CRITICAL NATURAL RESOURCES IN THE MESA VERDE REGION, A.D. 600-1300: DISTRIBUTION, USE, AND INFLUENCE ON PUEBLOAN SETTLEMENT

By

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the dissertation of CHARLES DAVID JOHNSON find it satisfactory and recommend that it be accepted.

Chair

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Abstract

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This dissertation reports on an intense effort to model the natural ecology of multiple resources in a large study area of the southwest United States. The dynamic simulation of standing crops of fuel woods and populations of wild herbivores is designed to provide natural resources in an agent-based model of long-term human settlement strategies in a bounded landscape under changing natural and social environmental conditions. Model agents are simulated households that settle particular areas to survive on a spatially and temporally variable landscape providing different resources at different locations. These households are required to obtain basic necessities in the forms of water, food, and fuels as supplied by the model world.

The resources modeled here include woody species available as fuels, the primary productivity of other native species that provide the food to support wild herbivores, and three animal species commonly recovered from archaeological contexts. The three animal species are mule deer, black-tailed jackrabbits, and cottontail rabbits. Populations of these animals are simulated based on the annual productivity of their preferred foods as supplied by the native vegetation communities associated with study area soils.

Requiring model households to satify basic natural resource needs is intended to improve the fit of simulated household settlement patterns with the long-term settlement patterns observed from the archaeological record of agrarian peoples in the Meas Verde region from A.D. 600 to 1300. Result indicate that inclusion of these critical natural resources on the model landscape as requirements of sustained life for model households does improve the goodness-of-fit between simulated and observed settlement patterns.

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CHAPTER 1: INTRODUCTION

Questions of human evolutionary ecology (Shennan 2005; Winterhalder and Goland 1997), evolutionarily adaptive strategies (Read and LeBlanc 2003), and social organization (Kuijt 2000; Redman 1999, 2004; Varien et al. 1996) have long interested anthropologists. Investigation of these problems in long-term human contexts lies in the realm of anthropological archaeology. There are numerous natural and cultural aspects to such research, a subset of which this dissertation strives to address. In the natural realm, this research simulates a suite of resources on which simulated households can rely in satisfying daily requirements. On the cultural front, the simulated households, as model agents, produce variation in long-term settlement distributions that are compared to those oserved in the archaeological record. The result is that I am able to show that supply and demand for some resources are more effective in recreating observed settlement patterns than others, which allows me to address issues relating resources and social organization.

Evolutionary ecology suggests that adaptive strategies optimize the attainment of basic survival needs, frequently using energy as a currency. Support for many theories of human evolution is often sought in studies of modern foragers and/or subsistence farmers (Hawkes and O'Connell 1992; Kaplan and Hill 1985; Kent 1989; Smith and Winterhalder 1992), where the strategies used are commonly assumed to resemble those developed by prehistoric populations believed to have subsisted on similar resources (Winterhalder and Goland 1997). However, theories of past behaviors based on modern or ethnographic analogy are at best difficult to validate. A primary reason for this is that many of the resources researchers are very confident prehistoric peoples required for survival are rarely recovered in archaeological contexts.

An important task is, therefore, to predict, or retrodict, the availability and distribution of resources considered essential to ancient populations in given environments. This study aims to do so for one such region located in the Montezuma Valley of southwestern Colorado in the American Southwest. Obviously, the more closely resources deemed important in ancient times correspond to those in use in ethnographic or modern times, the easier it is to suggest that similar production and distributions were obtainable in the distant past (Burns 1983; Van West 1994).

Archaeologists, who of necessity work with material culture, are interested in the sources of and procurement strategies for raw materials used to manufacture artifacts, and behaviors associated with their uses. The quantities and locations of mineral resources commonly recovered from Mesa Verde region archaeological contexts are relatively static in time and space (Arakawa 2006; Glowacki 2006), and artifacts made from them are usually durable and readily recovered. But what about the sources of and procurement strategies for raw materials that result in what Binford (1964) describes as “ecofacts”? They tend to be elusive in the archaeological record, and difficult to quantify within sites and their catchments. This is especially true since their productivity and distribution can change on time scales much shorter than archaeological resolution normally provides.

Long-term supply of, and demand for, the organic resources that ancient peoples relied on for subsistence (Flannery 1972), construction materials (Glennie 1983; Hovezak 1994; Varien 1984), and fuel (Plog 1981; Samuels and Betancourt 1982), were arguably more influential in the evolution of adaptive strategies and social organization than were those of mineral resources. Studying the dynamic nature of both the natural production and human consumption of biotic resources may well add significant explanatory power to models of long-term human ecological and social adaptations (Hill 2000; Wilkinson 1994).

The work reported in this dissertation models the changing availabilities and human use rates of natural resources critical to the prehispanic Puebloans of the Mesa Verde region of the American Southwest (Figure 1.1) from A.D. 600 to 1300. This research complements and adds to development of the agent-based modeling project formally entitled “Coupled Human/Ecosystems Over Long Periods: Mesa Verde Region Prehispanic Ecodynamics”, hereafter referred to as the “Village Project” (Kohler et al. 2000, 2006).

This research is designed to investigate the influences of varying distributions of selected natural resources on human social organization and long-term settlement patterns. Agent-based modeling of households on a dynamically reconstructed landscape provides a test case for the results of long-term human-ecodynamics in the semi-arid environment of the upland American Southwest. Paleoenvironmental reconstructions produced as part of the larger Village Project (Kohler et al. 2000, 2006) is combined with study area soil distributions, associated native plant communities, and annual net primary productivity of those native plants. This combination allows the modeling of an annually dynamic model world on which simulated households, as adaptable and mobile agents, make decisions needed to survive and reproduce.

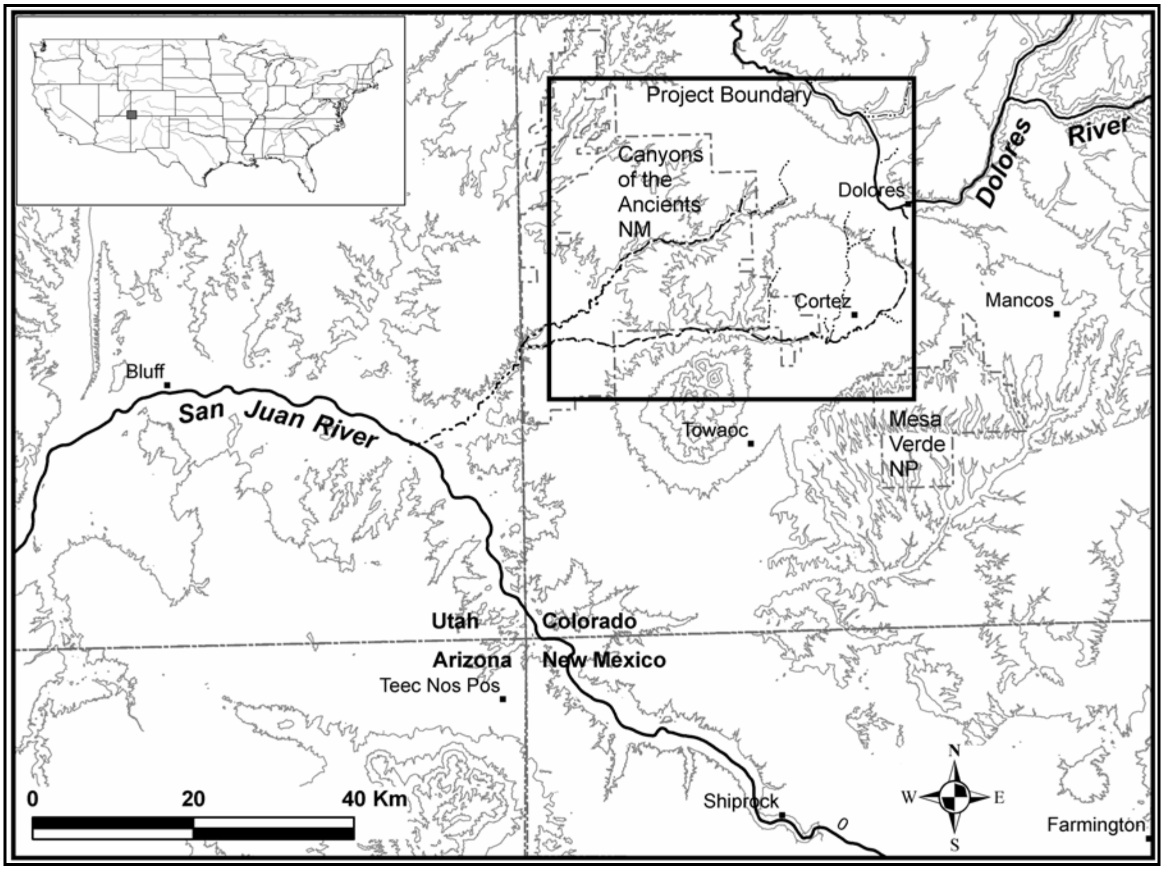

Figure 1.1. Map of the Four Corners Region, showing the Village Project study area and surrounding features.

By combining long-term tree-ring data and modern weather records with natural native vegetation productivity reported for area soils, I model the distributions and fluctuations of populations of three herbivorous species ─ mule deer, black-tailed jackrabbits, and desert cottontails ─ known from the archaeological record to have been important meat sources for prehistoric Puebloans. Model households developed for the Village Project to which this research contributes are made to harvest fuel wood and animals to satisfy needs for heat and high-quality protein.

One goal of this research is to determine whether and how much the spatial distribution of fuels and game animals in the study area might have significantly influenced prehistoric Puebloan settlement decisions. To the extent that they did, this research is designed to determine how much the consideration of natural resources improves the match between simulated and observed household locations at numerous points in the 700-year history of settled occupation, and which resources are most important in doing so. A second goal is to determine if the moderate rates of consumption required of model agents lead to natural resource depletion in the long-term. The results will allow evaluation of arguments that prehistoric populations overexploited the regional environment (Kohler and Matthews 1988; Muir and Driver 2002).

If resource depletion is indicated, model results should show which resources are most susceptible to depletion and by how much. Finally, how is it that model households respond to their degradation of the model landscape's natural resources; does their simulated harvesting correspond to that indicated by the archaeological record, and how might the fit between simulated and observed resource use be improved?

This research is undertaken to investigate how human procurement and potential depletion of critical natural resources influence long-term household settlement strategies and resulting changes in social organization (Lipe 1994). Although Rohn (1996) argues that the Anasazi avoided developing their social organization to the level considered "complex," the two cycles of population aggregation within the study area (Varien et al. 2006) suggest that some of these prehistoric communities may have approached more complex social organization, only to have it break down (Schachner 2001). By periodically dispersing, communities were apparently able to remain below a population density threshold that would have required increased social complexity in the form of hierarchical stratification.

Recent models of Read and LeBlanc (2003) provide scenarios closely approximating what may have occurred prehistorically within the study area. The main thrust of their argument is that spatial and temporal variations in resource and human population densities lead to competition, cooperation, and conflict over resource acquisition. Varien (1999, 2002) and Varien, Van West, and Patterson (2000) argue this was indeed the case for late communities within the study area used here. Modeling the interaction of critical natural resources and simulated households over seven centuries within this study area is designed to provide baseline data as to the nature and extent of such interaction.

Complex social organization has been evolving for millennia and now affects all of humanity in various ways. The evolution of social organization, from its beginnings in communities of small-scale, regularly mobile, generally egalitarian bands of subsistence-level peoples, to those of medium-scale, regularly sedentary, potentially stratified peoples, has been of great interest to anthropologists for many years (Bodley 2000, 2003; Carniero 1976; Fried 1967; Johnson and Earle 2000; Sahlins and Service 1960; Service 1962; Spencer 1860; Tyler 1871; White 1943). Theories of social evolution have evolved as well, from the unilineal models of the nineteenth century (Morgan 1877; Tylor 1865), through the multilineal model of Steward (1955), to Flannery's (1972) proposed generative model of social complexity. Much discussion has concerned the results of variations in resource (or energy, e.g., White 1959) capture of different social systems at various levels of social organization.

In his description of Shoshonean adaptations in the Great Basin, for instance, Steward (1955) reports that the minimal (nuclear family-based) social organization resulted from a generally low density of natural resources. In times of relative resource abundance, family groups coalesced, and, under the direction of impromptu leaders, conducted mass harvesting of faunal resources such as rabbits and antelope. Steward (1955) suggests that if resource levels had supported it, Shoshonean social organization would have developed as it had in areas where, for example, reliable salmon runs were frequent, such as along the Columbia and Snake rivers, or on the Northwest Coast. Given the low density of Great Basin resources however, Steward notes that the social organization in these areas remained small in scale until the re-introduction of the horse, which allowed the high mobility needed to conduct raids on encroaching Euroamericans. In lieu of increased resource density, or increased mobility provided by European-introduced horses, Steward believed that Shosonean social organization would not have evolved beyond the egalitarian, family-based stage.

Reliable access to resources, important to the everyday lives of people in all natural and cultural environments, is commonly cited as key in leading to both organizational changes and settlement distributions in middle-range societies, both past and present (Adler 1990; Adler and Varien 1994; Chisholm 1968; Stone 1996). Michael Adler (1990), for example, views the increasing scale of what he terms “resource access groups” as the result of increased competition over available resources needed for group survival. There are, of course, a number of avenues leading to greater competition for resources. Increased human population density is a primary reason local resources might become over-utilized, though declining natural productivities could also be responsible. Regardless of the cause of perceived decreases in the ratio of supply to demand, social groups devise strategies to improve their sustained access to critical resources. In Adler's view, resource scarcities lead to increasingly formalized systems of land tenure, eventually requiring consensual oversight of resource-access rights by community leaders. The shift from a family-based to a community-based system of land tenure thus requires a larger scale of social organization in at least the intra-community context, and possibly at an inter-community level as well (Adler 1990).

Inorganic resources have always been necessary items in the everyday lives of all modern humans. Until the advent of complex societies (Meyer et al. 1996; Tainter and Tainter 1996) however, the consumption/turnover rates of inorganic resources were likely of little importance in social group mobility and organizational strategies, at least in comparison to those of organic resources used primarily for foods and fuels.

While durable, inorganic artifacts commonly facilitate the processing of organic resources, consumption of the latter is often a matter of life or death. The use of tool stone to make projectile points, for example, can greatly enhance game harvest potential, but is not absolutely necessary to procure animal protein in many situations. So even though the bulk of the archaeological record consists of inorganic materials, I suggest that the procurement and consumption of organic resources surpassed both the costs and benefits of mineral resources for most of human history, including the centuries of interest here.

Addressing the importance of biotic resources with respect to human settlement and organizational strategies may well be more difficult than doing so by reference to abiotic resources. There are a number of reasons why this should be so, the ubiquity of inorganic artifacts and the relative paucity of ecofacts in the archaeological record not being the least of these. Moreover, the spatial and temporal availability of organic resources is potentially variable, making it difficult to estimate the costs of procuring them at any given time or place. This research provides a test case of variation in organic resource availability for the long-term occupation of a specific area, by tracking the costs of biotic resource procurement for simulated households. The expectation is that model agents will overexploit critical natural resources produced on the model landscape, and their settlement distributions will shift in response to variation in local availabilities.

Degradation of landscapes is generally understood as the result of increasing exploitation of resources by human groups. Intensification of resource consumption can lead to a “tragedy of the commons” (Hardin 1968; Kohler 1992b; McCay and Acheson 1987), territory formation (Adler 1996; Zedeño 1997), and community aggregation (Dohm 1994; Hunter-Anderson 1979; Varien et al. 2000; Wilshusen and Blinman 1992). Resource intensification, territorial organization, and aggregation can lead to conflict (Jochim 1981; LeBlanc 1999) and influence regional abandonment (Cameron 1995; Lekson and Cameron 1995; Lipe 1995; Nelson and Schachner 2002). An important key to understanding long-term social dynamics is learning how households respond to options for natural resource acquisition in the face of changing human population densities (Lipe and Pitblado 1999).

Resource Consumption and Settlement Patterns

"It is often the case that as formerly mobile people become sedentary the rate of population growth increases" (Kelly 1995:254). If growing populations cannot expand into less-populous areas they must intensify their local resource production. Domestication is one long-term outcome of subsistence production intensification, and in many environments domesticating plants is typically more profitable than domesticating animals. This may be due to the fact that, as Timothy Kohler suggests, plant domestication provides a more secure resource base for individual households than domesticating animals "because norms for meat sharing are more common and perhaps more strongly held" (Kohler 2004:263). Thus those who strive to improve household food supply will likely first turn to horticulture when possible. Increasing resource extraction from a given area, by whatever means, eventually leads to changes in the landscape, some of which are virtually irreversible with continued exploitation.

With the adoption of agriculture, a series of changes frequently occurs in social organization. Redman (1999) describes three basic changes (in human social organization) resulting from the shift to agriculture that have strong impacts on the environment. The first of these, sedentary settlement, leads to more intense use of local resources, commonly leading to degradation. The second, population aggregation, leads to additional sustained pressure on local resources, further degrading local landscapes and frequently promoting intensification of production (Boserup 1965). Lastly, when people realize the limits of their domesticated environment, they settle all locations suitable for their subsistence strategy. At the outset (in most cases, but see Fagan 2003 for a discussion of similar adaptations lacking domestication) the preference was for the best dry-farmed arable lands. But all of these were soon claimed (Redman 1999), presumably leading other corporate groups to intensify production on less favorable land, or to choose lands with high potential for procurement of other resources.

In order to increase land efficiency (Jochim 1981), communities favor places where their new subsistence strategies can be most profitably applied (e.g., Shennan 2006). When this occurs, population can increase as a result of increased food production. Once a subsistence strategy has proven effective in a particular environmental setting, and been widely accepted, the resulting increase in production can lead to increased fitness for those using it. This can then lead to increased needs for resources produced with that strategy, encouraging colonization of additional settings where the strategy will be effective (Shennan 2006). Alternately, those settlements located in more productive areas also tend to attract population from surrounding settlements. Either of these avenues to production increases may eventually lead to competition and potential conflict (LeBlanc 1999; Read and LeBlanc 2003).

Denser concentrations of human population, relative to a fixed natural resource base, can lead to increasingly complex systems of resource production and allocation. Changes in the scale of human interaction require strategies to cope with potential conflicts and issues of resource allocation (Johnson and Earle 2000). Reliance on either limited or locally abundant resources can lead some individuals to monopolize access to those resources (Hayden 1990). In lieu of hierarchic social control, settlement relocation or migration are common means of population adjustment to resource imbalances (Cameron 1995; Varien 1999a). The advantages of leaving a densely populated area include personal autonomy (Bodley 2003), greater access to required resources (Read and LeBlanc 2003), and, frequently, greater stability in securing subsistence resources. Long-term and/or long-distance migration is commonly referred to as local or regional abandonment in Southwestern archaeology (Nelson and Schachner 2002).

Higher human population densities commonly lead to increased complexity of social systems, including more frequent exchange, greater reliance on one's community for cooperative production and protection, and greater risk of exploitation by the powerful members of the community. Elevating levels of social complexity affects human-ecodynamics, particularly with respect to the production of subsistence resources (Minnis 1985a, 1996). Expanding the size and spatial scale of social groups involves organizational strategies that commonly shift power from local levels (e.g., the household or local kin group) to fewer and fewer powerful leaders (Bodley 2003). The result is the hierarchical social structure common in the world today. Of course maintenance of any scale of social system requires its acceptance and cooperation by a majority of participants.

Human ecodynamics studies long-term interactions of people with their landscapes. This includes anthropogenic changes in natural landscapes and ecosystems resulting from the long-term effects of human manipulation of the environment.

Intensification of resource use in a particular ecosystem can lead to a variety of environmental problems and potential human reactions, some of which this research is designed to investigate. On the group level, there are three social mechanisms that are commonly pursued to ensure access to needed resources. Most often, all of these are simultaneously occuring (to greater or lesser degrees), both within and among social groups. In the following discussion, I present brief descriptions of cooperation, competition, and conflict, the three mechanisms often recognized as important consequences of groups living in close proximity.

Cooperation

The survival of many species requires some level of cooperation, at least between individuals, frequently between groups of individuals as well. Numerous animal species live in groups, cooperating in reproduction and defense (Knauft 1991), if not the sharing of procured resources. Primate populations are perhaps the most reliant on cooperation within groups, sharing male progenitors, juvenile care, some foods, and defense responsibilities.

The human species has probably benefited more than any other by way of individual, intra-, and inter-group cooperation. For much of human history, people have shared the effort and returns of group hunting and gathering of wild foods and fuels, and benefited from the safety of living in numbers. As long as bands remained manageably small, relatively dispersed, and below the optimal carrying capacity (Hassan 1981) of their home ranges, competition for access to critical resources was relatively rare (Bodley

1999; Gumerman and Dean 1989). Increasing population densities, however, frequently led to decreases in procurement efficiency (Jochim 1981), prompting a shift to less preferred (and less efficiently exploited) resources (Fagan 2003).

Cooperative efforts among group members can raise the return on procurement efforts, increasing fitness for the entire group. Similarly, cooperative strategies of resource sharing between groups can likewise support higher populations on a given landscape (Read and LeBlanc 2003). As happens with many other species, however, high population densities become increasingly vulnerable to environmental perturbations, such that natural declines in resource productivities can mean hard times for many. Thus in times of plenty groups are expected to share with their neighbors, but with shortages, inter-group cooperation, in terms of access to resources, can turn to competition (Kohler and Van West 1996; Varien et al. 2000).

Kohler and Van West (1996) suggest that households should be risk-averse when resources are generally plentiful, and especially when resources are highly variable either spatially, temporally, or both. It is during these times that households should aggregate to promote the pooling of resources. I employ a measure of household concentration, termed an aggregation index, to compare settlement patterns exhibited by the archaeological record with those of different simulations. Although some aggregation (in areas of high resource abundance) is likely without household exchange, model runs in which cooperation (limited to exchange in this model) is enabled are expected to produce higher aggregation indices when resources are locally abundant.

