	0.0192	12.255	0.0037	72	0.0072	22	0.0053
8850	61.94	0.0192	10.755	0.0037	70	0.0072	21	0.0053
8900	61.94	0.0195	10.755	0.0037	70	0.0086	21	0.0055
8950	63.14	0.0231	10.755	0.0042	84	0.0099	22	0.0065
9000	74.824	0.0176	12.255	0.0046	96	0.0087	26	0.0063
9050	56.824	0.0176	13.255	0.0046	85	0.0089	25	0.0060
9100	56.744	0.0175	13.255	0.0044	87	0.0085	24	0.0055
9150	56.424	0.0175	12.655	0.0044	83	0.0085	22	0.0055
9200	56.424	0.0169	12.655	0.0056	83	0.0096	22	0.0063
9250	54.649	0.0166	16.155	0.0052	93	0.0106	25	0.0060
9300	53.649	0.0166	15.155	0.0052	103	0.0089	24	0.0058
9350	53.649	0.0170	15.155	0.0055	87	0.0100	23	0.0065
9400	55.069	0.0173	15.905	0.0067	97	0.0097	26	0.0063
9450	55.819	0.0163	19.405	0.0067	94	0.0107	25	0.0060
9500	52.819	0.0163	19.405	0.0067	104	0.0106	24	0.0058
9550	52.795	0.0127	19.405	0.0064	103	0.0108	23	0.0053
9600	41.165	0.0115	18.405	0.0078	105	0.0112	21	0.0050
9650	37.065	0.0115	22.655	0.0078	109	0.0112	20	0.0050
9700	37.065	0.0115	22.655	0.0079	109	0.0114	20	0.0053
9750	37.235	0.0115	22.955	0.0079	111	0.0108	21	0.0053
9800	37.235	0.0115	22.955	0.0079	105	0.0108	21	0.0053
9850	37.235	0.0146	22.955	0.0086	105	0.0114	21	0.0053

Time	DOD	DOD%	SSH	SSH%	F14C	F14C%	FSO	FSO%
9900	47.195	0.0146	24.955	0.0086	111	0.0106	21	0.0053
9950	47.195	0.0146	24.955	0.0086	103	0.0098	21	0.0053
10000	47.195	0.0146	24.955	0.0086	95	0.0098	21	0.0053
10050	47.195	0.0146	24.955	0.0086	95	0.0098	21	0.0053
10100	47.195	0.0124	24.955	0.0088	95	0.0103	21	0.0058
10150	40.195	0.0105	25.455	0.0095	100	0.0099	23	0.0055
10200	34.015	0.0108	27.455	0.0102	96	0.0075	22	0.0053
10250	35.01	0.0108	29.455	0.0102	73	0.0054	21	0.0050
10300	35.01	0.0108	29.455	0.0102	53	0.0050	20	0.0050
10350	35.01	0.0110	29.455	0.0102	49	0.0057	20	0.0055
10400	35.53	0.0110	29.455	0.0102	55	0.0050	22	0.0055
10450	35.53	0.0097	29.455	0.0092	49	0.0046	22	0.0048
10500	31.48	0.0097	26.75	0.0092	45	0.0044	19	0.0048
10550	31.48	0.0066	26.75	0.0083	43	0.0041	19	0.0043
10600	21.44	0.0062	24	0.0097	40	0.0047	17	0.0048
10650	20.14	0.0062	28	0.0097	46	0.0050	19	0.0050
10700	19.985	0.0059	28.175	0.0102	49	0.0062	20	0.0050
10750	19.185	0.0059	29.675	0.0102	60	0.0058	20	0.0050
10800	19.185	0.0059	29.675	0.0102	56	0.0056	20	0.0050
10850	19.185	0.0059	29.675	0.0102	54	0.0057	20	0.0050
10900	19.185	0.0059	29.675	0.0102	55	0.0057	20	0.0050
10950	19.185	0.0060	29.675	0.0105	55	0.0057	20	0.0050