Investigation of aggregation under various model parameter settings is intended to illuminate the effects of variation in annual critical natural resource availabilities, and, more importantly, following long periods of exploitation. Long-term harvesting of natural resources from areas providing superior agricultural production should lead to competition between households. Intense, long-term competition for access to critical natural resources can lead to covert, and eventually, overt, conflict among groups vying for the same resources (LeBlanc 1999).

Competition

People living within the same environment often, though not always, exploit similar environmental niches. Read and LeBlanc point out that "[n]eighboring groups are in competition whenever the resources used by one group are thereby made unavailable to another group that would otherwise have access to those resources" (2003:60). Though there are ethnographic examples of different ethnic groups pursuing complementary subsistence strategies in the same region, this is not evident in the case of the Puebloan occupation of the Mesa Verde region.

For horticulturalists relying heavily on their crops, increasing demands for agricultural produce can prompt efforts to intensify production. Higher demands on landscape productivity can result from increasing population densities, deteriorating growing conditions, a combination of these, or other factors. Production concentration (Stone 1996) occurs when farmers strive to produce more food without increasing the amount of land cultivated. This is accomplished by increasing one or more of the following: labor input, water and/or nutrient input; or improving agricultural technology (such as shifting from hoe to plow tilling) or reducing fallow periods (Boserup 1965).

Greater investment of any kind is expected to raise both the overall productivity of the landscape and its value to those reaping the benefits. Increasing input costs should drive attempts to maximize efforts by focusing them on the most productive areas. Claims to the most productive lands by one group, to the exclusion of another, will surely lead to conflict between producers. Locations that are particularly amenable to production concentration through intensification are more likely to be sought after by outsiders and adamantly defended by those occupying them. Thus inter-community competition can lead to greater intra-community cooperation.

Disparities in resource allocation both within communities, and between neighboring communities, can result in intergroup competition. This promotes intragroup cooperation to: 1) increase production through labor pooling (Stone 1996); 2) maintain access to the most productive resources (Adler 1994, 1996); and 3) discourage conflict with neighboring competitors by establishing larger groups (LeBlanc 1999; Read and LeBlanc 2003). In cases where community catchments become constricted, as shown by Varien (1999, 2002; Varien et al. 2000) for the Mesa Verde region, all communities are likely to eventually coalesce and intensify to maintain themselves in the face of inter-community competition.

Modeling long-term production and harvest of critical natural resources can shed light on the adaptive strategies of households in meeting their resource requirements in changing environments. Annual productivity, and thus availability, of the resources modeled herein is variable, so there is a limited supply of each on the model landscape at each model time step. Model households strive to meet their needs as efficiently as possible. Assuming that returns on energy expenditure are optimized is a primary tenet of human behavioral ecology (Bird and O'Connell 2005); in this simulation natural resource procurement costs calories, and households are designed to approximately maximize returns on labor. Since resource availabilities vary due to climate and harvest pressure, agent settlement decisions should reflect household efforts to optimize resource procurement.

If resource depression occurs in densely populated areas, critical natural resource acquisition costs should rise to levels prompting household dispersion to less heavily exploited areas (if any are available). During prolonged periods of below normal productivity in the real world, for instance, households should opt to be risk-prone, so as to avoid having to share their low returns with others (Kohler and Van West 1996). That is, small corporate groups are likely to prefer to take their chances on their own, so they will not be expected to provide for any others in difficult times. This should also prompt simulated households to disperse, since some agents are able to claim prime agricultural plots, and efficiently exploit natural resources, before other agents have the chance to do so. I expect the aggregation index, discussed more fully below, will demonstrate that household strategies do respond to resource availabilities and degradation.

Human behavioral ecology assumes that people attempt to be as efficient as is feasible in obtaining the necessities of life, including water, food, clothing, fuel, and shelter. At the same time, satisfying these necessities requires a variety of products, and balancing acquisition of all these resources might be difficult for entire populations in the long run. Therefore, it should be expected that some resources would be more expensive to procure than others, or may ultimately be replaced with less-preferred alternatives (hunting lagomorphs instead of artiodactyls, or collecting faster-growing fuelwood species). Increasing procurement costs due to overexploitation should lead to cooperation to increase production or to increase resource reliability, and competition between corporate groups for resources. Shortfalls in procurement of resources due to lack of availability, or restricted access, can lead to both intra- and inter-group strife.

Conflict

Intensive exploitation can lead to resource depression (Charnov, Orians, and Hyatt 1976), necessitating the use of less desirable alternatives. Depletion of local herbivore populations, for instance, requires implementation of alternate strategies to obtain high-quality protein (Spielmann and Angstadt-Leto 1996). In the prehistoric Mesa Verde region this may have entailed, for example, organizing long-distance hunting expeditions, or increasing production of maize to serve as feed for flocks of domesticated turkey (Kohler 2004).

The shift to use of less desired resources usually entails a decrease in procurement efficiency (Jochim 1981). Once procurement efficiency declines beyond a critical threshold, resource scarcity may prompt aggressive pursuit of resources elsewhere (LeBlanc and Rice 2001). Of course optimal patches are claimed early in a sequence of settlement (Varien et al. 2000). With increasing reliance on agricultural subsistence, project area Puebloan populations apparently became increasingly circumscribed (Varien 1999a). "In middle-range societies, social competition increases with the increase in fixed, high-value resources, sedentism, and population density" (Knauft 1991:403). This competition can often lead to conflict.

Obviously, competition can focus on one or more of the resources critical to normal life. The landscape surrounding a typical canyon-head community center, for instance, commonly contains mesa top soils that make for excellent agricultural production. Many canyon-head sites, such as Sand Canyon Pueblo (Figure 1.2), surround permanent springs, providing secure domestic water sources. The slopes of canyon walls generally support upland shrub communities, offering preferred browse for deer populations. Canyon bottoms support sage and grasses, in addition to occasional riparian vegetation, serving as prime habitat for lagomorphs.

This combination of resources could supply all the needs of an aggregated community, or greatly contribute to those of a community dispersed around a compact, canyon-head center. But not all locations provide the same mix of concentrated resources, nor allow access to more dispersed resources. Thus some communities, and/or households within them, may not have had equal access to all the resources they required. Long-term household and/or community settlement patterns are expected to be responsive to resource production, consumption, and potential degradation. Using an agent-based model of long-term human ecodynamics, this research is designed to model these interactions over seven centuries in the Mesa Verde region.

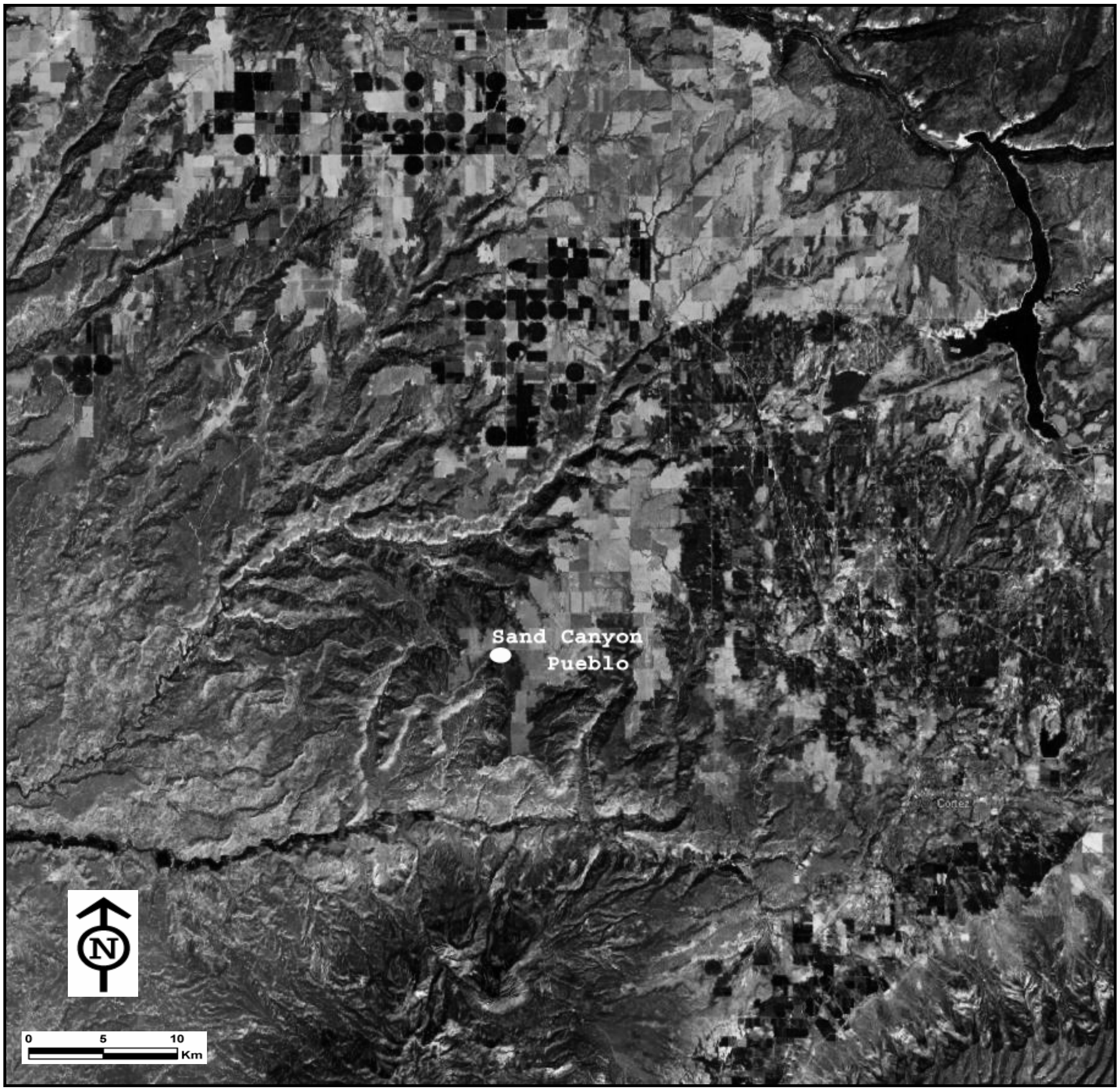

Figure 1.2. Satellite image of study area showing currently farmed mesa-top fields, southwest trending canyons, and the canyon-head location of Sand Canyon Pueblo.

Agent-Based Models of Long-Term Prehistoric Settlement

Since the turn of the twenty-first century, the National Science Foundation has taken considerable interest in models of long-term human/environmental interaction and begun funding projects under the "Human/Ecodynamics Biocomplexity" program. Given this funding, several research teams have undertaken large-scale, interdisciplinary projects investigating the long-term relationships of human occupation and environmental change. In addition to the Village Project, other research teams funded by this program are working in Hawaii (Kirch et al. 2003) and the eastern Mediterranean (Wilkinson et al. 2003); a recently funded project is now beginning on the Iberian Peninsula (Barton 2004). All of these study areas exhibit long-term human settlement in semi-arid environments and promise to shed light on evolving human/ecosystem dynamics.

Social science has recently turned to agent-based models (ABMs) to investigate the evolution of social systems (Doran et al. 1994) and prehistoric settlement patterns (Dean et al. 2000; Kohler et al. 2000). In constructing settlement models for prehistoric Southwestern communities, most researchers have emphasized agricultural potential of local landscapes as significant factors influencing settlement distributions (Axtell et al. 2002; Darling, Ravesloot, and Waters 2004; Dean et al. 2000; Kohler et al. 2000). As one component of the Village Project, in this research I point to the influence of other resources as contributing to household decisions as to when and where to relocate.

Modeling Household Settlement

A major focus of the Village Project is to investigate the factors responsible for the changing frequency and distribution of prehistoric households. I suggest there are many more factors involved than the potential for agricultural production in given locations. Therefore, the spatial and temporal variations in the distribution of a number of important natural resources are modeled. These data constitute the changing resource availabilities of the model world that forms the basis of this simulation of household settlement. Simulated (virtual) households are the agents that make decisions within the model. Animal populations are modeled as cell attributes with population growth rates and carrying capacities responsive to variations in the productivities of plants on which each species feeds.

As with the previous version of the Village model (Kohler et al. 2000), households are required to satisfy most of their calories from agriculture, presently limited to maize. In the current implementation 70 percent of simulated households' caloric intake is derived from agriculture. Household agents are also required to satisfy minimal protein needs, and in this implementation must do so based on the harvest of animals from the model landscape.

To provide high-quality protein on the model landscape, populations of three herbivorous species, mule deer (*Odocoileus hemionus*), black-tailed jackrabbits (*Lepus californicus*), and desert cottontail (*Sylvilagus audubonii*), are modeled. Artiodactyls and lagomorphs comprise the bulk of the archaeofaunal record in the Mesa Verde region (Muir and Driver 2002) and the Greater Southwest (Speth and Scott 1989; Szuter and

Bayham 1989), so were certainly important and are obvious candidates for this modeling effort. Additionally, data obtained from regional soil surveys include the distributions and productivities of plants providing preferred foods for these species, which allows realistic population levels to be modeled within various microenvironments.

Since there are undoubtedly numerous other resources prehistoric peoples relied on as food sources, it is assumed that the animal resources modeled here only supply some of the nutrient requirements of model agents. That is, we assume prehistoric peoples obtained food from various sources, so we only require our household agents to obtain small percentages of their protein requirements from the animal species whose populations we model. We also assume the calories gained in that process represent a portion of the 30 percent not supplied by the consumption of maize.

Long-term household and/or community settlement patterns are expected to be responsive to resource production, consumption, and potential degradation. This research is designed to investigate the influences of various resource productivities, distributions, and scarcities on household settlement decisions over long periods in the Mesa Verde region. The resources modeled here are in addition to those of agricultural potential and domestic water supplies already included in the village model.

The original version of the Village model (Kohler et al. 2000) was based on a virtual world providing only maize productivity and domestic water supplies to simulated households occupying the study area from A.D. 900 to 1300. Simulated households were required to satisfy 60 percent of their caloric needs from the production of maize. Water was not modeled as a dynamic resource, but was a static feature of the model landscape in the form of surface drainages. Maize potential was based on Van West's (1990, 1994) Palmer Drought Severity Index (Palmer 1965) (PDSI)-based reconstructions for all soils in the study area for which data were available.

Potential productivity was constrained by both climatic variation and potential soil degradation. Prolonged continuous farming of plots within the same 4-ha model cell could lead to reduction in soil fertility, controlled by a variable parameter. In model runs in which soil degradation was implemented, agricultural productivity was reduced up to 50 percent under continuous, long-term cultivation.

The best goodness-of-fit was achieved for the Pueblo II period when agents were required to live within 2 cells (.4 km) of a water source, and were subject to soil degradation if they continuously farmed plots within the piñon-juniper belt (Kohler et al. 2000). Simulation success within the Pueblo III period was best achieved when model households were required to live within 1 km of a water source and were also subject to soil degradation in the piñon-juniper belt.

The research reported in this dissertation begins by modeling the availability of critical natural resources across the 1816 km^2 study area for the 700 years spanning the period from A.D. 600 to 1300. The resource procurement strategies the simulated households adopt to consistently procure critical resources in an efficient manner lead to settlement distributions whose correspondence to those exhibited by households of the known archaeological record can be assessed. The inclusion of critical natural resources into the revised Village Project simulation should improve the goodness-of-fit between model households and those exhibited by the archaeological record.

Problem Statement

A multitude of social and ecological factors were likely responsible for the patterns of settlement distribution observed in the archaeological record of the study area. At the same time, it is proposed that the resource procurement strategies of model households should lead to similar patterns of household aggregation and dispersion, as well as ratios of faunal resources procured, as those observed in the archaeological record. In order to demonstrate this proposition, I have calculated indices of household aggregation, as well as faunal indices from available site records.

Using various values for model parameters, the best goodness-of-fit between simulated household locations and the settlement patterns shown by the archaeological record is determined. I then investigate which resources are most responsible in achieving the best results by incrementally adding complexity via the successive inclusion of each natural resource to the best fitting model. The expectation is that the inclusion of critical natural resources will result in a better fit with observations from the archaeological record than is obtained without their consideration. Therefore, the primary question this work aims to answer is: does the addition of the independent natural resource variables improve the goodness-of-fit between the simulated and observed household settlement patterns, and if so, which resources are most important in doing so? Once this is determined, the results may be applicable in producing predictive models of site locations in similar environments.

Also of interest in the current research is how spatial and temporal variation in productivity of critical natural resources, in conjunction with continuous harvesting of those resources, can influence both cooperation and competition among households and groups thereof. Modeling household reactions over many centuries of socio-environmental interaction can help identify social organizational strategies of potential significance to social evolution. This research addresses simulated scenarios of natural resource supply and demand in a bounded landscape. I investigate this in relation to how it might affect environmental degradation (Kohler 1992a, 2004; Kohler and Matthews 1988), lead to local resource scarcity (Cannon 2000; Nelson and Schollmeyer 2003), and influence long-term settlement patterns (Axtell et al. 2002; Kohler, Gumerman, and Reynolds 2005), including household aggregation and dispersion.

A second important question is then: do the simulated human populations significantly deplete the natural resources produced on the model landscape, if so, by how much; and which resources are most susceptible to depletion? Assuming there is significant degradation of at least some of the modeled natural resources leads to a final and most important compound question: how do households respond to changes in resource availabilities, how does model household resource use in general correspond to that observed in the archaeological record, and how might we improve the simulations' fit with what is known from the archaeological record?

Linking Soils, NPP, and Herbivore Production

Data on long-term climate, soil productivity, native vegetation communities, wildlife ecology, and human ecology are combined to address human behavior over seven centuries of occupation within the study area. Previous ABMs designed to investigate prehistoric settlement in the Southwest (Dean et al. 2000; Kohler et al. 2000) have used both long-term paleoclimatic reconstructions and retrodicted potential maize productivities (Burns 1983; Van West 1990) of soils in attempts to have household agents replicate prehistoric settlement distributions.

This research extends that methodology by incorporating natural resource productivities onto the model landscape. To do so I combine annual net primary productivity (NPP) of native plants, associated with each of the study area soils, that supports the production of both fuel woods and herbivorous animal populations. These secondary producers are deemed essential and highly desirable, respectively, to successful occupation of the semi-arid upland environment. In addition to maize and domestic water requirements, model agents (simulated households) must satisfy basic consumption needs from these variously distributed resources. The main goal of my modeling effort is to provide the most realistic, dynamic landscape possible which model households can utilize in meeting their resource requirements. By including natural resources within the model world, we are able to experiment with household strategies for satisfying a more complex combination of resource requirements than was previously possible. The following chapter describes the environmental context in which this project is set, including the physical and biological features of the study area in detail.

There are several expectations of the final model results: 1) that each of the critical natural resources will eventually be degraded to much less than optimal levels; 2) model households will develop strategies to overcome resulting shortages (such as altering hunting strategies or shifting residential location) and the results of similar strategies used in prehistoric times will be evident in the archaeological record and; 3) overall, simulated household settlement will better match those exhibited by the archaeological record than when critical natural resources are not considered in settlement location. Of course the prehistoric human inhabitants of the study area were certainly capable of adapting to changing resource availabilities in many ways our simulated households cannot.

Resource Productivity/Distributions

Variation in study-area topography creates a number of microenvironments supporting a wide range of plant and animal life. The critical natural resources of interest here are found throughout the study area, but some areas support higher densities of some resources than others. The basis for production of all the natural resources addressed is the different soils that blanket most of the landscape. Development of the model begins with mapping and describing study-area soils. The annual NPP of vegetation provides the basis for modeling the production of important resources, supplying both fuels and meat protein on the model landscape. Secondary productivity of natural resources depends on the primary productivity of the native vegetation communities associated with study area soils. Fuels are produced based on the annual NPP of woody plant species, while meat production relies on that of many of the plant species comprised by the native vegetation communities.

The distribution of fuels across the study area is highly variable. Preferred prehistoric fuel species were piñon (*Pinus edulis*) and juniper (*Juniperus spp*.), as evidenced by their common recovery from excavated hearths (Adams and Bowyer 2002; Kohler and Matthews 1988). Other common fuels are oak (*Quercus gambelii*), sage (*Artemisia spp*.), and a variety of other shrubs. Piñon-juniper forest is prominent on thin mesa-top soils and the more gentle slopes of canyon sides. Shrubs are common cover on the steeper slopes of canyon sides, and sage parks are common on mesa tops, interspersed with piñon-juniper, and frequent on alluvial soils located at the bottoms of canyons.

Of course the distribution of native plant species heavily influences that of animal species as well. Mule deer, for instance, prefer edge zones (Dasmann 1981) where browse is available in clearings and cover is provided by nearby trees. In the Mesa Verde region, edge zones are abundant both within canyons and in mesa-top piñon-juniper forests. Black-tailed jackrabbits, on the other hand, prefer open habitats that provide plenty of running room to escape predators. The low-lying valleys supporting saltbush (*Atriplex gardneri)* and greasewood (*Sarcobatus vermiculatus*) communities in the southwestern portion of the study area are one such habitat. Cottontail rabbits prefer closed environments providing cover that allows them to hide from predators. The slopes of canyon sides and canyon-bottom riparian zones provide shrubby cover ideal for cottontails.

The variation in distribution and productivities of all resources modeled here is dependent on both spatial and temporal changes in climate, as well as spatial variation in soils. As with agricultural production and, to a lesser degree, dynamic spring discharge rates, overall annual NPP is dependent on annual precipitation. Increased soil moisture (or “available water capacity”, hereafter referred to as AWC) is highly advantageous to the productivity of annual new growth of most local plant species, except in a few isolated areas of poor drainage. Net primary productivity of annual new growth is the productivity on which the abundance of critical natural resources is dependent.

Although maize productivity declines with low average annual temperature in the current Village model, no such adjustment is made for the productivity of natural plant biomass. I have found no reference to the direct effects of annual temperature fluctuations on the NPP of native vegetation in the upland Southwest. On the other hand, much higher annual temperatures do affect AWC, and are accounted for by the variation in PDSI which is calculated for the dominant soil within each model cell to determine plant productivity.

The spatial distribution of study area soils also contributes significantly to variation in the productivities of the other resources modeled. Different native plant species are associated with each soil complex, and the herbivores prey on different combinations of those plants. As discussed in chapter six, there is great variation in both plant community composition and NPP values reported for each of the many soils within the study area.

An important consideration in the productivity of modeled resources is that each resource used by people is supported by different combinations of the many primary-producing plant species. Only certain of the 93 reported plant species contribute to woody biomass and each of the herbivorous species prefers a different combination of plants as food sources. Thus the distribution of soil components and their associated plants is of primary importance with respect to variation in production of any particular resource in any given year.

Overview of Methods

This study has entailed a great deal of research into the natural productivities of study area soils and the native vegetation communities associated with those soils. There are many ecological details of interactions between the three species of herbivores, the 139 soil complexes, and the 93 native plants addressed in this study.

Given changing distributions of known archaeological sites and potential resource production within the study area over the 700 years of occupation of interest to this study, there is a strong spatial aspect to this research. Fortunately, current computer technology allows analyses of spatial data using geographic information systems (GIS) applications, and the industry standard Environmental Systems Research Incorporated (ESRI) ArcGIS™ (v. 9) software is employed extensively in this project. As discussed more fully in the following chapter, the base data for this project are the physical landscape attributes found within the study area. These attributes are primarily composed of topographic features such as terrain elevation and derived attributes such as slope and aspect, water resource locations, the distribution of soil complexes, and the native plant communities supported by the various soil components.

Generally, the effects of relief on various areas within the study area are implicit in the data used in this part of the modeling effort. Differences in soil components, their associated native vegetation communities, and the NPP of these communities are strongly correlated with elevation, aspect, and slope (Karlen 2005). There are strong correspondences, for instance, between elevation and precipitation that greatly affect potential plant productivities. Similarly, interactions of elevation, aspect, and temperature greatly affect growing season lengths. Variation in slope affects soil properties such as depth and texture.

Primary productivity of plant biomass results from the interaction of soils and annual variation in climate. Climate − long-term trends in weather − includes effective moisture and temperature as the most important factors. Effective moisture supports plant growth, and we use PDSI to indicate relative soil moisture. Mean annual temperature affects both soil moisture and growing season length. Although warmer annual temperatures generally provide longer growing seasons, extremely warm temperatures can deplete soil moisture, depriving plants of water. Conversely, below normal temperatures promote soil moisture retention, but can shorten growing seasons (particularly at higher elevations), potentially greatly reducing maize harvests, but are not expected to significantly affect long-term production of critical natural resources.

Three adjacent soil surveys have mapped and described the many soil complexes that are widely distributed across the study area. Each of the soil complexes comprises one or more soil components, each of which has an associated native plant community composed of different combinations and abundances of various species, so the distributions of vegetation species are mapped as well. Ecological literature, in turn, describes which plants are food sources for which herbivores. So, the soil distributions determine plant distributions, and the plants differentially support the herbivores whose populations we model.

The production and consumption of critical natural resources is expected to noticeably affect long-term household survival strategies, resulting in observable patterns that are comparable to those surviving in the archaeological record. I discuss how those patterns actually compare, and reasons for divergences between models and reality.

Organization of the Dissertation

The first chapter of this dissertation has laid out the main thesis of the research reported herein. Following theories of social evolution and behavioral ecology, I have discussed the expectations that variations in resource availabilities and access/procurement strategies will influence long-term human behaviors. The various natural resources modeled as the bases of this work have been introduced, as well as several questions this work aims to address.

The second chapter provides a detailed discussion of the environmental context of the region and study area in which this research is set. I describe the regional topography, geology, hydrology, and biotic communities. Of particular interest here are the physiographic characteristics that determine the various environments that support biotic productivity in the region. Climate is a major interest as well (including variations in temperature and precipitation). The larger-scale environmental characteristics discussed in chapter two set the stage for more detailed discussion of locally important variations in the many microenvironments within the study area.

Chapter three sets the archaeological context for the study of prehistoric settlement patterns. The spatial and temporal distributions of prehispanic Puebloan households are described, as is the varying tendency of households to aggregate at different times as indicated by the calculation of an aggregation index. Distinguishing characteristics of the archaeological record are discussed for each of the 14 modeling periods used in this study, including settlement sizes, variation in construction techniques, and differences in ceramic styles that indicate periods of occupation. Site distributions are mapped based on model period and number of households, providing the data to which simulated household settlement distributions are compared.

The fourth chapter provides an overview of the techniques employed to model the production and consumption of critical natural resources. These resources include fuel wood and animals that simulated households are required to harvest. Discussions of studies of subsistence and fuel wood requirements are provided, as are relevant zooarchaeological data in the form of faunal indices calculated from assemblages recovered through excavation of study area sites. This chapter sets the stage for the following chapters that detail how the model of critical natural resources is developed.

Chapter five presents relevant data taken from the three soil surveys that describe study area soils. Both regional and local soil properties are described. Conversion of soil survey data to that appropriate for use in the model is the main topic, including how the 193 soils described in the soil surveys are numbered as consecutive soil codes specific to this project. I discuss how the 148 soils mapped within the study area are converted to 4-ha raster data, resulting in a total of 139 soil complexes actually underlying the model landscape. Finally, a discussion of the normal-year productivity of soil complexes vs. the long-term mean produced by the simulation is presented.

Chapter six describes how the model of vegetation is constructed. Information on each vegetation class (trees, shrubs, and grasses) is presented, including their component species, distributions, and productivities. Examples of normal-year net primary productivity are provided and compared to that produced by the simulation. The simulation of fuel wood production is also discussed, and compared with rates of deadwood production determined by a collection study.

The three herbivore species are the topic of chapter seven. I detail the ecology of each species, their habitat and food preferences, and map out their distributions across the model landscape based on the availability of preferred foods. Modeling population fluctuations of each species is based on their respective logistic growth rates. As suppliers of high-quality protein, discussion of individual characteristics is also important, such as body weights and protein supplied by average individuals of each species.

Output data of the model are presented in chapter eight. Each model run produces abundant information on household settlement distributions, effort expended in obtaining resources, numbers of animals hunted, and amounts of resources maintained in model cells. How these various data sets are processed is the main goal of this chapter.

The final chapter is devoted to the various implications of the results of this modeling effort. Comparison of model output to observations from the archaeological record is discussed, describing which resources are most important in providing the best fit of simulated vs. observed data. Indices of faunal use and household aggregation calculated from both observed and simulated data are presented and discussed in relation to changes in social organization. Potential problems, improvements, and future directions are also suggested.

CHAPTER 2: ENVIRONMENTAL CONTEXT

Modeling the production and distributions of natural resources across a large area requires a detailed knowledge of factors responsible for their occurrence. This chapter provides descriptions of the major components of regional and study-area environmental characteristics underlying the resources of interest. These include topography, geology, hydrology, and climate, as well as the larger biotic contexts in which the relevant resources are found. As discussed below, there is great variety in landscape features within both the greater Mesa Verde region and the Village Project study area.

The study area is situated in the uplands of the American Southwest in the area historically known as the Four Corners region. Geographically, this region is located in the physiographic province known as the Colorado Plateau, which is approximately coterminous with the Colorado River basin (Baars 1995).

Elevations on the Colorado Plateau range from 672 m (2500’) on the Colorado River (where it exits the plateau) to greater than 3962 m (13,000’) at the higher peaks (Smith 1970). Deeply incised canyons cut into relatively flat-lying sedimentary formations, adding to regional relief. The Mesa Verde region has a number of these canyons, many presenting significant barriers to foot travel. Features such as Navajo Canyon on the Mesa Verde proper, and Yellow Jacket, Ruin, and Cross canyons in the Montezuma Valley, are hundreds of meters deep with long outcrops of sandstone rimrock and steep colluvial slopes common.

Physical Environment

The study region comprises a wide variety of microenvironments (Winter 1976). Differences in elevation, slope, and aspect all contribute to variation in both landscape productivity potentials as well as suitability for habitation by various plants and animals, including humans. Many of the changes in microenvironments are the result of more precipitation at the higher elevations, different degrees of soil formation and associated water capacities, and levels of solar irradiation on various aspects.

Topographic Setting

The Village project study area covers 1816 km^2 in the northwestern part of Montezuma County, Colorado. The Utah state line lies just to the west of the western border of the study area, while the Four Corners lies approximately 25 km to the south (Figure 1.1). The entire study area is depicted by a block of twelve United States Geological Survey (USGS) 7.5' topographic quadrangle maps as shown and labeled in Figure 2.1.

Topographic relief within the study area is high, ranging from 1499 m at the point where McElmo Canyon exits to the west, to 3040 m at the top of Ute Mountain just north of the southern study area border. The largest and deepest canyons within the study area are Cross Canyon in the northwest, Yellow Jacket Canyon crossing the central portion, and the Dolores Canyon in the northeast, each of which is approximately 305 m (1000′) from rim to floodplain at their deepest points. Other canyons are shallower, and their walls are generally not as steep. The generally high relief in the study area, combined with highly variable slopes and exposures with virtually all aspects, results in many microenvironments supporting numerous vegetation communities as discussed below.

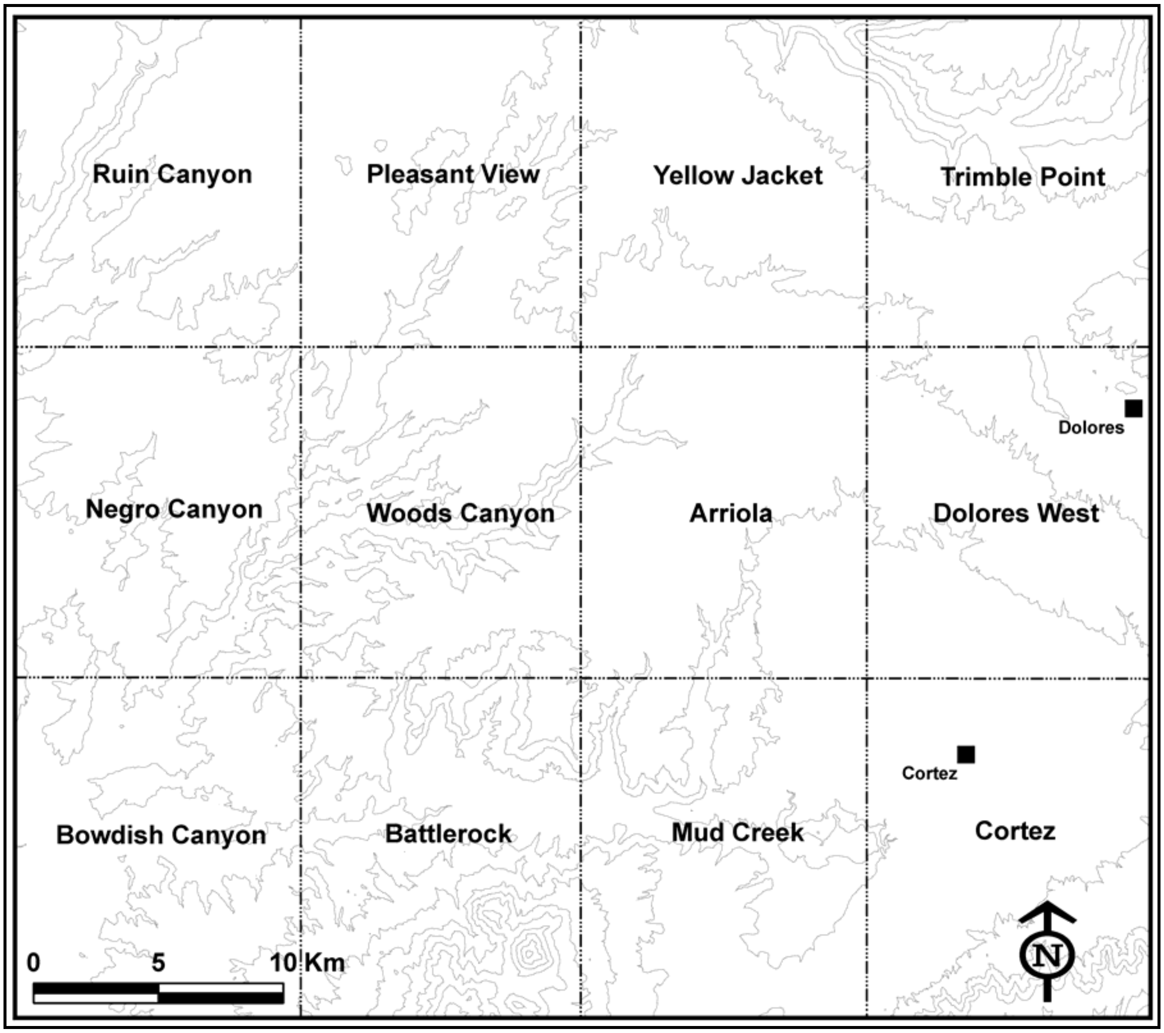

Figure 2.1. The 12 USGS 7.5' quadrangle map names and locations in the study area.

The terrain within the study area consists of rolling mesa tops deeply dissected by numerous canyons, most of which trend to the southwest, with two important exceptions. The exception most likely of primary importance in prehistoric times is the Dolores River Canyon (Figure 2.2), located in the extreme northeastern part of the study area. It contains the only (naturally) perennial flowing water within the study area. The Dolores flows into the study area from the east, turns north and then winds northwest across the northern border of the study area.

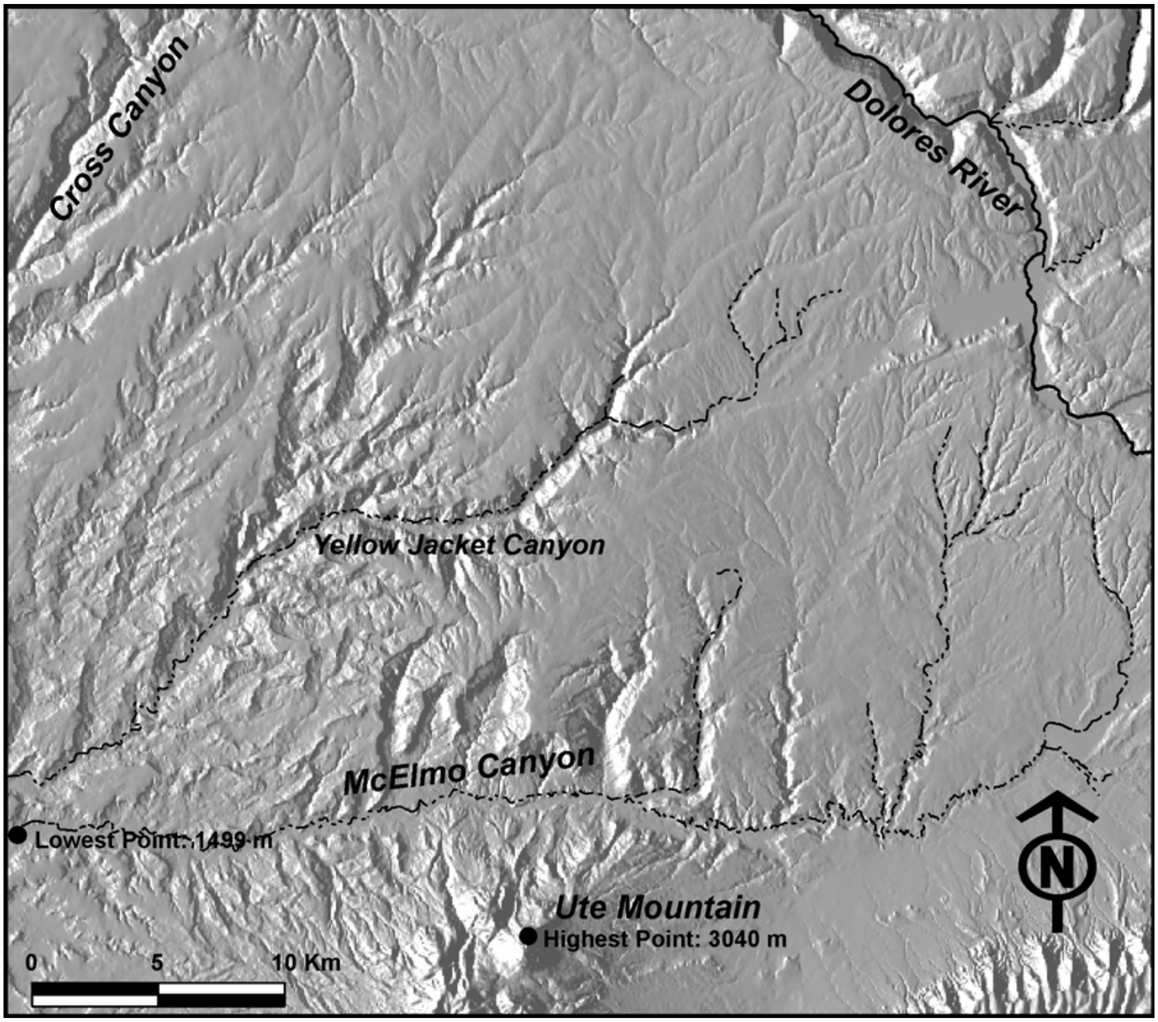

Figure 2.2. Map of study area showing major canyons and locations of elevation extremes.

The flow of this river is the result of both runoff from the La Plata Mountains to the east of the study area, and the base flow contribution of the Navajo formation (N) aquifer (Kolm 2004). The ultimate effect of these two sources of water supply to this drainage is that, regardless of questions of water quality, the Dolores always provides a source of fresh water and habitat for riparian and aquatic species. In my experience, even in the driest of years, the Dolores flows cold and clear, at least in those portions above the modern McPhee reservoir. I would suggest that the same was true for its entire length within the study area in pre-dammed times.

The other exception is McElmo Canyon that trends generally west, approximately 10 km north of the southern border of the study area (Figure 2.2). Most of the extent of this drainage is shown as intermittent on the USGS topographic maps on which it is depicted. Nevertheless, Kolm (2004) describes at least a small section of this drainage as being perennially fed by the N aquifer as well. Riparian vegetation along much of the present-day length of upper McElmo Creek indicates a generally high water table. Given this, it may be reasonable to assume that soils on the north side of McElmo Creek were rarely, if ever, not considered highly arable by the prehispanic inhabitants of the region. In fact, in their study of alluvial deposition in McElmo Canyon, Force and Howell (1997) found a correspondence between concentrations of Pueblo II and Pueblo III artifacts and alluvial fans. Interestingly, these alluvial fans, containing ^{14}C dated samples correlating with Pueblo II and Pueblo III occupations, enter the drainage from the north side, where virtually all known Pueblo sites within the canyon are located. The terrain on the south side of McElmo Creek is generally too steep to provide much arable land, and Puebloan sites are much less common except to the west of Ute Mountain where the terrain exhibits much less relief.

Geology

The Mesa Verde region lies on the Colorado Plateau just north and slightly east of the Four Corners, the point where the state lines of Arizona, Colorado, New Mexico, and Utah intersect. The Colorado Plateau is a huge land mass separated from surrounding areas by numerous, large, Pre-Cambrian faults (Baars 1983). The Colorado Plateau is bounded by the Uinta mountains on the north, the Mogollon Rim on the south and southwest, the Nacimiento uplift and Rio Grande trench to the southeast (Smith 1970), and both the Wasatch Front and the basin-and range desert on the west (Dunmire and Tierney 1997).

The regional landscape is dominated by gently sloping beds of sedimentary rocks, interrupted by widely spaced intrusive mountains considered to be of laccolithic origin (Baars 1995). These igneous laccoliths intruded into fractures in the overlying sedimentary beds and were then were exposed by erosion of those overlying formations. The more prominent laccolithic mountains (visible from the study area) include the La Sal Mountains to the north, Mount Hesperus to the east in the La Plata Mountains, Ute Mountain at the southern edge of the study area, Shiprock on the distant southern horizon, and the Abajo Mountains on the western horizon.

Most of the study area (except for small portions in the east, northeast, and south) lies in the Monument-McElmo section of the southern Colorado River basin (Lipe, Varien, and Wilshusen 1999:Figure 1.2). Within this area, geologic features are dominated by gently dipping sedimentary beds of sandstones and shales, predominantly of Late Cretaceous age (Wanek 1959). The sedimentary formations are slightly deformed and variously eroded, producing a variety of contacts among them.

The youngest formations of the Four Corners region are early-to-mid Tertiary intrusive igneous bodies that have been exposed via erosion and now form the La Plata and Ute Mountains that dominate the skyline from many points. Aside from these young intrusives, the latest sedimentary formations are those that compose the Mesa Verde group. These are, from youngest to oldest, the Cliff House sandstone that generally conformably overlies (with local disconformities being exceptions) the Menefee formation which, in turn, conformably overlies the Point Lookout formation.

Each of these Late Cretaceous age formations is the result of sedimentary deposition in an environment varying from shallow marine through estuarine to low-lying swamps. The upper and lower members of the Mesa Verde group are predominantly sandstones, while the middle Menefee formation is composed of sandstone beds interspersed with beds of siltstone, shale and coal (Wanek 1959). Although these formations are present on the Mesa Verde proper, in the extreme southeastern portion of the study area, the bulk of the study area lies in the Montezuma Valley to the north and west of the modern town of Cortez, CO.

Geologic outcrops in the greater part of the study area are represented by widely scattered deposits of Mancos Shale, and common exposures of Dakota Sandstone. The Mancos Shale Formation conformably underlies the Point Lookout Formation and conformably overlies the Dakota Sandstone Formation. This latter formation caps the bulk of study area terrain and forms most of the canyon rims. Dakota Sandstone and its Burro Canyon Member act as the primary regional near-surface groundwater aquifer (Kolm 2004). This formation "is the basal formation of the Upper Cretaceous series and lies unconformably upon the Morrison Formation of Late Jurassic age" (Wanek 1959:680). The Morrison Formation presents limited exposures within the study area, primarily at the bottoms of the deeper canyons. In some of these locations, this formation also discharges groundwater and acts as a regional aquifer with limited surface discharge.