11000	19.275	0.0066	30.425	0.0105	55	0.0062	20	0.0053
11050	21.275	0.0066	30.425	0.0105	60	0.0060	21	0.0055
11100	21.275	0.0066	30.425	0.0100	58	0.0068	22	0.0060
11150	21.335	0.0036	29.075	0.0084	66	0.0067	24	0.0058
11200	11.635	0.0036	24.325	0.0084	65	0.0072	23	0.0058
11250	11.615	0.0030	24.325	0.0077	70	0.0068	23	0.0050
11300	9.615	0.0030	22.325	0.0077	66	0.0067	20	0.0050
11350	9.615	0.0030	22.325	0.0081	65	0.0066	20	0.0050
11400	9.615	0.0030	23.325	0.0081	64	0.0062	20	0.0050
11450	9.615	0.0030	23.325	0.0081	60	0.0062	20	0.0053
11500	9.615	0.0024	23.325	0.0081	60	0.0061	21	0.0050
11550	7.615	0.0024	23.325	0.0081	59	0.0063	20	0.0050
11600	7.615	0.0024	23.325	0.0081	61	0.0065	20	0.0050
11650	7.615	0.0024	23.325	0.0081	63	0.0061	20	0.0050
11700	7.615	0.0024	23.325	0.0081	59	0.0057	20	0.0050
11750	7.615	0.0024	23.325	0.0082	55	0.0057	20	0.0053

Time	DOD	DOD%	SSH	SSH%	F14C	F14C%	FSO	FSO%
11800	7.615	0.0023	23.825	0.0077	55	0.0057	21	0.0050
11850	7.435	0.0023	22.325	0.0077	55	0.0057	20	0.0050
11900	7.435	0.0023	22.325	0.0082	55	0.0056	20	0.0053
11950	7.487	0.0023	23.625	0.0082	54	0.0058	21	0.0055
12000	7.4934	0.0020	23.625	0.0084	56	0.0058	22	0.0058
12050	6.5134	0.0020	24.4	0.0084	56	0.0058	23	0.0058
12100	6.5134	0.0020	24.4	0.0085	56	0.0058	23	0.0060
12150	6.5534	0.0019	24.75	0.0082	56	0.0052	24	0.0058
12200	6.0534	0.0016	23.75	0.0077	51	0.0050	23	0.0055
12250	5.0534	0.0015	22.25	0.0070	49	0.0048	22	0.0053
12300	4.7534	0.0015	20.25	0.0072	47	0.0052	21	0.0055
12350	4.7534	0.0015	21	0.0072	51	0.0052	22	0.0055
12400	4.7534	0.0015	21	0.0068	51	0.0053	22	0.0053
12450	4.6934	0.0014	19.75	0.0068	52	0.0049	21	0.0050
12500	4.3934	0.0014	19.75	0.0068	48	0.0049	20	0.0050
12550	4.3934	0.0014	19.75	0.0068	48	0.0050	20	0.0050
12600	4.3934	0.0014	19.75	0.0068	49	0.0050	20	0.0050
12650	4.3934	0.0014	19.75	0.0067	49	0.0041	20	0.0055
12700	4.5934	0.0014	19.34	0.0067	40	0.0037	22	0.0055
12750	4.6534	0.0014	19.34	0.0063	36	0.0035	22	0.0053
12800	4.4534	0.0014	18.34	0.0063	34	0.0036	21	0.0048
12850	4.4334	0.0014	18.34	0.0062	35	0.0029	19	0.0043
12900	4.4034	0.0009	18.05	0.0050	28	0.0029	17	0.0040
12950	2.9034	0.0009	14.55	0.0050	28	0.0029	16	0.0040
13000	2.9034	0.0009	14.55	0.0050	28	0.0027	16	0.0040
13050	2.9034	0.0009	14.55	0.0048	26	0.0028	16	0.0038
13100	2.9034	0.0009	13.8	0.0048	27	0.0026	15	0.0035
13150	2.897	0.0009	13.8	0.0022	25	0.0023	14	0.0035