Exposed contacts between porous sandstones overlying impermeable shales frequently exhibit springs at fracture zones. Groundwater discharge points are generally easily identified by the localized occurrence of phreatophyte plant species.

All these geologic features heavily influence the regional topography. The topography, in turn, directly affects the formation and retention of study area soils and thus contributes substantially to the overall distribution and productivity of critical resources they support.

Elevation

Transforming the various data reflecting study area physiography requires the use of many GIS functions. In constructing the elevation data planes used in the original version of the Village model, Van West (1990) used digital elevation models (DEMs) of the 12 7.5' quadrangles (Figure 2.1) obtained (at a cost) from the USGS EROS data center, supplied on magnetic tape. By the time these same data were needed for the current project, DEMs were available for free from geocommunity.com (http://data.geocomm.com/catalog/US/61076/1590/group4-3.html), downloaded as 12 individual files in spatial data transfer standard (SDTS) format.

These files were imported to ESRI's ArcView 3.2 and concatenated using the "mosaic" function of the raster calculator. More recently, the USGS began providing similar data from the "seamless" data website (http://seamless.usgs.gov/website/seamless/viewer.php), allowing users to download large datasets by supplying bounding coordinates or selecting the area of interest using a rectangular graphic. This latter option was used for the final digital elevation data, retrieving data with 30-m horizontal, and 1-m vertical resolution for the entire study area.

These data are applied in a variety of ways in this project. Digital elevation data were reclassified to provide more manageable data for various purposes. The first reclass operation created four elevation classes to replace the five used by Van West (1990, 1994) in forming new paleoproductivity reconstructions. The four elevation classes are: 1499-1604 m (4918-5262 ft), 1605-1992 m (5265-6535 ft), 1993-2130 m (6538-6988 ft), and >2130 m (Figure 2.3). These elevation bands contain the elevations of the four weather stations from which historic weather data were obtained for use in the paleoclimatic reconstructions.

The same elevation bands are also used in conjunction with block survey data and study area quadrants in estimating prehistoric population (Varien et al. 2006). This stratification allows more accurate population estimates, since site densities are higher at some elevations and in some quarters of the study area than in others. Variation in area relief was also used in the calculation of drainages as described below.

In order to create study area maps with enhanced readability, a series of shaded relief maps were produced using the “hillshade” function of the “Spatial Analyst” module in ArcGIS. This function allows the user to designate the angle of illumination of the elevation surface, resulting in optimal representation of the terrain of interest. Experimentation with different angle values reveals a surprising amount of variation in surface detail. For general display purposes in this study area, I found the illumination angle values of 275˚ azimuth and 40˚ altitude (zenith) to reveal the most landscape detail. This combination of values produced a much more detailed display of terrain (e.g., Figure

2.2) than use of either the default "hillshade" values or various color schemes of the DEM as the base map (e.g., Figure 2.3).

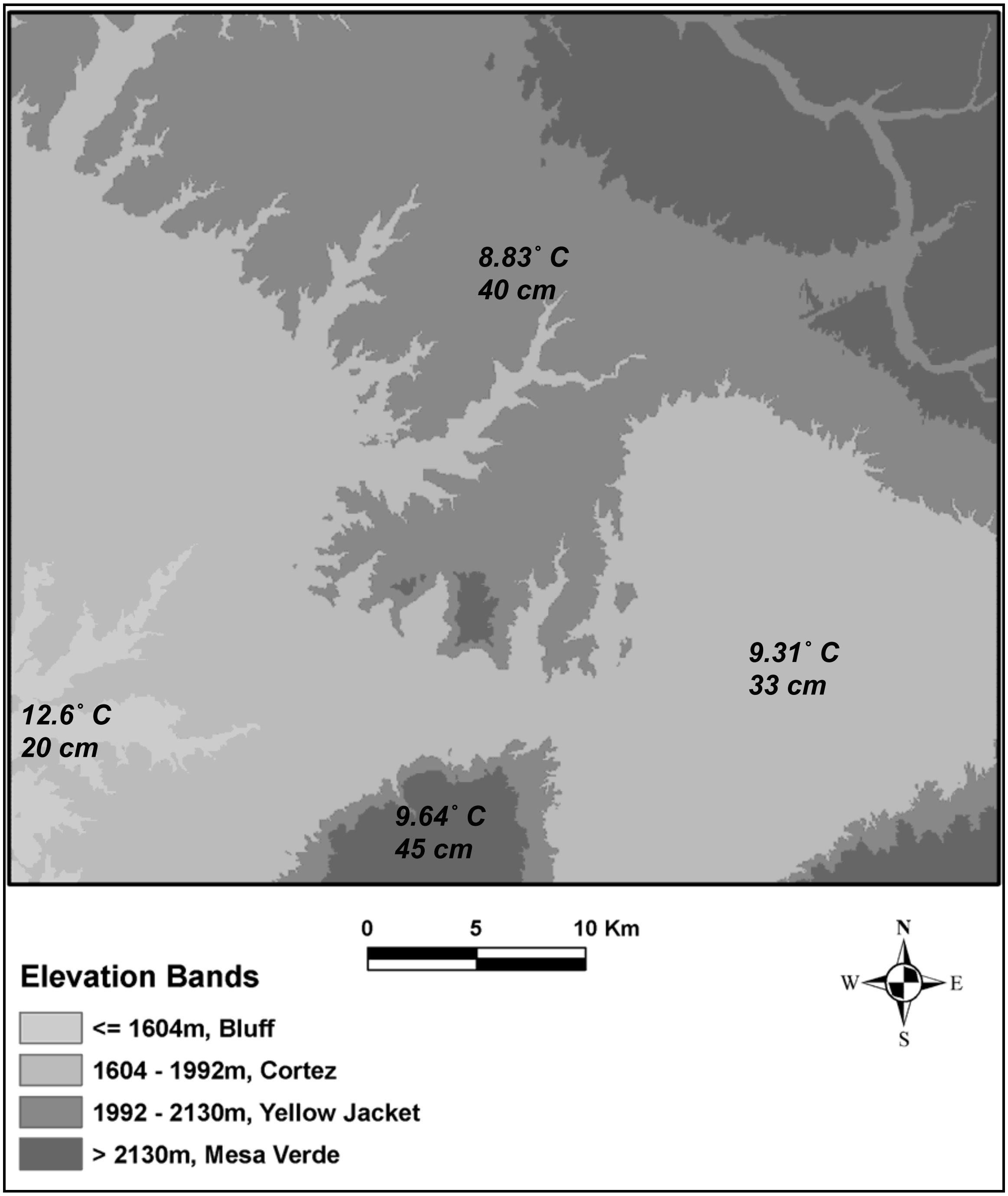

Figure 2.3. Map of elevation bands showing mean annual temperature and precipitation recorded at associated weather stations.

Hydrology

Water is comparatively scarce on the Colorado Plateau, with perennial sources of flowing water few and far between. The more prominent of these include the Colorado, Little Colorado, San Juan, and Dolores Rivers. Less prominent perennial rivers of the Mesa Verde region include, from east to west, the Piedra, Los Piños, Animas, La Plata, and Mancos rivers, all of which are southerly flowing tributaries of the San Juan. Intermittent and ephemeral drainages of this semiarid and generally sparsely vegetated landscape are common and ubiquitous respectively.

Permanent sources of water in the study area are widely spaced, with the Dolores River being the only major source of continuously flowing water. The larger canyons, though classified as intermittent drainages, generally retain pools of water in some locations, even in the driest years. Pools are most likely to persist in those parts of these canyons lying closest to the water table. The remaining drainages are ephemeral streams flowing either during heavy snow melts or following localized monsoon rains. Regardless of stream classification, many drainages within the region host riparian vegetation. Areas providing near-surface water tables are commonly indicated by cottonwood trees.

In addition to recording flowing surface water, the Village Project has compiled a list of 267 springs occurring within the project area boundary. This list probably includes all major springs, but almost certainly excludes many small springs and seeps. Springs are most commonly found at the exposed contacts where the permeable Dakota Formation’s Burro Canyon Member overlies impermeable Morrison Formation. Canyon heads are often groundwater discharge areas, as are other exposed fracture zones along canyon walls. As is the case with surface water drainages, phreatophyte vegetation thrives at groundwater discharge points.

Of course, the amount of water available for domestic use will vary at any given location, depending on the amount of precipitation received within the watershed (in the case of surface water) or the recharge zone (in the case of groundwater). The rate of groundwater discharge is expected to change much less dramatically than surface water flow because there is usually a long lag time between substantial departures from mean recharge influx and those of discharge. Regional aquifers store large amounts of groundwater so even long-term reduction in mean annual precipitation within the recharge zone is not expected to noticeably decrease discharge at springs for many years. Groundwater will continue to flow through the aquifer, slowly reducing the amount of water stored in the host rocks.

One goal of current Village project research is to model groundwater recharge, flow, and discharge (Kolm 2004). We expect that most of the prehistoric inhabitants of the region obtained domestic water from groundwater discharge points, primarily springs. Therefore, calculating the discharge rates of study area springs is highly desirable. The groundwater modeling effort has mapped regional aquifers of the Dakota/Burro Canyon Formation and studied their permeability to calculate both their capacities and groundwater flow velocities.

Combining these data with the sizes of recharge zones, number of discharge points (seeps and springs), and modeled precipitation (based on the same tree-ring data used in the paleoproductivity studies), Kolm (2004) is able to provide dynamic rates of discharge at many of the known drains. Discharge rates are modeled as daily output in m^3

by five-year periods. Discharge rates of other known spring locations are not currently dynamically modeled. These “static-flow” springs are modeled as discharging groundwater at a constant 2.5 m^3 per day.

Other sources of groundwater may have provided adequate domestic water supplies, but are assumed to be less efficient. That is, there are countless seeps along canyon walls, but the rate of discharge at these locations is not expected to have been adequate to allow the efficient collection of domestic water. In areas where spring discharge is not sufficient, though other resources are abundant enough to support local populations, it is certainly possible that shallow wells excavated into high water tables could have supplied domestic water in most years. It seems reasonable to assume that the Puebloans understood the connection between phreatophytes and high water tables. Thus, water-loving plants would have indicated near-surface water easily accessed via shallow excavation. Prehistoric wells are not (to my knowledge) reported within the study area although prehistoric reservoirs have been (Wilshusen et al.1997; Wright Water Engineers 1999). Reservoirs are believed to have supplied domestic water needs, and may have served as sources for pot irrigation.

In the current version of the model, a revised version of the surface water data layer was needed since visual inspection of the correspondence between study area drainages and overlaid surface water data in the previous version of the model showed a poor fit between model cells coded as containing either perennial, intermittent or ephemeral surface water, and the actual drainages on the landscape. The discrepancy was on the order of several hundred meters (2-3 model cells) in many cases. The reasons for this inaccurate registration of water to drainages are unknown, but I preferred to correct the problem.

With the release of ESRI's ArcGIS™ v. 8.3, a new hydrology modeling module became available. This allows one to calculate drainages based on digital elevation data, and was found to work very well for constructing an accurate surface hydrology dataset for model input. The resulting water course arcs directly correspond to drainages and are constructed in long-enough segments that selecting an entire drainage for proper coding was relatively easy. For the final hydrologic data the coding scheme used in the earlier model was modified with water codes 1, 2, and 3 representing ephemeral, intermittent, and perennial drainages, respectively (as before) (Figure 2.4), with springs now coded as 4 (Figure 2.5).

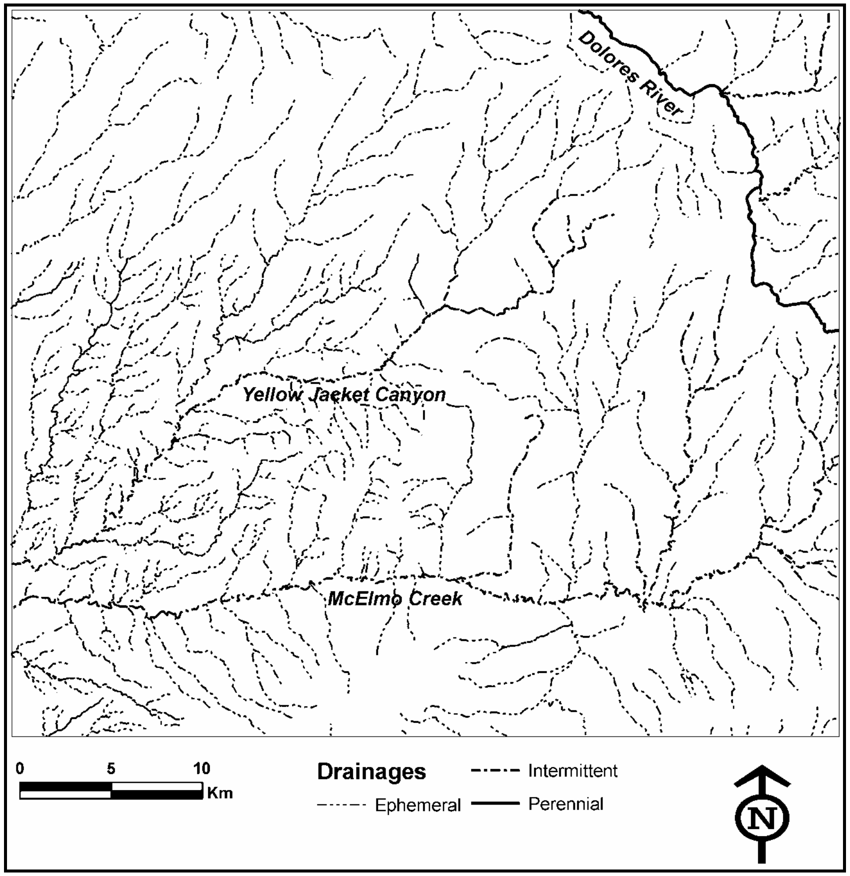

Figure 2.4. Map of study area drainages.

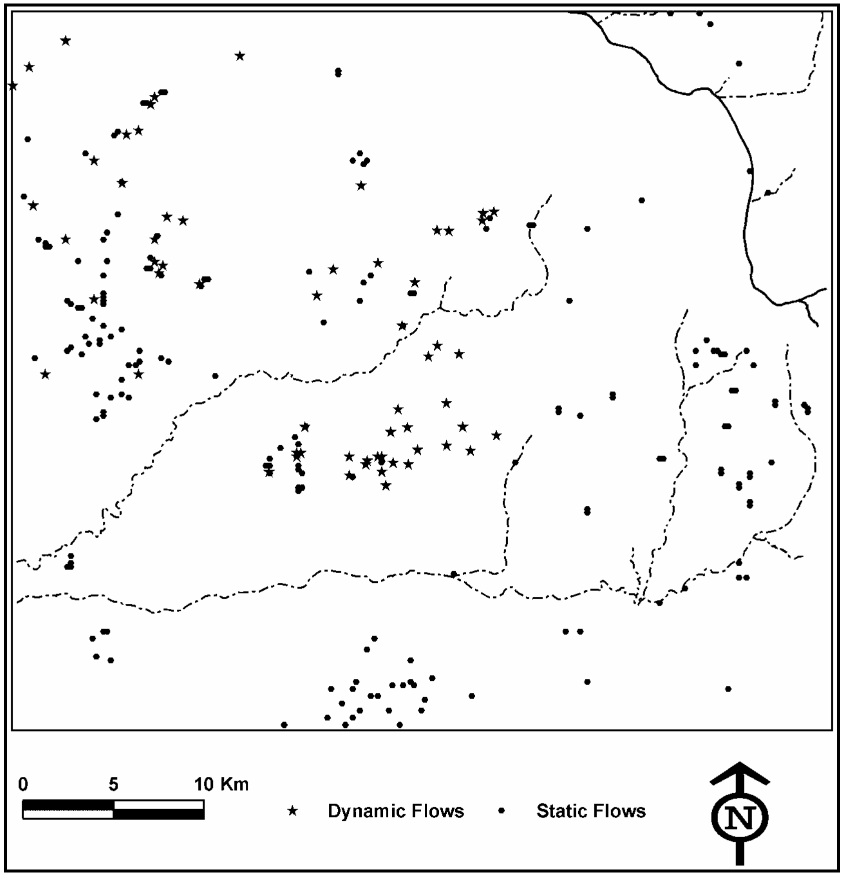

Figure 2.5. Locations of currently mapped and modeled springs in relation to perennial and intermittent streams.

Climate

"Climate can be viewed as the composite of all weather systems and events, and it fluctuates on all time scales: monthly, yearly, decadally, centennially, millennially, and longer" (Petersen 1998:28). An important assumption in modeling the annual productivity of natural resources in this study is that the observed climate of the study area can be reliably modeled for centuries past.

We assume that variation in temperature and precipitation recorded over the past several decades is similar to the variability over the 700 years of interest to this study. These are correlated with standard deviation departures from mean tree-ring widths for the years with historic weather records. It is presumed that variations in ring-widths for years prior to weather records indicate similar variations in climate for those respective years. This study uses the correlation of historic weather records from four area weather stations with tree-ring data extending from the present back to A.D. 600 for this purpose.

Modern Weather Data

The present climate of the Northern San Juan region is semi-arid. In this Upper Sonoran biotic province (Brown 1982), primary components of climate (precipitation and temperature) generally vary with elevation. Mean annual precipitation recorded at relevant weather stations (Figure 2.6) ranges from 20 cm on the San Juan River at Bluff, UT to 45 cm on Chapin Mesa in Mesa Verde National Park.

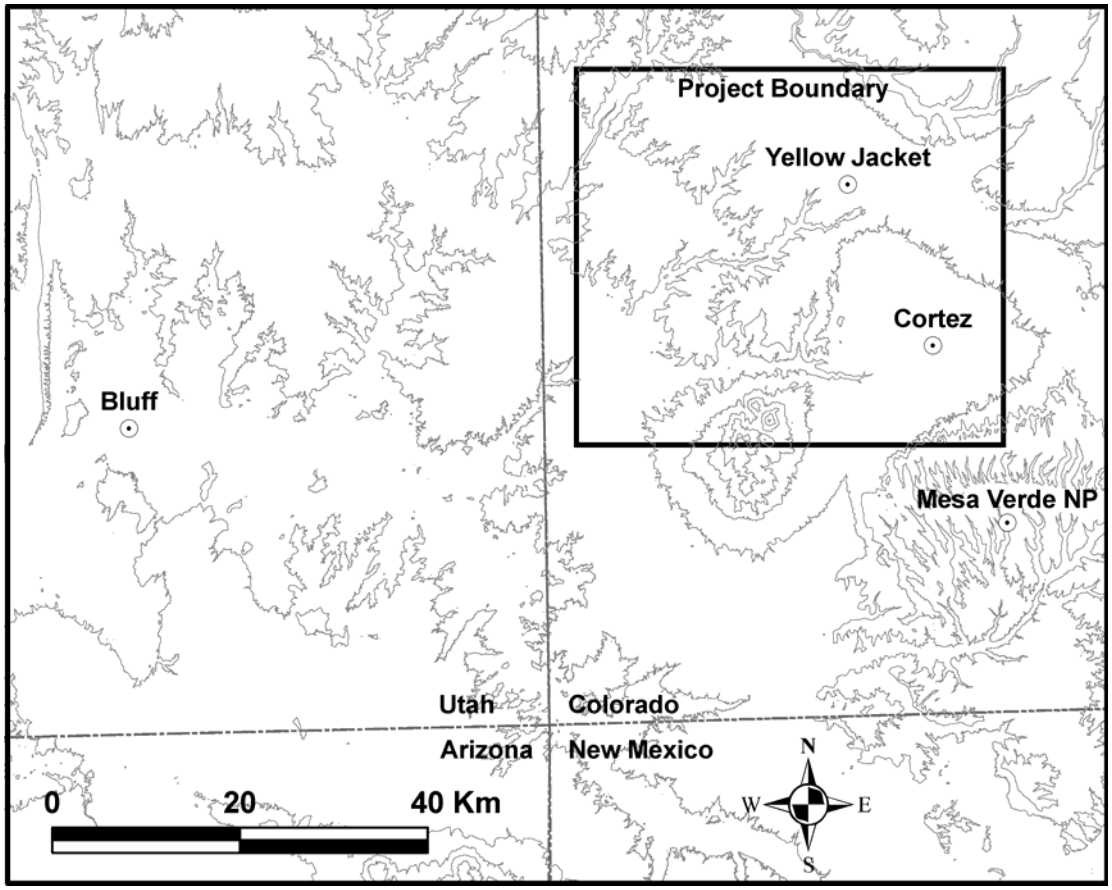

Figure 2.6. Location of weather stations providing instrumented data used for paleoproductivity reconstructions.

Precipitation occurs bi-seasonally, predominantly in the winter months (often as snow) and as mid-summer monsoonal rains (Figure 2.7, top). Variation in both mean annual precipitation and temperatures correlates fairly well with elevation of the weather stations. Although there is slight overlap in monthly precipitation, the higher elevation Mesa Verde and Yellow Jacket weather stations receive more annual precipitation on average than do the lower Cortez and Bluff stations. Similarly, higher elevations generally experience lower temperatures (Figure 2.7, bottom).

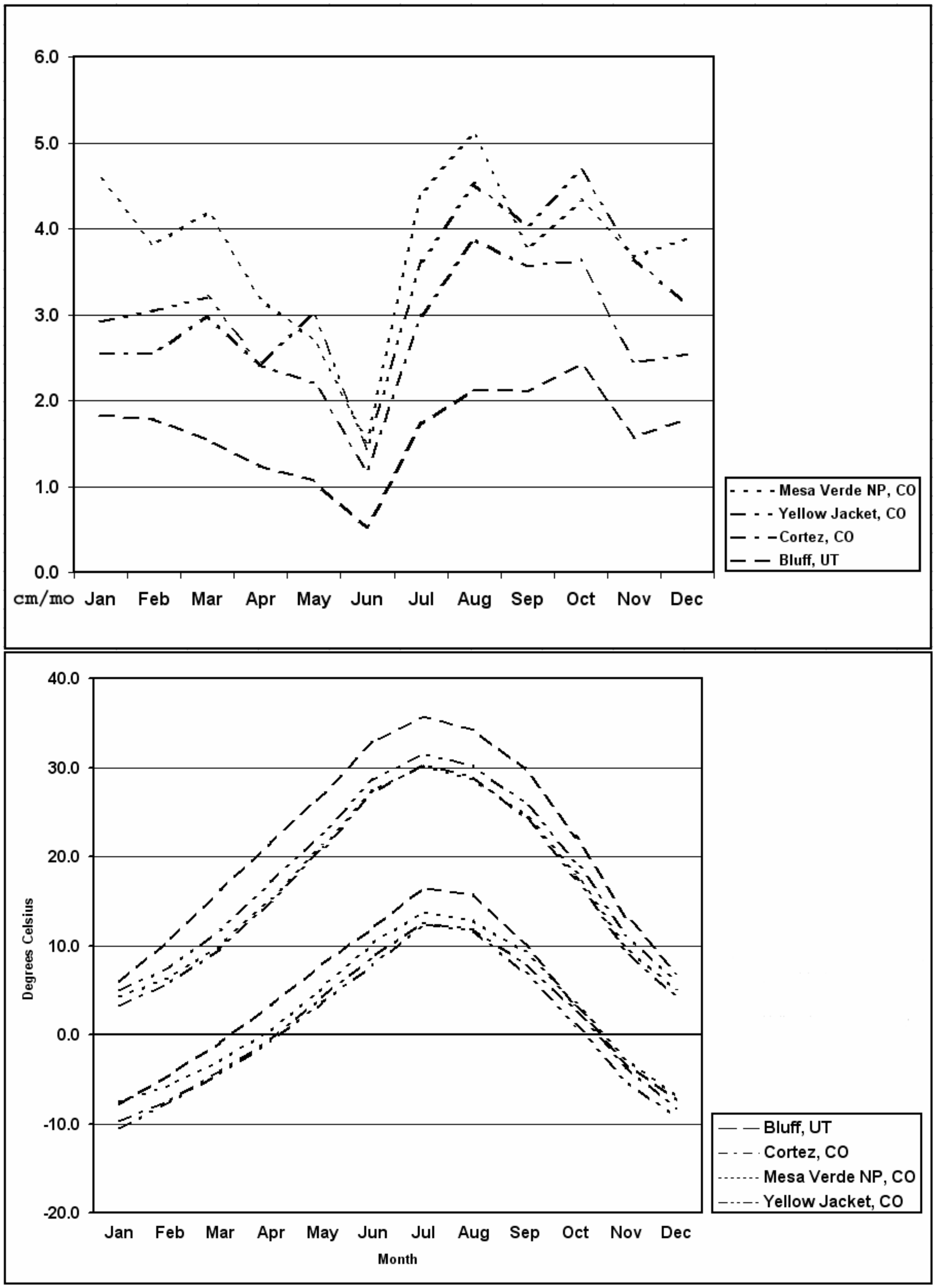

Figure 2.7. Historic average precipitation (top) and average high and low temperatures (bottom) at area weather stations.

Two exceptions are notable in this latter respect, and are likely the result of topographic situation. The monthly (and probably annual) low temperatures of both the high-elevation Mesa Verde, and much lower elevation Cortez weather station records do not fit the expectation that elevation is the sole determinant of temperature. In the Cortez case, the lower than expected low temperatures are most likely due to cold air drainage off the north rim of the Mesa Verde. The higher than expected lows recorded at Mesa Verde, in contrast, are probably due to both the prevalence of cold air drainage down the canyons to the south, as well as the favorable southerly exposure of the mesa tops.

Biotic Environment

This topographic variety and climatic variability leads to a variety of plant distributions. Regional geology places some control on the distribution of plant species. Betancourt (1990) suggests three aspects of geology affect vegetation growth patterns: 1) regional relief constrains many species due to the vertical limits of plants; 2) soil development on various parent material substrates can cause disruption or total exclusion of vegetation zones; and 3) plants can be edaphic specialists. That is, many plant species thrive on soils with particular characteristics, determined primarily by their geologic parent materials, regardless of climatic factors.

Topographic and related climatic factors, such as minimum temperatures and precipitation, control the locations of biotic communities, and also affect plant distributions (Brown 1982). Colorado Plateau biomes include alpine tundra; subalpine conifer (spruce-fir) forest, scrubland, and grassland; Ponderosa pine – Douglas-fir forest; Great Basin woodland (piñon-juniper); Great Basin montane (gamble oak, mountain mahogany, serviceberry, snowberry) scrubland; Great Basin desert (sagebrush and shadscale) scrubland; and low elevation grasslands (for detailed description of these biomes see Brown 1982; see also Adams and Petersen 1999).

Despite the high elevation of El Late (Sleeping Ute Mountain), neither the alpine tundra biome nor the subalpine conifer forest and scrubland-grassland are present in the study area (Adams and Petersen 1999:Figure 2-1). Ponderosa forest occurs in the higher elevations on Ute Mountain, Mesa Verde, and north-facing slopes above the Dolores River. Piñon-juniper woodland is common, particularly (barring major fires) on the edges of mesa tops, along canyon rims, and within many of the larger canyons of the study area. Scrublands are also common throughout the study area, their compositions varying widely with topography, soil, slope, aspect, and elevation.

The highly diverse microenvironments host a variety of fauna whose densities are mostly dependent on the annual productivity of their preferred feed species. Although a wide range of vertebrate and invertebrate species occur within the present study area, most are seldom recovered from archaeological contexts. Therefore, this study addresses only those wild mammalian taxa most commonly recovered from prehispanic Puebloan faunal assemblages, which are of the orders Artiodactyla and Lagomorpha (Driver 2002).

Within the Four Corners region, commonly observed artiodactyls are mule deer and elk, though pronghorns are known to occur and were likely more prevalent prehistorically. Though now rare, bighorn sheep are also reported from prehistoric assemblages (Driver 2002; Neusius 1985a; Shelley 1993). Lagomorphs are represented by cottontail rabbits, jackrabbits, and pika in some environments, and are reported in varying quantities from Mesa Verde region sites.

The bones of turkey are also recovered from study area sites, and are more frequent on sites occupied in the later periods. Turkey are thought to have been domesticatedin this region at least by Pueblo II times, initially for use as sources of feathers used in making ceremonial objects as well as blankets and robes (Munro 1994). On sites dating to Pueblo III times turkey replace artiodactyl and lagomorph bones as the most commonly recovered faunal remains (Muir and Driver 2002), suggesting these domestic animals were providing more meat than wild game.

Zooarchaeological studies of the Greater Southwest find cottontail remains generally outnumber those of other lagomorphs in prehistoric faunal assemblages (Szuter and Gillespie 1994). This suggests that, overall, prehistoric clearing of fields for agriculture, and subsequent “garden hunting” (Linares 1976) of increasing jackrabbit populations was not as common as one might expect, given the high reliance of prehispanic Puebloans on farming.

Summary. This chapter has presented a detailed discussion of the environment within which the present research is conducted, and described how landscape attributes are incorporated in the model. It is assumed that the topographic, geologic, hydrologic, climatic, and biotic components of this area were similar, overall, during the 700 years of interest in this study to conditions experienced today. With the environmental context of the study area now described, I can proceed to discuss the cultural context within which this modeling effort is set. The following chapter discusses settlement archaeology, previous research on regional and study area archaeology, the settlement model, and introduces some additional settlement data analyses.

CHAPTER 3: ARCHAEOLOGICAL CONTEXT

Settlement/Landscape Archaeology

The study of human land use strategies has a long history in anthropology. In western North America, Julian Steward (1937) studied the lifeways of the desert dwelling Shoshone of the Great Basin. Based on his study of memory culture, Steward (1937) describes these aborigines' traditional subsistence strategies, hunting and gathering on landscapes not yet altered by Euroamericans. The nature of the seasonal round carried out by these groups is assumed to be the one replaced by the earliest sedentary settlers of the Northern San Juan region. As the prehistoric inhabitants within the study area became more reliant on agricultural subsistence, settlement mobility decreased dramatically (cf. Varien 1999a).

Habitation sites occupied by seasonally mobile peoples are generally ephemeral in the archaeological record, making their discovery much less likely than residential sites of agrarian peoples. Within southwestern Colorado, in fact, only 432 pre-agricultural sites have been recorded in the Colorado State site database. Eighty-three of these lie within the Monument-McElmo drainage (1.7 percent of all sites recorded for the drainage) in which most of the present study area lies (Lipe and Pitblado 1999:Table 4-1). The majority represent limited activity areas thought to have been used as part of seasonal rounds. Pre-agricultural habitation sites are very rare, occurring primarily in lower elevations associated with grassland environments (Billman 1997; Lipe and Pitblado 1999).

The ephemeral nature and wide distribution of pre-agricultural sites in the Four Corners region suggests that the highly mobile early inhabitants of the area used a variety of subsistence resources at a low intensity. Settlements were short-lived, widely dispersed, and most likely result from the activities of small groups as observed for aborigines in the Great Basin region to the northwest (Steward 1937). This adaptive strategy eventually gave way to one requiring a greater investment of time and energy in the production of domesticated crops resulting in, or allowing, more sedentary settlement. The resulting settlement distributions of this latter adaptation are one focus of the current study.

As prehistoric peoples of the Southwest began to rely more heavily on agriculture for subsistence, and grew in number, settlements became more substantial and were occupied longer. Early horticultural habitation sites in the region, those of the Basketmaker II period (1000 B.C. to A.D. 500), generally consisted of one or more pitstructures located on or near arable lands (Lipe 1999c).

Prime agricultural lands in the study area result from the long-term deposition of loess derived from the lower reaches of the San Juan River, transported by the prevailing southwesterly winds of the region (Arrhenius and Bonatti 1965). Deep deposits of these fine-grained sediments occur primarily on level to gently sloping mesa tops, and support native vegetation communities dominated by shrubs and grasses, primarily sagebrush parks. Basketmaker III (A.D. 500 – 750) settlements in the study area are located primarily on the mesa tops where soils are deep and fertile. This settlement strategy is long-lived in the study area, with many of the known habitation sites located in such settings throughout the Puebloan occupation (Figure 3.1).

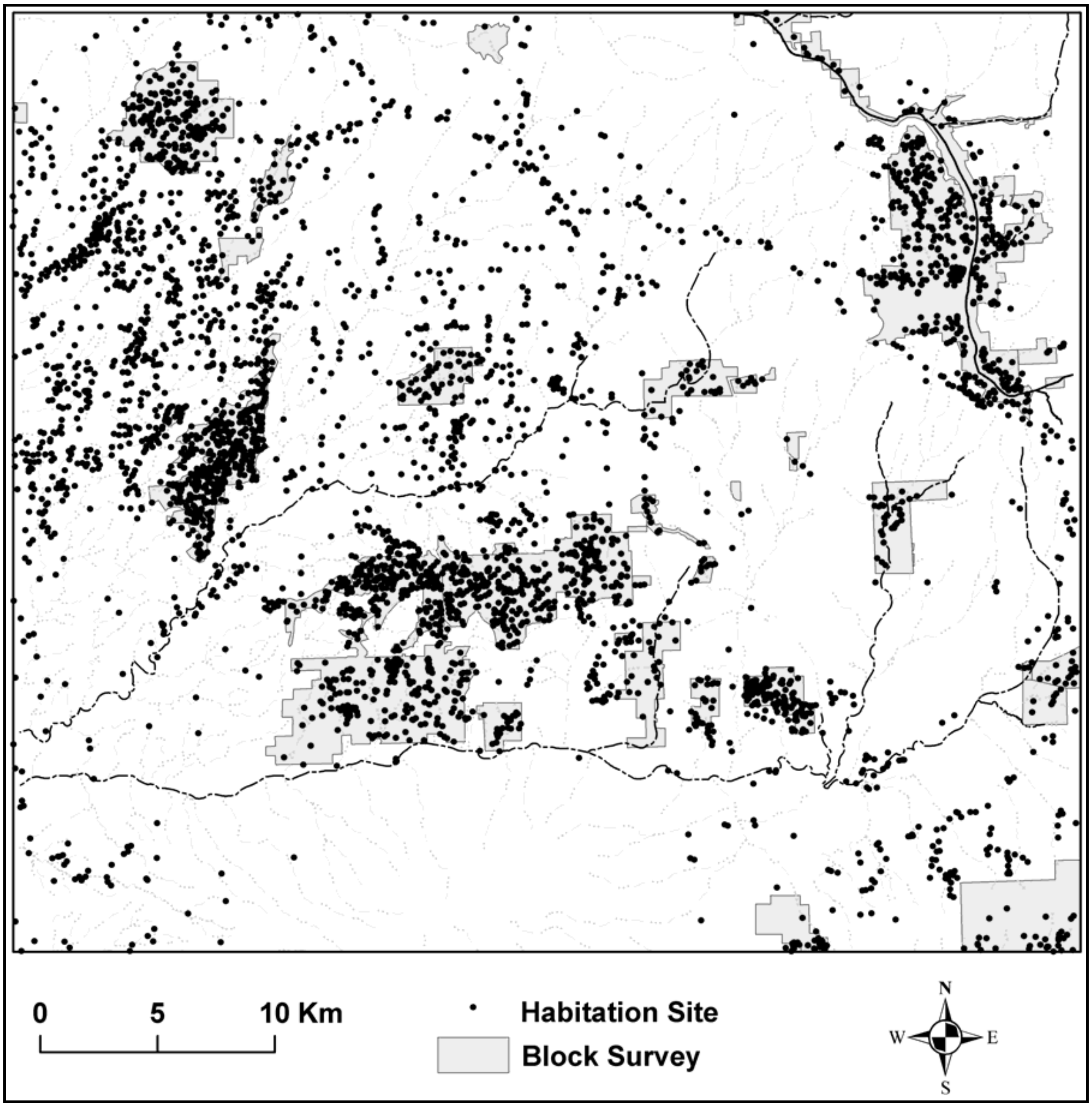

Figure 3.1. Study area map showing the locations of all known Puebloan habitation sites and major archaeological surveys.

Alluvial soils found in canyon-bottom settings are also commonly deeply deposited, well developed, and exhibit better than average available moisture capacities amenable to agricultural production. Daytime temperatures in many canyon bottom locations may be significantly higher than those of the higher mesa-tops, though nighttime cold-air drainage may have reduced crop production in many of these locations

(Adams 1979; Erdman et al. 1969). Note particularly the location of numerous sites in the Dolores River canyon, which, given its relatively higher elevation, is normally cooler than other deep canyons of the region (Petersen 1985), such as Yellow Jacket or Cross canyons.

Obviously, the more than 4000 sites within the study area were not all occupied simultaneously. Fortunately, numerous sites in the region have been excavated providing tree-ring dates (Varien 1999a) recovered in association with many well-dated ceramic types (Breternitz, Rohn, and Morris 1974; Ortman et al. 2005; Wilson and Blinman 1993) allowing relatively precise dating of unexcavated sites based on surface artifacts. Primary among surface indicators of occupation dates are ceramic styles, although architectural features also tend to represent particular time periods (Lipe and Ortman 2000; Ortman et al. 2006).

A major effort of the current Village Project has been the development of a settlement model by researchers at the Crow Canyon Archaeological Center (CCAC). This has allowed us to place many study area sites into well-defined temporal spans, and to form accurate estimates of site sizes. The techniques making this possible are reported in detail by Ortman, Varien and Gripp (2006) and Kohler et al. (2006). Fourteen modeling periods (MPs) within the A.D. 600 – 1300 period are distinguished in this project (Table 3.1).

Table 3.1. Village Project Modeling Periods and Associated Habitation Data.

MP[1]	Begin[2]	End[2]	Duration	Site Occupation Span-Yrs.[3]	# Sites[4]	Total # HHs[5]	Pecos Classification[6]
6	600	725	125	8	1480	1572	BM III
7	725	800	75	13	534	633	BM III-PI
8	800	840	40	18	402	516	P I
9	840	880	40	18	474	615	P I
10	880	920	40	18	155	295	P I – P II
11	920	980	60	18	210	282	P II
12	980	1020	40	18	328	381	P II
13	1020	1060	40	21	281	342	P II
14	1060	1100	40	21	669	949	P II
15	1100	1140	40	40	547	859	P II
16	1140	1180	40	40	544	933	P II – P III
17	1180	1225	45	45	456	1044	P III
18	1225	1260	35	35	711	1689	P III
19	1260	1280	20	20	317	1150	P III

[1] Village project modeling period. As with the Pecos classification, earlier period designations are available for future use.
[2] All dates are A.D.
[3] Estimated use life of households based on studies of ceramic artifact accumulation rates (Varien and Mills 1997).
[4] Recorded habitation sites within the study area based on the McElmo-Yellow Jacket Settlement model v. 5.4, CCAC/WSU (2004).
[5] Estimated number of households (HHs) based on the McElmo-Yellow Jacket Settlement model v. 5.4, CCAC/WSU (2004)
[6] From Lipe, Varien, and Wilshusen (1999).

The McElmo-Yellow Jacket Settlement Model

The ultimate goal of this research is to investigate how and why agrarian households distributed themselves over a variable landscape throughout the course of the 700 years of prehispanic Puebloan occupation of the Mesa Verde region. Some of their needs (e.g., fuels, water, and food) can be relatively accurately modeled through the work of scientists in related fields. This section introduces the methods and data used in the study of prehistoric household settlement patterns.

Based on the reconstructed climate and landscape productivity potential of various resources, simulated households are intended to display similar locations and levels of aggregation as those in the archaeological record. That is, if the factors modeled here were important considerations in the settlement decisions of the prehistoric occupants of the study area, model households should converge on those locations at similar points in model time. Therefore, the archaeological database is of primary importance in this work, since without it I would have no data with which to validate the results of the critical natural resource model.

Crow Canyon Archaeological Center has developed the model of prehistoric settlement within the Village Project study area that provides the bulk of the archaeological data used in this study. The McElmo-Yellow Jacket settlement model (Ortman et al. 2006) is based on records for all sites recorded within the study area. The model uses Bayesian statistical analyses to place each site into one or more modeling periods. Modeling periods range from 125 to 20 years in length (Table 3.1), and are based on combinations of archaeological attributes observed through survey, testing, and excavation of sites, correlated with dendrochronologically determined dates of excavated sites.

Conversion to Model Input

Known site locations are provided in universal transverse mercator (UTM) metric coordinates, using the 1927 North American Datum (NAD 27). Although much of the environmental data, discussed elsewhere in this document, are supplied in reference to the 1983 North American Datum (NAD 83), the current version of the model continues to use the older datum. This is because the original version of the model used environmental data set to NAD 27, and the Colorado state site files still list site locations in NAD 27 UTMs, as does the McElmo-Yellow Jacket site database. Thus, all physiographic data is reprojected to coincide with NAD 27 datum coordinates.

Data on the sites of interest in this study are exported from the Microsoft Access™ database containing the McElmo-Yellow Jacket settlement model to a Microsoft Excel™ spreadsheet. These data are then exported in dbase IV format to ArcGIS. The data are imported into the GIS as x, y locational data, based on the UTM easting and northing coordinates of each record. This results in a vector map of points representing the locations of each site (e.g., Figure 3.1). These maps are the primary displays of site distributions within the study area. A few sites in the database lie beyond study area boundaries and are excluded from current analyses.

Each site distribution map has an associated feature attribute table (FAT) that includes all the data from the file used to display the point locations. The final fields of these tables are the series of 14 modeling periods (MPs). Modeling periods are used to segregate sites based on the best estimate of their times of occupation, as explained by Ortman et al. (2006).

For each record in the FAT, the value in each of the 14 modeling period fields represents the number of households estimated to have occupied that site during that modeling period. These estimates are also the result of a series of Bayesian statistical analyses performed on the data (Ortman et al. 2006). Within the GIS, segregation of sites by MP is accomplished by selecting all records (from the FAT) with values greater than or equal to one for each of the modeling periods. For MP 6, for instance, I selected all records from the associated FAT with a value >= 1. These records and the associated points are copied to a new map layer that then shows the distribution of all sites occupied during the 125 years included in MP 6. This operation was completed for all of the modeling periods to produce a site distribution map for each, as presented with the relevant discussions below.

The 14 vector maps produced in this way display site distributions within each of the modeling periods, but require further processing for producing model input data. Using the ArcGIS function for point statistics (sum), I processed each of the 14 maps such that every point has the value of the number of estimated households at each site within each of the 4-ha model cells. Those sites not located within the same model cell as another simply retain the value (number of households) recorded for that site in that MP. Some sites, however, are located close enough to others occupied during the same MP, and for the purpose of model input, the number of households in all adjacent sites (within each of the 4-ha cells) are summed using the point statistics function. Once this was completed, the vector files were converted to raster maps and exported to text files using the ArcToolBox “Raster to ASCII” function. The resulting text files were then stripped of their header information to become 200 row by 227 column matrices (two dimensional arrays) ready to be read by the Village model. This simulation model is implemented using the Swarm libraries (version 2.2) originally developed at the Santa Fe Institute

The model display normally shows some landscape attribute such as elevation, water (or both), or the productivity of any of the resources we model (maize, fuels, deer, hare or rabbits) as the background for the model world. In addition to whichever background attribute is selected, the running model display shows agent-occupied model cells, color-coded by numbers of households within them. Three household-number classes are currently distinguished; red represents 1-2 households (hamlets), yellow represents 3-8 households (large hamlets), and larger, white colored symbols represent model cells occupied by 9 or more households (community centers).