13200	2.897	0.0009	6.3	0.0022	22	0.0022	14	0.0033
13250	2.897	0.0009	6.3	0.0022	21	0.0019	13	0.0030
13300	2.897	0.0008	6.3	0.0031	18	0.0021	12	0.0030
13350	2.72	0.0015	9.05	0.0033	20	0.0022	12	0.0033
13400	4.72	0.0015	9.7	0.0033	21	0.0022	13	0.0030
13450	4.72	0.0015	9.7	0.0033	21	0.0021	12	0.0028
13500	4.72	0.0015	9.7	0.0033	20	0.0023	11	0.0028
13550	4.72	0.0015	9.45	0.0033	22	0.0022	11	0.0028
13600	4.72	0.0015	9.45	0.0033	21	0.0023	11	0.0028
13650	4.72	0.0015	9.45	0.0033	22	0.0023	11	0.0028

Time	DOD	DOD%	SSH	SSH%	F14C	F14C%	FSO	FSO%
13700	4.72	0.0015	9.45	0.0033	22	0.0024	11	0.0030
13750	4.721	0.0015	9.55	0.0033	23	0.0024	12	0.0030
13800	4.721	0.0015	9.55	0.0037	23	0.0025	12	0.0033
13850	4.721	0.0014	10.85	0.0037	24	0.0023	13	0.0030
13900	4.641	0.0014	10.85	0.0038	22	0.0025	12	0.0033
13950	4.641	0.0014	11.05	0.0029	24	0.0022	13	0.0030
14000	4.596	0.0014	8.5	0.0027	21	0.0021	12	0.0028
14050	4.536	0.0014	7.95	0.0027	20	0.0021	11	0.0028
14100	4.536	0.0014	7.95	0.0027	20	0.0020	11	0.0028
14150	4.536	0.0014	7.95	0.0027	19	0.0022	11	0.0033
14200	4.536	0.0014	7.95	0.0027	21	0.0023	13	0.0035
14250	4.536	0.0014	7.95	0.0027	22	0.0023	14	0.0035
14300	4.536	0.0014	7.95	0.0027	22	0.0023	14	0.0035
14350	4.536	0.0014	7.95	0.0027	22	0.0023	14	0.0035
14400	4.536	0.0014	7.95	0.0027	22	0.0023	14	0.0035
14450	4.536	0.0014	7.95	0.0027	22	0.0023	14	0.0038
14500	4.536	0.0014	7.95	0.0027	22	0.0024	15	0.0038
14550	4.536	0.0014	7.95	0.0028	23	0.0024	15	0.0038
14600	4.536	0.0015	8.225	0.0028	23	0.0025	15	0.0040
14650	4.886	0.0015	8.225	0.0028	24	0.0025	16	0.0040
14700	4.886	0.0015	8.225	0.0028	24	0.0026	16	0.0043
14750	4.886	0.0015	8.225	0.0028	25	0.0026	17	0.0043
14800	4.886	0.0015	8.225	0.0028	25	0.0027	17	0.0043
14850	4.886	0.0009	8.225	0.0026	26	0.0024	17	0.0038
14900	2.885	0.0009	7.475	0.0027	23	0.0026	15	0.0040
14950	2.893	0.0009	7.775	0.0027	25	0.0027	16	0.0040
15000	2.893	0.0010	7.775	0.0028	26	0.0030	16	0.0043
15050	3.203	0.0009	8.075	0.0014	29	0.0028	17	0.0038
15100	3.06	0.0009	4.125	0.0014	27	0.0028	15	0.0038
15150	3.06	0.0009	4.125	0.0013	27	0.0025	15	0.0035
15200	3.008	0.0009	3.875	0.0013	24	0.0025	14	0.0035
15250	3.008	0.0009	3.875	0.0013	24	0.0024	14	0.0038
15300	3.008	0.0011	3.875	0.0015	23	0.0025	15	0.0040
15350	3.638	0.0011	4.375	0.0015	24	0.0023	16	0.0040
15400	3.638	0.0011	4.375	0.0019	22	0.0026	16	0.0043
15450	3.638	0.0011	5.375	0.0019	25	0.0026	17	0.0043
15500	3.638	0.0011	5.375	0.0019	25	0.0028	17	0.0043
15550	3.638	0.0011	5.375	0.0015	27	0.0028	17	0.0040

Time	DOD	DOD%	SSH	SSH%	F14C	F14C%	FSO	FSO%
15600	3.438	0.0011	4.375	0.0015	27	0.0029	16	0.0043
15650	3.438	0.0011	4.375	0.0015	28	0.0029	17	0.0043
15700	3.438	0.0011	4.375	0.0015	28	0.0029	17	0.0043
15750	3.438	0.0011	4.375	0.0015	28	0.0029	17	0.0043
15800	3.438	0.0011	4.375	0.0015	28	0.0029	17	0.0040
15850	3.438	0.0011	4.375	0.0011	28	0.0027	16	0.0038
15900	3.438	0.0011	3.075	0.0011	26	0.0028	15	0.0038
15950	3.438	0.0010	3.075	0.0011	27	0.0026	15	0.0035
16000	3.338	0.0009	3.075	0.0011	25	0.0026	14	0.0035
16050	2.988	0.0003	3.075	0.0010	25	0.0024	14	0.0033
16100	0.988	0.0003	2.925	0.0010	23	0.0025	13	0.0035
16150	0.988	0.0003	2.925	0.0009	24	0.0024	14	0.0033
16200	0.988	0.0003	2.725	0.0009	23	0.0024	13	0.0033
16250	0.988	0.0003	2.725	0.0009	23	0.0023	13	0.0028
16300	0.988	0.0001	2.725	0.0008	22	0.0022	11	0.0025
16350	0.358	0.0001	2.225	0.0008	21	0.0021	10	0.0025
16400	0.358	0.0001	2.225	0.0008	20	0.0021	10	0.0025
16450	0.358	0.0000	2.225	0.0007	20	0.0017	10	0.0023
16500	0.048	0.0000	1.925	0.0014	17	0.0017	9	0.0023
16550	0.048	0.0000	3.925	0.0014	17	0.0016	9	0.0020
16600	0.048	0.0000	3.925	0.0013	16	0.0015	8	0.0020
16650	0.048	0.0000	3.65	0.0012	15	0.0015	8	0.0018
16700	0.04	0.0000	3.35	0.0012	15	0.0017	7	0.0020
16750	0.04	0.0000	3.35	0.0012	17	0.0017	8	0.0020
16800	0.04	0.0000	3.35	0.0012	17	0.0017	8	0.0020
16850	0.04	0.0000	3.35	0.0012	17	0.0015	8	0.0020
16900	0.04	0.0007	3.35	0.0012	15	0.0019	8	0.0023
16950	2.14	0.0007	3.35	0.0012	18	0.0017	9	0.0023
17000	2.14	0.0007	3.35	0.0012	17	0.0017	9	0.0023
17050	2.14	0.0007	3.35	0.0012	17	0.0014	9	0.0020
17100	2.14	0.0007	3.35	0.0012	14	0.0015	8	0.0023
17150	2.14	0.0007	3.55	0.0012	15	0.0015	9	0.0023
17200	2.14	0.0007	3.55	0.0012	15	0.0015	9	0.0023
17250	2.14	0.0007	3.55	0.0012	15	0.0014	9	0.0023
17300	2.14	0.0007	3.55	0.0012	14	0.0016	9	0.0025
17350	2.14	0.0007	3.55	0.0012	16	0.0016	10	0.0025
17400	2.14	0.0007	3.55	0.0012	16	0.0016	10	0.0025
17450	2.14	0.0007	3.55	0.0012	16	0.0016	10	0.0025

Time	DOD	DOD%	SSH	SSH%	F14C	F14C%	FSO	FSO%
17500	2.14	0.0007	3.55	0.0012	16	0.0019	10	0.0025
17550	2.14	0.0007	3.55	0.0012	18	0.0017	10	0.0023
17600	2.14	0.0007	3.55	0.0012	17	0.0019	9	0.0023
17650	2.14	0.0007	3.55	0.0012	18	0.0019	9	0.0023
17700	2.14	0.0007	3.55	0.0012	18	0.0019	9	0.0023