Another “ObserverSwarm” function allows the concurrent display of actual archaeological site locations for the current modeling period (MP). This function facilitates runtime comparison of simulated versus observed household locations throughout the model run. During simulation, the cumulative locations of simulated household years are output to 2-dimensional arrays at the end of each MP. Goodness-of-fit statistics are calculated between the locations of simulated households and those of observed households for each MP. This allows us to determine which parameter values generate a settlement system most closely coinciding with that known from the archaeological record.

In the discussion that follows, Village Project modeling periods are grouped within the more familiar Pecos classification (Kidder 1927) of the regional prehistoric cultural chronology. Household settlement patterns, architectural features, and ceramic design styles (indicating periods of occupations) are presented for sites of each MP. This discussion puts the observed archaeological households into the spatial and temporal contexts within which the simulated households are later analyzed.

Study Area Archaeological Data

The primary source of prehistoric cultural data for this study is the archaeological record of the Mesa Verde region. The bulk of the archaeological record of this region pertains to the prehispanic Puebloan (historically referred to as Anasazi by the subsequent Navajo inhabitants of the region, as well as most archaeologists) settlement, most of which date between A.D. 600 and 1300. The McElmo-Yellow Jacket settlement model (v. 5.4, Crow Canyon Archaeological Center and Washington State University Department of Anthropology 2004) used in this study comprises 4477 records of post-A.D. 599 Anasazi sites within the study area. These records provide the locations, sizes, functions, periods of occupation, and many other types of data about these prehistoric properties. The site attributes listed here are those that the Village Project attempts to simulate as precisely as possible.

Prehistoric Puebloan settlement within the study area shows a recurrent temporal pattern of movement from widely dispersed farmsteads and/or small hamlets to aggregation in much larger clustered communities commonly focused on a community center (Varien 1999a; Varien et al. 2006). Community centers with some dispersed hamlets are most common in periods of high population, which, in this area, are mid- to late Pueblo I (ca. A.D. 840 to 880), and late Pueblo II – P III (ca. A.D. 1100 to 1280).

Households are assumed to consist of nuclear families. These are delineated in the archaeological record by the occurrence of either a kiva depression or 50 m^2 of roomblock rubble present on the modern ground surface. The McElmo-Yellow Jacket settlement database includes data on numbers of households at each habitation site that we believe was occupied within each MP. Another field in the database provides estimates of peak population (number of concurrently occupied households) at each site. In the discussion that follows, the numbers of households depicted on the maps and presented in the text refer to those listed in the database for each MP (Table 3.1).

Populations moved from dispersed to aggregated settlement cycle stances twice during the prehispanic Puebloan occupation of the study area (Lipe, Varien, and Wilshusen 1999; Varien et al. 2006). Dispersed farms began to appear regularly in the sixth century A.D. (Lipe 1999c), and grow increasingly clustered until the turn of the tenth century when the population of the greater Mesa Verde region appears to have decreased sharply (Wilshusen 1999b). Regional occupation remained low for a generation or two, after which the number of dispersed farms began to increase. By the middle of the twelfth century community centers were prominent features on the landscape and dominated the settlement pattern until the late thirteenth-century depopulation (Varien 1999a; Varien et al. 2000; Varien et al. 2006). By the latter half of the thirteenth century, population once again began to decline (Wilshusen 2002), and by the close of the century there is no evidence for permanent Puebloan occupation of the region (Kohler 2000; Lipe 1995).

Population increases in the upper Little Colorado River basin in northeastern Arizona and the upper Rio Grande basin in northeastern New Mexico, along with the occurrence of artifact design elements similar to those of the Mesa Verde region, suggest at least some of the 13th century population from the study area migrated to these distant locales. The reasons for the migration from the Mesa Verde region have been a major research interest of Southwestern archaeologists for many decades (Ahlstrom et al.1995; Cameron 1995; Cordell 1984, 1995, 1997; Lipe 1995, 1999a).

Prior to the abandonment of the Northern San Juan region, the long-term Puebloan occupation is marked by slowly changing patterns of habitation site distributions, architectural characteristics, ceramic styles, and, to a lesser extent, subsistence strategies. Many of these long-term changes are likely the result, at least in part, of adjustments by households to variations in the availability of critical natural resources. The present study is designed to shed light on which of these changes in household characteristics were most likely caused by the interactions of prehispanic Puebloans and their natural environments. Recorded differences in prehistoric household material remains are presented for each of the Village Project modeling periods, to provide a basis for comparison with patterns exhibited by simulated households under various model parameter combinations. Of primary interest here are household distributions, settlement sizes, and aggregation. The archaeological record indicates corporate groups varied their settlement strategies over the generations, shifting from primarily small hamlets, to larger hamlets, then to large clusters of residences. This appears to have occurred in two major cycles, both terminating in regional abandonment. The settlement strategies of simulated households are discussed as results of model runs in the concluding chapters of this work.

Characteristics of Prehispanic Puebloan Households

In comparison with those of many other times and places, the changes in material remains, and likely social organization as well, over the seven centuries of prehispanic Puebloan occupation in the study area are not very striking. Once the regional population adopted a relatively settled agrarian lifestyle, many aspects of daily behavior appear to have been long lived. The changes that are apparent are often subtle; decades of archaeological research provide some insight into various aspects of these changes. The following discussion presents selected evidence important to the present research. Topics of major interest are those that provide bases for inferences about natural resource use at specific places and times in the past. These include observations that support chronological and spatial indicators of site occupation, occupation spans, settlement distributions and sizes.

Although utilitarian gray ware vessels are common throughout the Puebloan occupation of the study area, numerous variations on white ware clay-temper combinations, paint types, and interior and exterior designs allow distinctions to be made between ceramics characteristic of the modeling periods (Ortman et al. 2005). Variations in both ceramic and architectural attributes have been correlated with those of sites dated by multiple tree-ring specimens collected from cultural contexts. Despite frequent overlap in temporal assignments of many of these cultural traits, Scott Ortman's statistical model allows combinations of these to be correlated with Village Project MPs (Ortman et al. 2006).

The resulting database contains a record for each habitation site recorded within the study area, including data on modeling period(s) to which each site is assigned, as well as the number of households occupied during each of those time periods (Table 3.1 and Figure 3.2a). Sites with one or two households are termed hamlets, sites with three through eight households are considered large hamlets, and sites with more than eight households are designated as community centers. Community centers are frequently associated with some form of public architecture (Lipe and Ortman 2000), and are often surrounded by numerous smaller contemporary habitation sites.

To facilitate comparison of prehistoric household settlement strategies with those of Village Project simulated households, I have analyzed household clustering by dividing the number of households in community centers by the total number of households for each modeling period. The proportions of households in community centers are presented as indices of aggregation in Figure 3.2b for both total households and momentized households based on Varien et al. (2006:Table 3). The index shows the changes in household settlement aggregation across modeling periods, as calculated from the McElmo-Yellow Jacket settlement model. The higher the aggregation index, the more households are clustering together.

Household aggregation evidenced by the archaeological record can be postulated to have resulted from a number of social and/or economic factors, such as corporate unit cooperation, community organization for economic or security purposes, or ideological purposes. Gradual changes in household aggregation can be seen in the maps of site distributions, below, which are all based on data derived from the McElmo-Yellow Jacket (v 5.4) settlement model (CCAC and WSU 2004), discussed above.

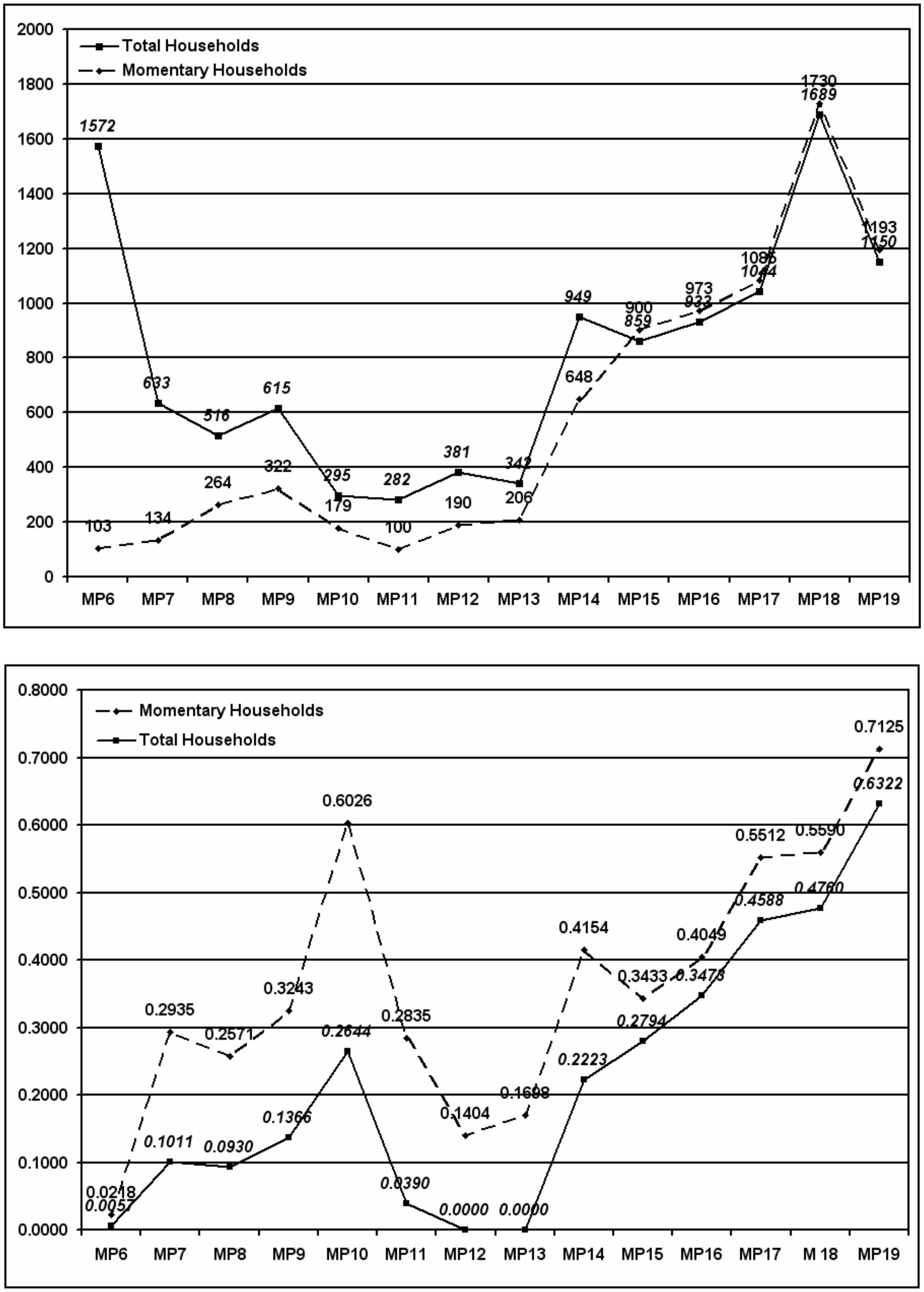

Figure 3.2. a) Numbers of households modeled from all habitation sites (top) and b) Plot of prehistoric household aggregation indices (bottom) for Village Project modeling periods. Total household figures based on the McElmo-Yellow Jacket v. 5.4 settlement model, momentary household figures from Varien et al. 2006:Table 3.

Basketmaker III Period Sites

The Basketmaker III period dates from A.D. 500 to 750 and is well represented within the study area by numerous, presumably single-family, hamlets. Several large hamlets representing the dwellings of multiple households (assumed to have been inhabited by several nuclear families) are evident in the archaeological record as well. In addition to these are a small number of larger concentrations of household structures considered community centers (Varien 1999a). Although the Pecos classification of Basketmaker III covers 250 years, the finer resolution chronological scheme used by the Village Project divides it into two MPs, the second of which extends into the subsequent Pueblo I period. The majority of Basketmaker III period habitation structures date to between A.D. 590 and 720 (Wilshusen 1999a), and thus fall primarily within the first of our modeling periods.

The McElmo-Yellow Jacket settlement model v.5.4 (CCAC and WSU 2004) begins with the Village Project's MP 6, the longest of the periods recognized, lasting from A.D. 600 to 725. Given this 125-year length and the relatively short occupation span of most structures (see column 5 of Table 3.1), it is not surprising that the period represents the largest number of habitation sites of the 14 MPs. This does not imply a larger total momentary population in the study area during this time period (see Figure 3.2b; Kohler et al. 2006; Varien et al. 2006). Momentary population represents what is believed to be the average number of households in the study area at any time within a modeling period. This figure is calculated by applying a scalar (household use-life divided by modeling period length) to the total number of households at each site for each modeling period. Figure 3.2a, for example, shows the relationship between total and momentary households recorded for each MP. The value of the scalar applied to known total household figures varies depending on site size (hamlet vs. community center) and MP (Varien et al. 2006:Table 3, columns 6 and 7).

There are 1470 habitation sites recorded in the study area during MP 6 (Table 3.1). Although hamlets are undoubtedly the norm during the early sedentary occupation of the region (Wilshusen 1999a), there are 18 large hamlets currently recognized in the study area and there is one community center dating to this modeling period.

The recognition of only one community center during this long period probably stems from at least two facts. The first is that many of these early sites are relatively ephemeral in the archaeological record. Compared to the later masonry sites, even large early sites, consisting primarily of pitstructures and small jacal surface structures, are generally not well preserved. Pitstructures of this early period were relatively shallow, have had many more years to accumulate sediments, and are therefore less visible on the modern ground surface. Jacal structures are much less resistant to weathering than later masonry structures and so are more difficult to recognize. Thus identification of early period sites on the landscape is much less likely.

Adding to the difficulty of finding sites of the Basketmaker occupation of the Mesa Verde region is the fact that early sites were commonly located on good arable land, locations that were subsequently settled by people building larger, more durable, longer-occupied structures, who also deposited more artifacts locally. Many of these same areas have historically been prime agricultural fields as well, and the remains of most sites on historic fields have been severely disturbed, if not obliterated (Connolly 1992). Furthermore, later pottery types frequently used ground sherd-based tempers, so early ceramic artifacts were likely recycled to make later vessels. These and numerous other factors, including the historic attraction to archaeologists of larger sites of later periods, may contribute to lower numbers of sites recognized during this long initial modeling period.

As shown on the map for sites of this MP, households are widely dispersed, and most commonly are located on mesa tops where the most fertile agricultural soils typically occur. Comparison of the maps for all 14 MPs shows this pattern to be common throughout the prehispanic Puebloan occupation of the study area. This is expected since MP 6 exhibits the highest number of habitations, and the fact that sites were often occupied in multiple modeling periods.

Habitation sites of this MP, and the entire Basketmaker III period, are generally represented by a few pit structure depressions and the remains of small surface structures believed to have been storage facilities for agricultural produce. “Pit structures were the primary domestic structures with associated outside features such as storage cists, small domed storage structures, and hearths” (Wilshusen 1999a:174). These domestic structures were excavated about 1 m into the ground, and generally consisted of a main chamber connected by a short passageway to a smaller chamber, situated to the south. “In the Dolores area, between A.D. 600 and A.D. 700, pithouses were shallow and D-shaped, with benches, antechambers, above floor bins, slab wingwalls, and small hearths” (Glennie 1983:25). Pit structures of this early period measure approximately 5 to 6 m in diameter, with attached antechambers measuring closer to 3 m, and outlying structures somewhat smaller still at about 1.5 to 2 m across (see Wilshusen 1999a for discussion of Basketmaker III pitstructures in particular).

Early ceramics are primarily represented by gray ware (Chapin Gray) utility vessels, which is by far the most common ceramic type and "comprise[s] about 90 percent of total Basketmaker III site ceramic assemblages" (Wilshusen 1999a:173). Although the earliest ceramics in the region are brown wares made from alluvial clays (Eddy 1966; Wilson and Blinman 1993), gray wares are most common throughout the prehistoric Puebloan occupation of the study area.

In addition to gray ware, white ware pottery is also present within the study area in this early modeling period. Most of the white ware is Chapin Black-on-White, which is similar to Chapin Gray in construction, but exhibits exterior polishing and is painted with a dark, mineral-based paint on up to 40 percent of the exterior surface (Wilshusen 1999a).

The subsequent (MP 7) period is the second longest of our modeling periods, spanning 75 years from A.D. 725 to 800. Despite exhibiting many fewer total sites than the previous modeling period, it had a slightly higher momentary population and significantly more community centers. Five hundred and thirty-four habitation sites are recorded in the McElmo-Yellow Jacket (v. 5.4 CCAC and WSU 2004) settlement model database, of which 522 are hamlets, nine are large hamlets, and three are community center-sized villages. The largest of these is estimated to comprise 32 (total) households, compared to a total of just nine households for the largest site of the previous modeling period.

Architecture during this MP differs from that of the previous MP in that "between A.D. 700 and 760, pithouses are smaller, deeper, and subrectangular, with large vent shafts, earthen wingwalls, and small hearths, and lack benches and bins" (Glennie 1983:25). Associated surface structures become more substantial in the later years of this modeling period, and are generally constructed in contiguous blocks of rooms as opposed to isolated structures. It is this last architectural feature that inspires the “Pueblo” name, of Spanish origin, applied to native communities encountered during the Spanish Entrada into the Greater Southwest. These are described in more detail in the following section.

Ceramic assemblages of the second of our modeling periods continue to be dominated by both Chapin Gray and Chapin Black-on-White, but this period shows small proportions of Moccasin Gray and Piedra Black-on-White, as well as the introduction of some red wares such as Abajo Red-on-Orange and Bluff Black-on-Red (Ortman et al. 2006). Red ware ceramics typically originate well to the west and/or southwest of the study area, in southeastern Utah, and, less commonly, in northeastern Arizona. The relatively limited variation in ceramic type frequencies during these first two modeling periods suggests little differentiation of cultural affiliation, with low levels of trade of red wares from the west, and, perhaps, small but open social networks. Alternately, potters from the west may have begun to migrate into the study area in small numbers, adopting the gray and white wares more often recovered in the study area.

Although there are fewer than half as many sites recognized during this second MP as in the first, MP 7 settlement locations do not appear to differ. Habitations are consistently located in relatively level mesa-top settings. The large hamlets of this period are fairly evenly distributed among the more common small hamlets. Overall, settlement in the Basketmaker III period is consistently dispersed, as indicated by a low aggregation index (Figure 3.2b). Even though sites on the map for MP 6 may look clustered, it must be remembered that early hamlets were short lived and MP 6 spans 125 years.

Close inspection of Figures 3.3 and 3.4 highlights an important point. Most sites on these two maps are within the darker shaded areas that signify survey blocks (as are most sites in the study area, see Figure 3.1). These surveys are relatively recent, and represent the largest, most intensively investigated areas. Several linear alignments of sites often correspond to linear transect surveys not shown on the maps. Many of these are associated with either irrigation canals or mineral resource extraction facilities such as pipelines. The point is that although the locations of most of the large habitation sites within the study area are known, there is a near certainty that many smaller sites, particularly from these earlier modeling periods, have yet to be recorded.

The maps of site distributions on the following pages provide more detail than does Figure 3.1. The map of all known Puebloan sites (Figure 3.1) marks the location of each with a solid black dot. The remaining maps presented in this chapter show distributions of sites and their size classes (hamlets, large hamlets, or community centers) based on total numbers of households recorded for each (CCAC/WSU 2004).

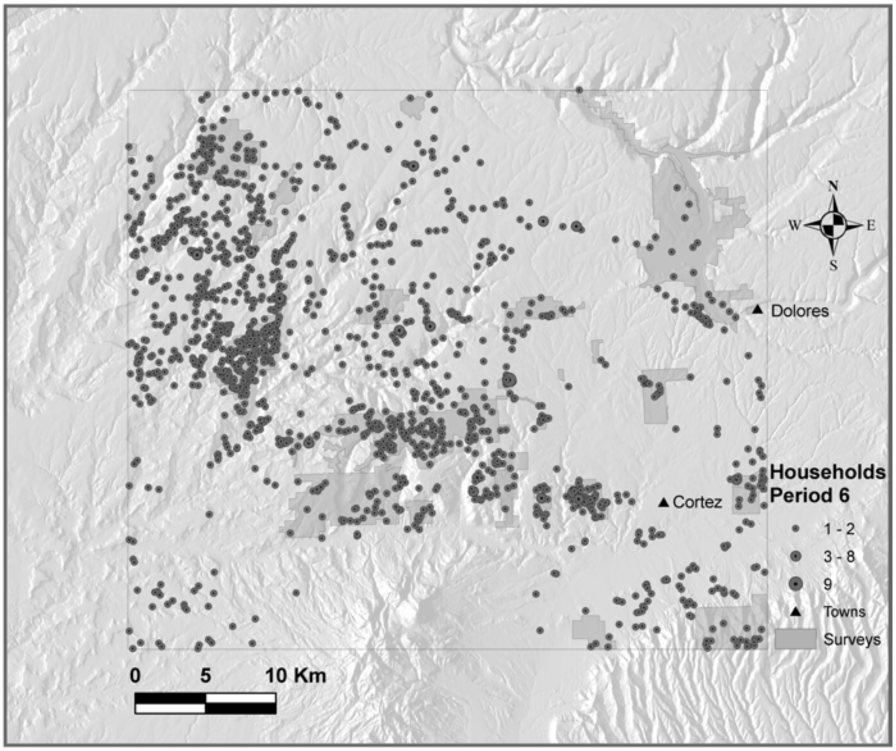

Figure 3.3. Distribution of known MP 6 (A.D. 600 – 725) habitation sites.

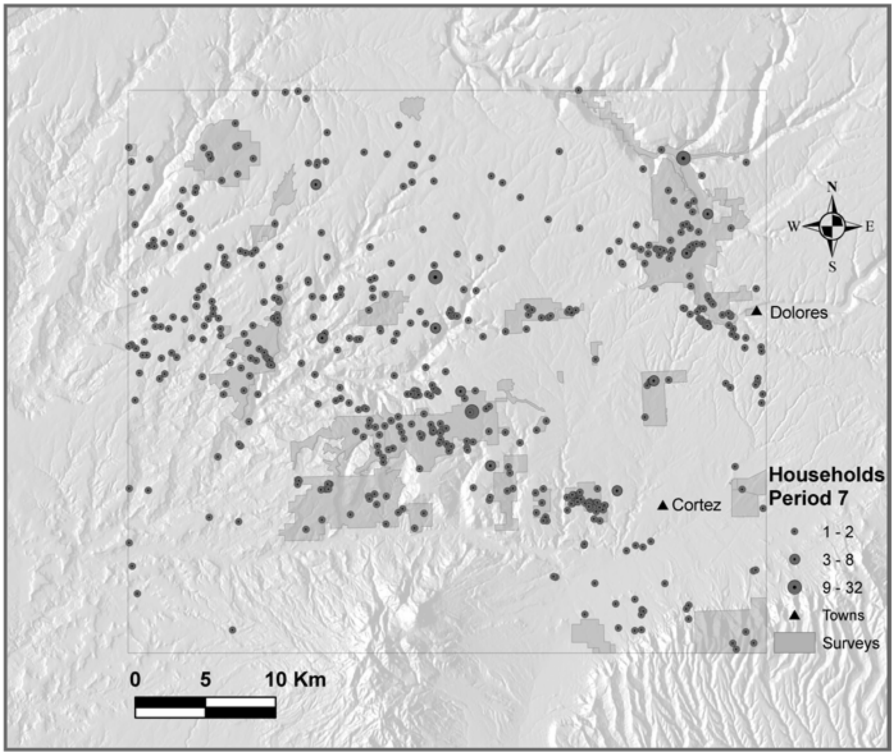

Figure 3.4. Distribution of known MP 7 (A.D. 725 – 800) habitation sites.

Pueblo I Period Sites

The Pueblo I period of the Pecos classification (Kidder 1927) traditionally spans the years from A.D. 700 to 900. The Village Project uses the local chronology for the Pueblo I period of A.D. 750 to 900 (Wilshusen 1999b) so the period comprises the latter two thirds of MP 7, MPs 8 and 9, as well as the first half of MP 10. Comparison of the settlement distributions for these modeling periods shows that households become increasingly clustered on the study area landscape, although the number of households (Figure 3.2a) declines significantly by the end of the Pueblo I period (Ortman et al. 2006; Wilshusen 1999; Wilshusen and Ortman 1999). During these four modeling periods the settlement system exhibits the first of the two cycles of aggregation, with a decline in regional occupation occurring between MPs 9 and 10. The largest sites range in size from 32 total households in MP 7 to 47 total households in MP 10. The total number of households, however, decreases from 633 in MP 7 to 295 in MP 10. This could be due in part to the shorter site occupation span (13 years) of MP 7, but there is a significant decrease in numbers of total households from MP 8 through MPs 9 and 10, all of which span 40 years and are modeled as having site occupation lengths of 18 years.

The Pueblo I period is marked not only by the formation of large villages in the study area, but also by changes in both architecture and ceramics. Glennie describes changes in Dolores-area pitstructure characteristics occurring during the PI period as follows:

> From A.D. 760 to 840, pithouses were generally larger, square, with benches, slab wingwalls, ashpits, larger hearths, and smaller vent shafts. In the A.D. 840-880 period, pithouses are large, deep, and square, with

> complex or coursed masonry wingwalls, ashpits, large hearths, and small vent shafts, and lack benches and bins. The latest pithouses, dated about A.D. 880-900, are small, moderately deep, and round or square, with a small vent shaft, and usually lack wingwalls, ashpits, and benches [1983:25].

This description generally applies to pit structures constructed within each of the four Village Project MPs distinguished for the Pueblo I period, and agrees with that of other study area pithouses. Those excavated at the Duckfoot site (Lightfoot 1994; Lightfoot and Etzkorn 1993), for example, are located in an upland setting of the Monument-McElmo drainage (Lipe, Varien, and Wilshusen 1999) and show the same squared layout as those described above for the Dolores pithouses of MP 9.

Throughout the PI period, pithouses become increasingly subterranean such that "pit structure roofs at A.D. 750 would have been 50 cm to 75 cm above the ground surface, whereas pit structure roofs at A.D. 850 would have been almost level with the ground surface" (Wilshusen 1999b:201). This change in construction technique may well have been in response to dwindling supplies of woody biomass documented by Kohler and Matthews (1988), since the more exposed surface areas of earlier pithouses would have required both greater amounts of fire wood for heating, as well as more wood in their construction.

Surface architecture at Pueblo I period sites becomes increasingly substantial, shifting from primarily jacal structures to increasing use of masonry construction by the mid-ninth century (Wilshusen 1999b). Lightfoot suggests that "the need for sturdy, rodent-resistant, stable-temperature storage facilities might have resulted in an emphasis on storage rooms built to last" (1994:19). In general, the size of pueblos also increases, from one to two rows of rooms within typical roomblocks. Each of these changes is likely the result of increasing production and storage of, and reliance upon, agricultural crops throughout the period. Increases in population throughout the first half of the PI period (Varien et al. 2006), combined with more intensive farming, may have begun to stress the resource base, leading to tighter social controls on resource access.

Changes in resource procurement, use, and control strategies might be evidenced in a variety of ways. A primary indicator of increased effort to secure basic resources is the development of resource, or land, ownership, whether by aggrandizing individuals or corporate groups (Adler 1990, 2002; Johnson and Earle 2000). Kohler (1992a) argues that indications of the adoption of distinctive land tenure systems are evidenced by the increasing use of field houses late in the PI period. Study area populations began to place visible, durable claims on lands their lineages had used in the past, even though those lands were not necessarily in full-time production on a permanent basis. Field houses are thus seen as markers of land ownership, reserving fallowed fields for future use.

Another potential indicator of increasing social control over particular resource areas is the greater degree of household aggregation exhibited by the archaeological record during the Pueblo I period. As corporate groups tighten their collective grips on resource patches, it can be beneficial to cooperate with other such groups in protecting resource access rights (Adler 1990, 1996). This can lead to cooperative groups coalescing around preferred resource areas, increasing the ratio of clustered households to dispersed households. Comparison of Figures 3.2a and 3.2b shows that although the number of households decreases significantly between MPs 9 and 10, the degree of aggregation increases substantially, declining only after MP 10 as household population levels off well below previous numbers. One of the aims of the present research is to investigate possible relationships between household aggregation and resource consumption and depletion over the centuries of this study.

Ceramic types from the Pueblo I period change slightly from those of the previous Basketmaker III period. Ortman's statistical model of ceramic distribution probabilities (Ortman et al. 2006) places the introduction of Mancos Gray and Cortez Black-on-white in MP 8, indicates significant increases in probabilities of occurrence of Moccasin Gray, Piedra Black-on-white, Abajo Red-on-orange, and Bluff Red-on-black, and documenting a doubling of the proportion of unidentified San Juan red wares. The probabilities of Chapin Gray and Chapin Black-on-white decrease substantially, with the probability of Early White ware declining as well (Ortman et al. 2006:Table 4). The increases in ceramic types originating to the west in southeast Utah suggest either migration of, or increased trade with, people from the west. Wilshusen and Ortman (1999) argue that by Pueblo I times, the Dolores River valley was home to groups of different ethnic origin, including those from the west who commonly made and used red wares.

Settlement distributions of households in the four modeling periods delineated for the PI period remain somewhat well distributed across the landscape, but do show increased clustering in the later years of the period. Comparison of Figures 3.4 through 3.7 shows a marked decrease in total number of sites between MPs 7 and 8, a slight increase in number of sites in MP 9, and a large decrease in site numbers (and decrease in momentary population) in MP 10, coinciding with the plot shown in Figure 3.2a.

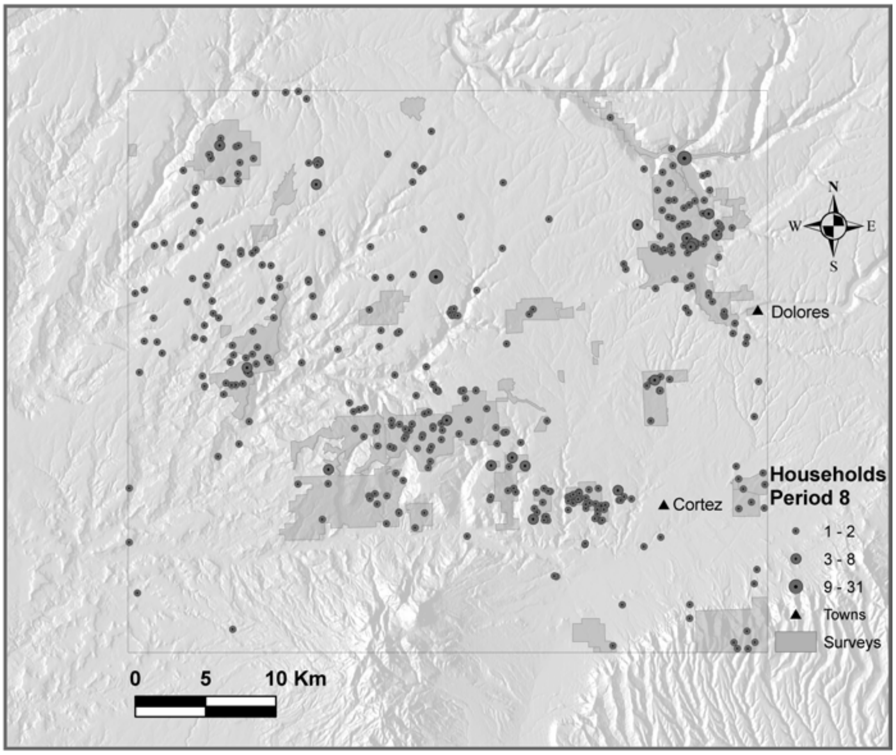

Figure 3.5. Distribution of known MP 8 (A.D. 800 – 840) habitation sites.

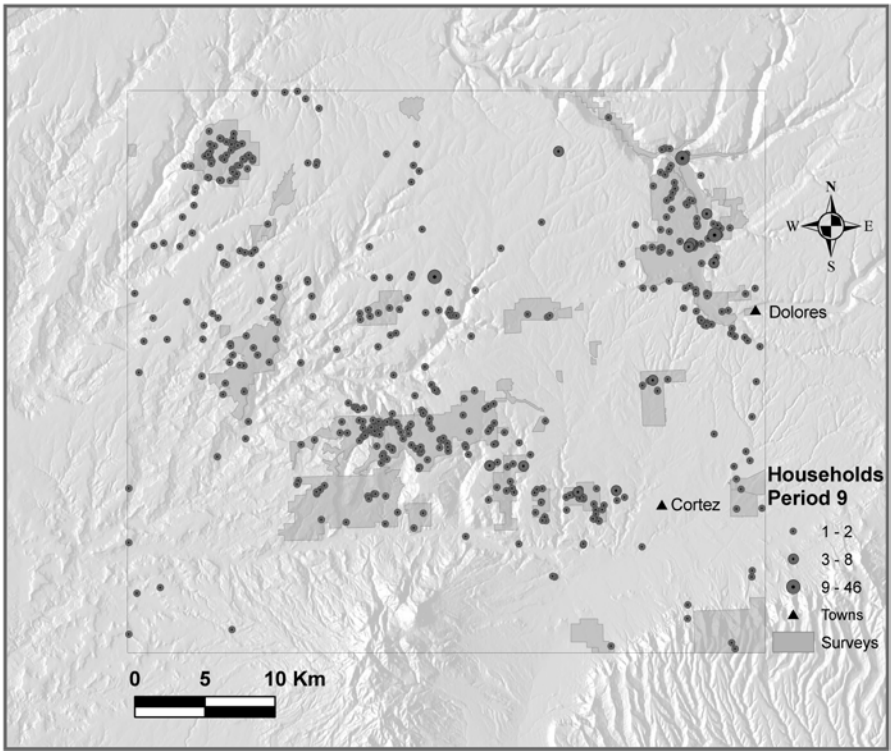

Figure 3.6. Distribution of known MP 9 (A.D. 840 – 880) habitation sites.

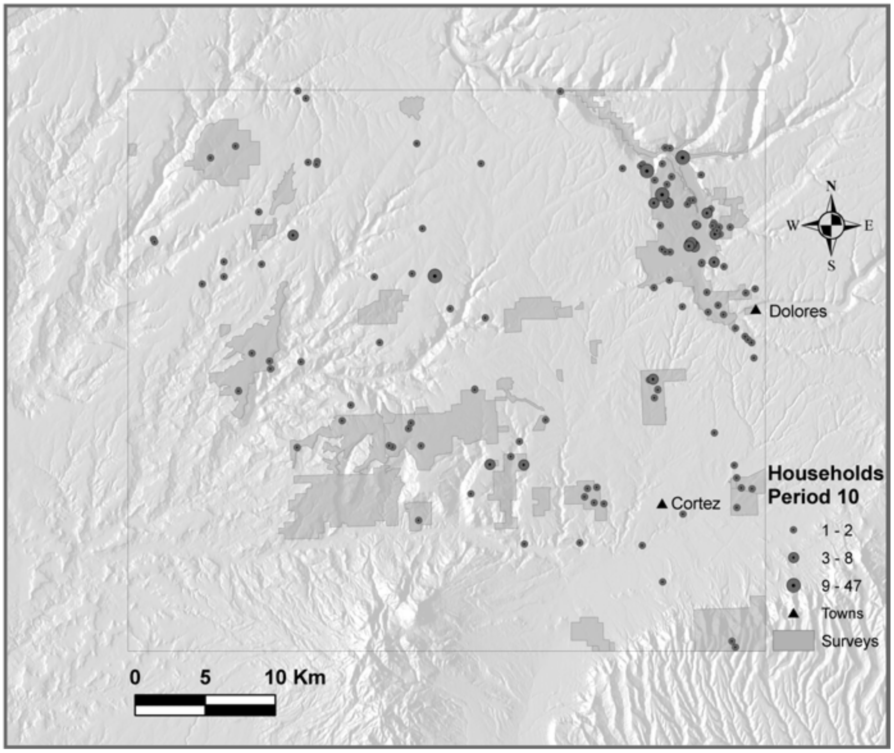

Figure 3.7. Distribution of known MP 10 (A.D. 880 – 920) habitation sites.

At the same time, the increased aggregation of households from MP 8 through MP 10 is most apparent on Figure 3.7, as one would expect given the strong upward trend in aggregation index plotted in Figure 3.2b.

Modeled site occupation span increases from 13 years in MP 7 to 18 years for MPs 8, 9, and 10 (Varien et al. 2006). This may account to some extent for the 71 percent decrease in total number of habitation sites from early to late PI times, but is taken into account in the decrease in the number of momentary households within the study area during the Pueblo I period. In fact, comparing the declines of total households to momentary households during the late P I period (see Figure 3.2a) shows that the former decrease in number by 53 percent, while the latter decrease by only 47 percent. Some of the decline in household numbers may be the result of deteriorating climatic conditions (Varien et al. 2006) hindering crop production. It may also be that critical natural resources became depleted to the point that families opted to move to places that were less heavily exploited, or into communities insuring access to the best resource patches. Throughout the Pueblo I period, household settlement shifted from mainly dispersed, meaning non-aggregated, to the most aggregated level since farmers initially settled the study area in dispersed hamlets. As will be seen in the following section, households soon dispersed once more, for several generations.

Pueblo II Period Sites

The original Pecos classification (Kidder 1927) of the Pueblo II period for the Greater Southwest has it spanning the years from A.D. 900 to A.D. 1100. Within the Mesa Verde region current practice terminates the Pueblo II period at A.D. 1150 (Lipe and Varien 1999a). Extension of the P II period to A.D. 1150 "has the advantage of falling after construction of classic Chaco-style great houses had ceased, and during a time when population in the study area may have been relatively low" (Lipe and Varien 1999a:242). In the Village Project context, the Pueblo II period comprises the last half of MP 10, MPs 11 through 15, as well as the first decade of MP 16. The modeling periods within the Pueblo II period include the end of the first cycle of aggregation, an intervening period, and the beginning of the second cycle of aggregation. The decades between the two cycles are a time when study area population is low (Figure 3.2a), and households are disaggregated (Figure 3.2b) and spread widely across the study area.

The typical habitation site in the early Pueblo II period houses a single household in a small compound known as a unit-type pueblo (Prudden 1903) comprising a pithouse or kiva, one or more surface rooms, and a midden area. Additional structures and/or features are also commonly associated with these small sites, often including "another small pit structure used as a grinding or mealing room…extramural pits, small pit rooms, ramadas, and/or an enclosing stockade" (Lipe and Varien 1999a:244).

Kivas are generally round in plan and have ventilator shafts as opposed to the antechambers common in Pueblo I period pit houses. Although masonry construction was frequently used during the earlier period, unlined pit structures continued to be used in the P II period as well, though masonry construction becomes ever more common in the latter part of this period. "Kiva architecture generally shows a trend 1) from unlined to masonry lined; 2) from four posts set in the wall or bench to four masonry pilasters set on the bench to six masonry pilasters set on the bench; and 3) from no southern recess to a short rounded southern recess to a deep, well-defined keyhole-type southern recess" (Lipe and Varien 1999a:262).

Hamlet roomblocks are usually composed of two rows of rooms, constructed of single-coursed masonry, one to two stories high. Masonry towers make their appearance in the Pueblo II period, often attached to the ends of roomblocks and occasionally attached via a tunnel to a kiva, such as at Herren Farm Pueblo (Martin 1929), or to other subsurface or surface rooms (Lipe and Ortman 2000).

The association of this full suite of features at many small sites suggests households were self-sufficient. Close comparison of Figures 3.6 and 3.7 shows that many, if not most, small sites in the later MP 10 are located very near small sites of the preceding period. Relatively low site density and population, in conjunction with the fact that many early P II sites are very near those of Late P I sites, suggests that access to construction materials was not a problem in site location. That is both smaller construction elements and fuel wood supplies had likely been replenished. Therefore, it appears that settlement locations, at least those of hamlets, were not necessarily in response to depletion of critical natural resources.

Village, or community center, architecture in Pueblo II period contexts is much more substantial than that of hamlets. At community centers, the largest building was frequently constructed in the Chaco-style great house tradition. These sites are interpreted as having served "as central places in an otherwise dispersed late Pueblo II community" (Lipe and Varien 1999a:272). Double-coursed masonry first occurs in great house construction in the study area at the turn of the twelfth century (Lipe and Varien 1999a). Other community-level architecture is also constructed with increasing frequency throughout the P II period, including great kivas and roadways.

Ceramic styles become much more varied in the P II period. During MP 10 (A.D. 880-920) both Mancos corrugated gray wares and Mancos Black-on-white first appear. Dolores corrugated first appears in MP 12 (A.D. 980-1020) assemblages, and during MP 13 (A.D. 1020-1060) the Mesa Verde corrugated style is introduced. There is also an increase in the probability of Cortez Black-on-white, though the frequencies of both Chapin and Piedra black-on-white decrease to zero by MP 14 (Ortman, Varien and Gripp 2006:Table 4). With the exception of Deadman's Black-on-red, the frequencies of red wares occurring in assemblages from MP 10 and later decline substantially. By the end of the P II period red wares are very rare, and organic paint becomes prominent on white wares. Ceramic variation may indicate less region-wide social coherence, as corporate groups distinguish themselves in a competitive environment.

Study area population and settlement strategies also fluctuate substantially during the P II modeling periods. Although the total number of households decreases from 295 in MP 10 to 282 in MP 11, the number of habitation sites actually increases from 155 to 210 in MPs 10 and 11 respectively (Table 3.1), and their distribution becomes more dispersed (Figure 3.8). At the same time, the size of villages also decreases dramatically, from a largest community center of 47 households in MP 10, to one of only 11 households in MP 11, indicating a shift in settlement strategy.

During the tenth and early eleventh centuries households disperse from small numbers of aggregated villages to larger numbers of large and small hamlets. Most "residential sites each consisted of a small roomblock with a single pit structure or kiva; the average size for habitation sites is six rooms" (Varien 1999a:146). By MP 12, in fact, there are no known community centers recorded within the Village Project study area (see Figure 3.9), and none are known to have formed during the subsequent modeling period (Table 3.2). Moreover, while the total number of habitation sites increases from MP 11 to MP 12, that number then decreases in MP 13 (Figures 3.2a and 3.10).

Throughout the 250 years of the P II period, the numbers of both habitation sites and households recorded within the study area fluctuate early in the period, then begin to significantly increase. From MP 13 to MP 14 (A.D. 1060 – 1100), the number of study area momentary households increases from 206 to 648 (Figure 3.2a; compare Figures 3.10 and 3.11).

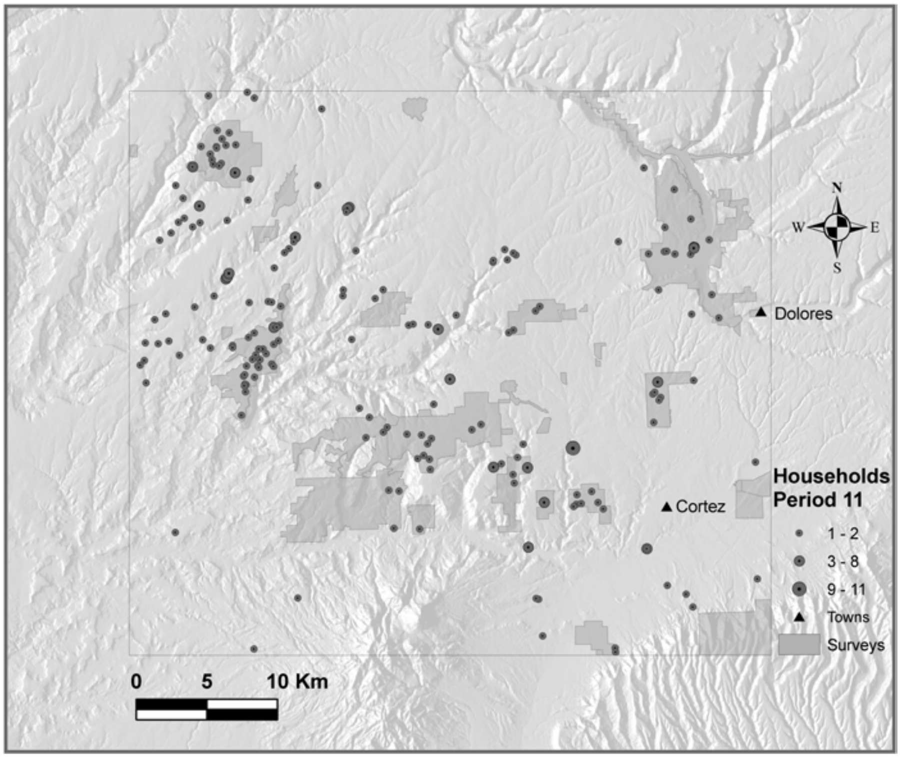

Figure 3.8. Distribution of known MP 11 (A.D. 920 – 980) habitation sites.