17750	2.14	0.0007	3.55	0.0012	18	0.0017	9	0.0023
17800	2.14	0.0007	3.55	0.0012	17	0.0017	9	0.0023
17850	2.14	0.0007	3.55	0.0012	17	0.0019	9	0.0023
17900	2.14	0.0007	3.55	0.0012	18	0.0020	9	0.0025
17950	2.163	0.0007	3.55	0.0012	19	0.0016	10	0.0025
18000	2.163	0.0007	3.55	0.0015	16	0.0016	10	0.0030
18050	2.2442	0.0007	4.3	0.0015	16	0.0019	12	0.0028
18100	2.2442	0.0007	4.3	0.0015	18	0.0021	11	0.0028
18150	2.2442	0.0007	4.3	0.0015	20	0.0019	11	0.0025
18200	2.2442	0.0007	4.3	0.0015	18	0.0019	10	0.0025
18250	2.2442	0.0007	4.3	0.0015	18	0.0019	10	0.0025
18300	2.2442	0.0007	4.3	0.0015	18	0.0019	10	0.0025
18350	2.2442	0.0007	4.3	0.0015	18	0.0017	10	0.0025
18400	2.2442	0.0013	4.3	0.0017	17	0.0019	10	0.0028
18450	4.2192	0.0013	4.8	0.0015	18	0.0017	11	0.0025
18500	4.1792	0.0013	4.4	0.0015	17	0.0020	10	0.0030
18550	4.1992	0.0013	4.4	0.0015	19	0.0020	12	0.0028
18600	4.1992	0.0013	4.45	0.0017	19	0.0020	11	0.0030
18650	4.1992	0.0013	4.8	0.0016	19	0.0015	12	0.0025
18700	4.1992	0.0013	4.6	0.0016	15	0.0016	10	0.0028
18750	4.1992	0.0013	4.6	0.0016	16	0.0017	11	0.0028
18800	4.1992	0.0013	4.6	0.0016	17	0.0015	11	0.0028
18850	4.1992	0.0013	4.6	0.0016	15	0.0014	11	0.0028
18900	4.1992	0.0013	4.6	0.0016	14	0.0020	11	0.0028
18950	4.1992	0.0013	4.6	0.0016	19	0.0019	11	0.0025
19000	4.1792	0.0013	4.6	0.0020	18	0.0020	10	0.0028
19050	4.1892	0.0013	5.8	0.0020	19	0.0020	11	0.0028
19100	4.1892	0.0013	5.8	0.0020	19	0.0022	11	0.0028
19150	4.1892	0.0013	5.8	0.0020	21	0.0022	11	0.0028
19200	4.1892	0.0013	5.8	0.0020	21	0.0022	11	0.0025
19250	4.1892	0.0013	5.8	0.0020	21	0.0021	10	0.0025
19300	4.1892	0.0013	5.8	0.0020	20	0.0021	10	0.0025
19350	4.1892	0.0006	5.8	0.0013	20	0.0021	10	0.0023

Time	DOD	DOD%	SSH	SSH%	F14C	F14C%	FSO	FSO%
19400	2.0892	0.0006	3.8	0.0018	20	0.0025	9	0.0028
19450	2.0917	0.0006	5.3	0.0018	24	0.0025	11	0.0028
19500	2.0892	0.0006	5.3	0.0018	24	0.0025	11	0.0028
19550	2.0892	0.0006	5.3	0.0018	24	0.0023	11	0.0028
19600	2.0892	0.0006	5.3	0.0018	22	0.0023	11	0.0028
19650	2.0892	0.0006	5.3	0.0018	22	0.0023	11	0.0028
19700	2.0892	0.0006	5.3	0.0018	22	0.0023	11	0.0028
19750	2.0892	0.0006	5.3	0.0018	22	0.0023	11	0.0028
19800	2.0892	0.0006	5.3	0.0018	22	0.0023	11	0.0025
19850	2.0892	0.0006	5.3	0.0015	22	0.0021	10	0.0020
19900	2.0892	0.0006	4.3	0.0015	20	0.0021	8	0.0020
19950	2.0892	0.0006	4.3	0.0015	20	0.0017	8	0.0020

APPENDIX C

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