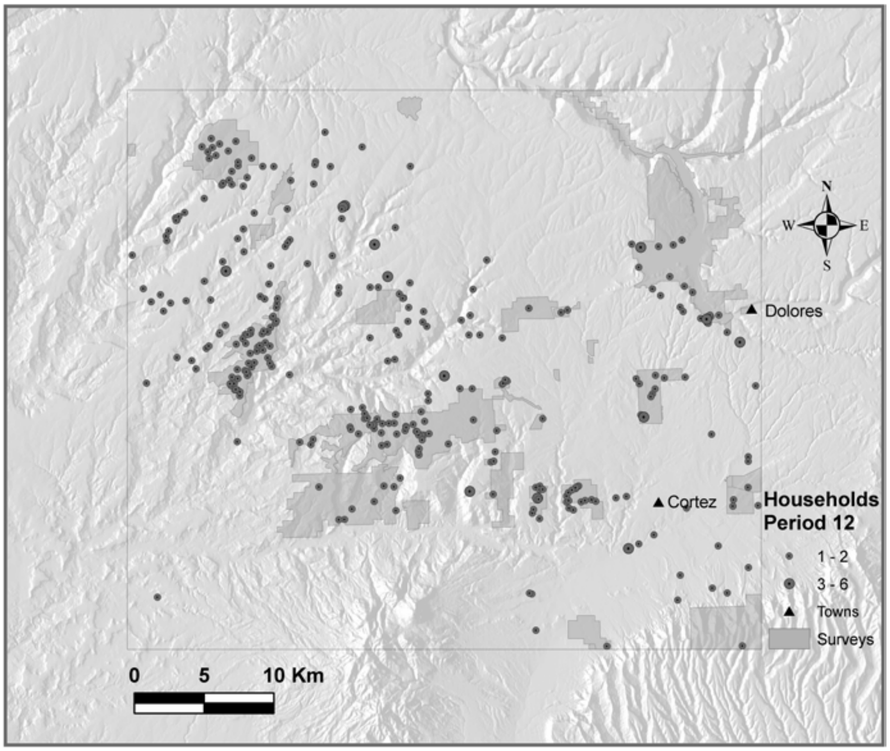

Figure 3.9. Distribution of known MP 12 (A.D. 980 – 1020) habitation sites.

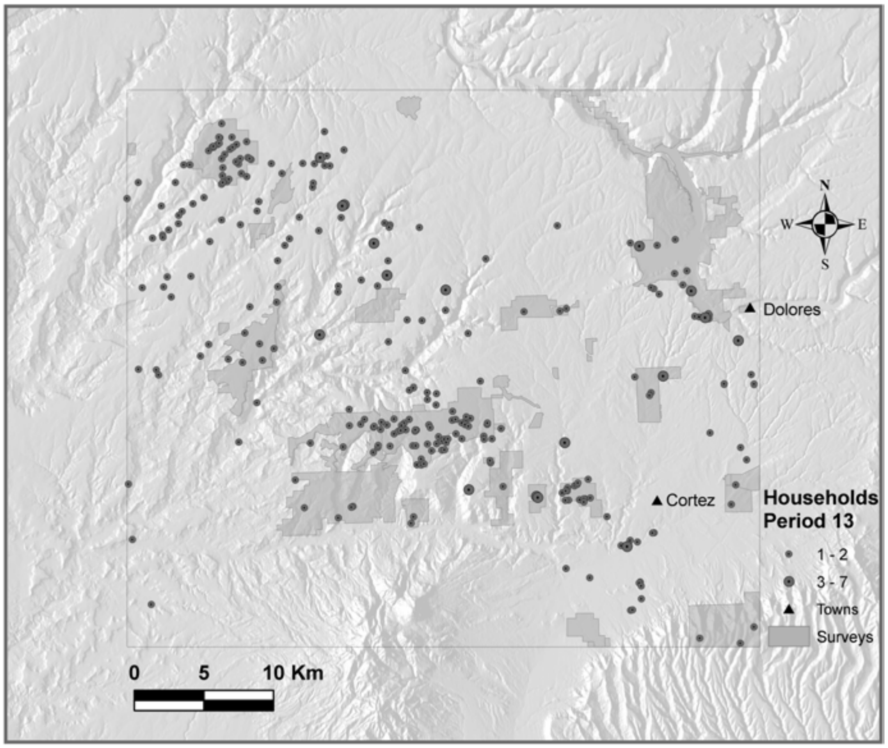

Figure 3.10. Distribution of known MP 13 (A.D. 1020 – 1060) habitation sites.

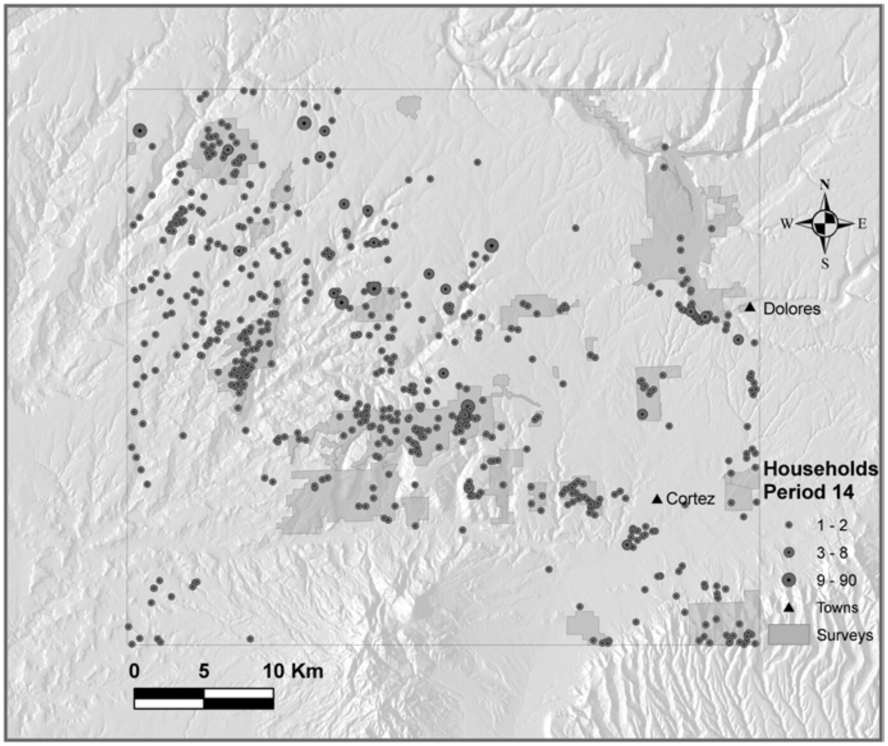

Figure 3.11. Distribution of known MP 14 (A.D. 1060 – 1100) habitation sites.

Community centers also reappear; six are established in MP 14 (up from zero in MPs 12 and 13), with an average of 35 households in each (Table 3.1), though the standard deviation is high.

Modeling period 15 (A.D. 1100 – 1140) shows a slight decrease in total number of study-area households, though the number of community centers remains at six and the average number of households per community center increases slightly to 40 (Figure 3.12; Table 3.2). By MP 16 (A.D. 1140 - 1180), there are slight decreases in the numbers of both hamlets and large hamlets (Figure 3.13), with a concurrent increase in the number of community centers, from 6 in MP 15 to 10 in MP 16. At the same time, the average number of households in community centers decreases from 40 to 32 (Table 3.2).

Overall, the archaeological record of the Pueblo II period indicates initiation of a second cycle of both population increase and community aggregation. During the first 150 years household numbers remain relatively low (Figure 3.2), households are dispersed across the landscape (Figures 3.7 – 3.9), and the aggregation index plummets. In the latter century of the P II period a significant increase in population and household aggregation occurs (Figures 3.2a and 3.2b); both the number of households and the aggregation index surpass the midpoint of values reached in the subsequent Pueblo III period. Across the entire P II period, the number of recorded habitation sites increases 260 percent and the total number of households increases 305 percent within the study area (Table 3.1:Columns 6 and 7). The highest number of different ceramic types is observed in contexts of this time period, which, combined with increasing population, suggests immigration from outside the study area (and potentially attendant segregation).

Table 3.2. Distribution of Total (non-momentized) Households by Habitation Site Type for all Modeling Periods.

Modeling Period	Hamlet Sites	Avg HHs Hamlets	SD	Large Hamlets	Avg HHs L-Hamlets	SD	Comm Centers	Avg HHs CCs	SD	Total HHs	Total CC HHs
6	1461	1.02	.14	18	3.94	1.43	1	9	0	1572	9
7	522	1.03	.16	9	3.67	.87	3	21.33	9.45	633	64
8	382	1.03	.18	18	4.06	1.51	2	24	9.90	516	48
9	458	1.03	.18	12	4.83	1.53	4	21	16.99	615	84
10	136	1.10	.31	15	4.47	1.81	4	19.50	18.38	295	78
11	189	1.04	.20	20	3.70	.98	1	11	0	282	11
12	315	1.06	.23	13	3.69	1.03	0	0	0	381	0
13	264	1.03	.16	17	4.18	1.29	0	0	0	342	0
14	645	1.03	.17	18	4.11	.96	6	35.17	27.66	949	211
15	519	1.03	.16	22	3.91	1.27	6	40.00	31.84	859	240
16	515	1.04	.20	19	3.84	1.01	10	32.40	31.55	933	324
17	412	1.08	.27	28	4.32	1.52	16	29.94	29.24	1044	479
18	635	1.07	.25	43	4.84	1.86	33	24.36	22.35	1689	804
19	268	1.09	.28	25	5.28	1.86	24	30.29	26.27	1150	727

Note: Data derived from the McElmo-Yellow Jacket settlement database (CCAC/WSU 2004).

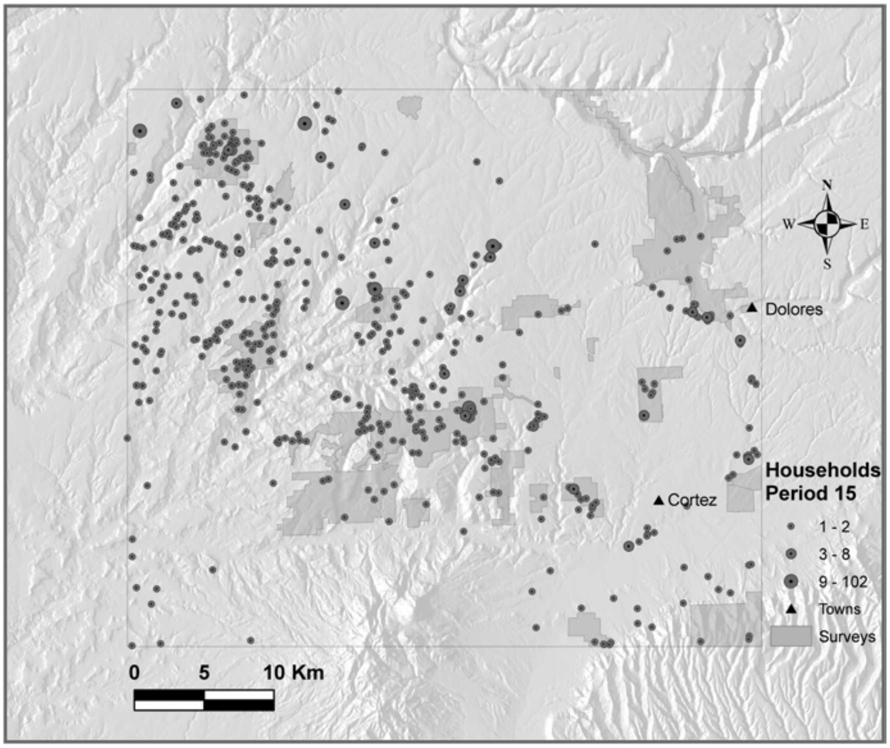

Figure 3.12. Distribution of known MP 15 (A.D. 1100 – 1140) habitation sites.

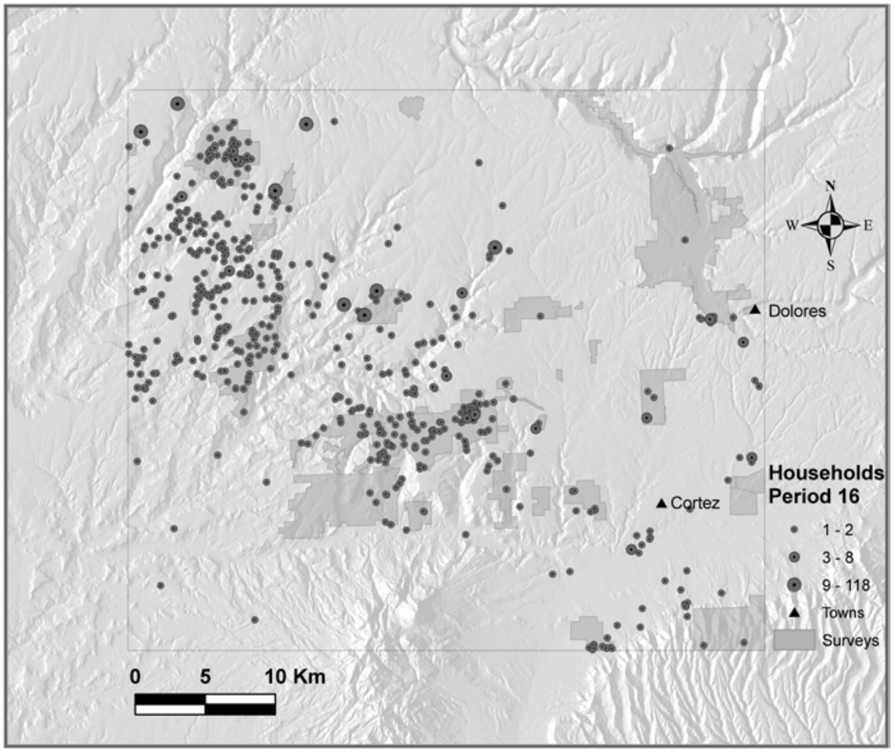

Figure 3.13. Distribution of known MP 16 (A.D. 1140 – 1180) habitation sites.

The increase in aggregation index in the second half of the P II period indicates communities were beginning to coalesce from the many previously dispersed households. A shift to the use of predominantly local sources of lithic raw material types for stone tool manufacture indicates a decrease in access to previously preferred, more distant, quarries, and may indicate less interaction between communities (Arakawa 2006).

It is possible that the increase in population began to severely depress the supplies of critical natural resources across much of the study area, particularly preferred resources like large game. I suggest that resource depression is a prime factor in the increased aggregation of households in their attempts to secure access to the best available locations for resource acquisition (Adler 1990, 1996), as well as to promote cooperative strategies of production concentration (Stone 1996), and possibly to enhance community security (LeBlanc 1999). Along with continued population growth, this trend in household aggregation intensifies in the following Pueblo III period.

Pueblo III Period Sites

The original Pecos classification of Kidder (1927) places the Pueblo III period for the Greater Southwest as lasting from A.D. 1100 to 1300. For present purposes, however, I'll continue to follow the more locally relevant chronology of Lipe and Varien (1999b) that has the P III period covering the years from A.D. 1150 to 1300. Within the Village Project chronology, this P III period comprises our modeling periods 16 (except for its first decade), 17, 18, and 19. All together these four MPs cover the 140 years from A.D. 1140 to 1280 (Table 3.1), ending in the decade in which permanent settlement of the prehispanic Puebloans in the northern San Juan region terminated (Lipe 1995).

Household settlement during the P III period becomes increasingly aggregated, with more community centers established than at any previous time in the study area (Table 3.2:Column 8). Community center villages become more numerous (Varien 1999a), and appear to have been occupied for much longer as well (Varien et al. 2006). Nonetheless, hamlets remain the dominant form of settlement, and "the archaeological signature of the residence of a household is…the 'Prudden Unit' consisting of a kiva and a small number of directly associated surface rooms" (Lipe and Varien 1999b:291). These residential units are, however, increasingly clustered. Large hamlets increase in number from 19 in MP 16 (A.D. 1140 – 1180) to 43 in MP 18 (A.D. 1225 – 1260), the latter figure much higher than that recorded for any other modeling period (Table 3.2). Communities become more easily identifiable as residential unit clusters often surrounding a center exhibiting some form(s) of public architecture (Lipe and Varien 1999b).

Architectural styles change from earlier times, becoming more substantial in general, with much more use of masonry in construction. This is true for sites of all sizes, from isolated structures such as granaries in small alcoves and towers atop detached boulders, to very large public buildings such as Sun Temple on Mesa Verde. Labor invested in masonry construction also appears to increase significantly, with sandstone blocks commonly uniformly shaped, rounded to conform to curved walls, and pecked into the easily recognizable "McElmo-style" commonly used on exterior tower walls and inside kivas on pilasters and lower lining walls (Lipe and Varien 1999b). Towers and subsurface masonry rooms are found on many sites dating to the P III period, as are various forms of substantially constructed architectural features presumably requiring the concerted efforts of members of the communities. These latter structures occur in various forms, ranging from site-enclosing walls (Kenzle 1997), to bi- and tri-walled structures common at canyon-oriented sites such as Woods Canyon Pueblo (Kelly 1996) and many of those included in Hovenweep National Monument, to the "Great Tower Complex" at Yellow Jacket Pueblo (Lipe and Varien 1999b).

No new ceramic styles originated during the P III period in the study area (Ortman et al. 2006). Red wares are virtually nonexistent in assemblages after MP 16, and frequencies of all gray wares other than Mesa Verde and undifferentiated corrugated decrease significantly by MP 15. Likewise, the frequencies of most white ware types decline by MP 16, while those of late white and late black-on-white organic varieties remain level and only those of Mesa Verde Black-on-white and P III black-on-white increase. Nevertheless, the wide variation in frequencies of ceramic types provide ample indicators of temporal placement for sites (Ortman et al. 2006).

Comparison of Figures 3.13 and 3.14 shows little change in overall site distribution between MP 16 and MP 17 (A.D. 1180 – 1225), and in fact there is only a slight increase in the number of households at the largest community center. The number of hamlets, however, decreases by 103 (a 20 percent decline), while the number of large hamlets increases by nine (33 percent). There is a 60 percent increase in the number of community centers, from 10 to 16 (Table 3.2), with only slight variation in average numbers of households in each settlement class.

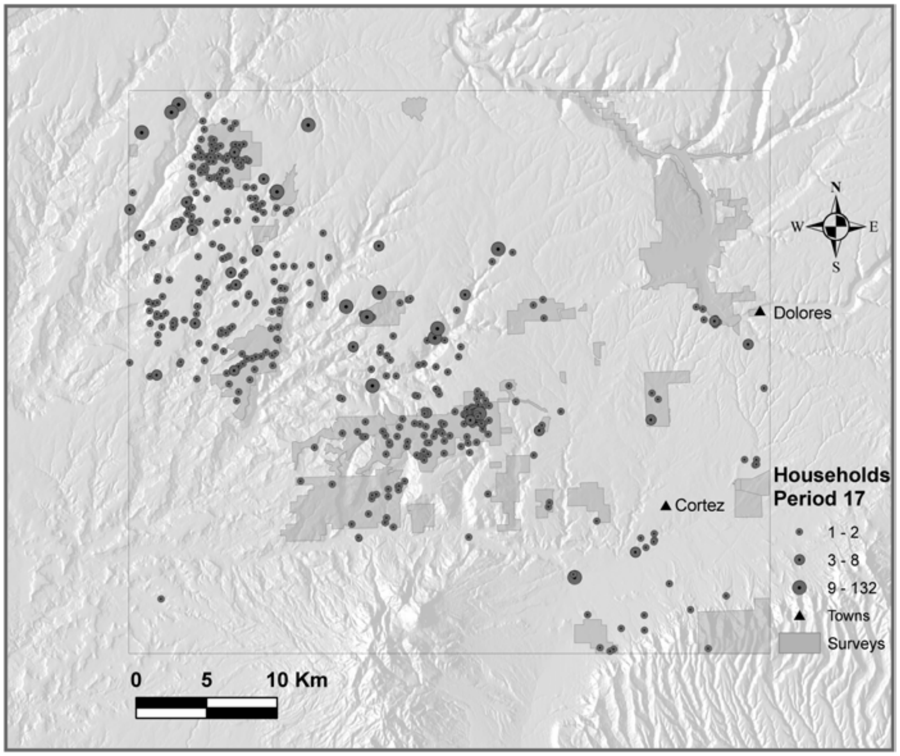

Figure 3.14. Distribution of known MP 17 (A.D. 1180 – 1225) habitation sites.

Data for MP 18 show substantial increases in the numbers of all habitation site classes, and significantly increased clustering is readily apparent (Figure 3.15). The numbers of hamlets and large hamlets increase 65 percent, from 412 and 28 respectively in MP 17 to 43 and 635 respectively in MP 18. The number of community centers more than doubles from 16 in MP 17 to 33 in MP 18, with only a slight decrease in average number of total households within community centers (Table 3.2).

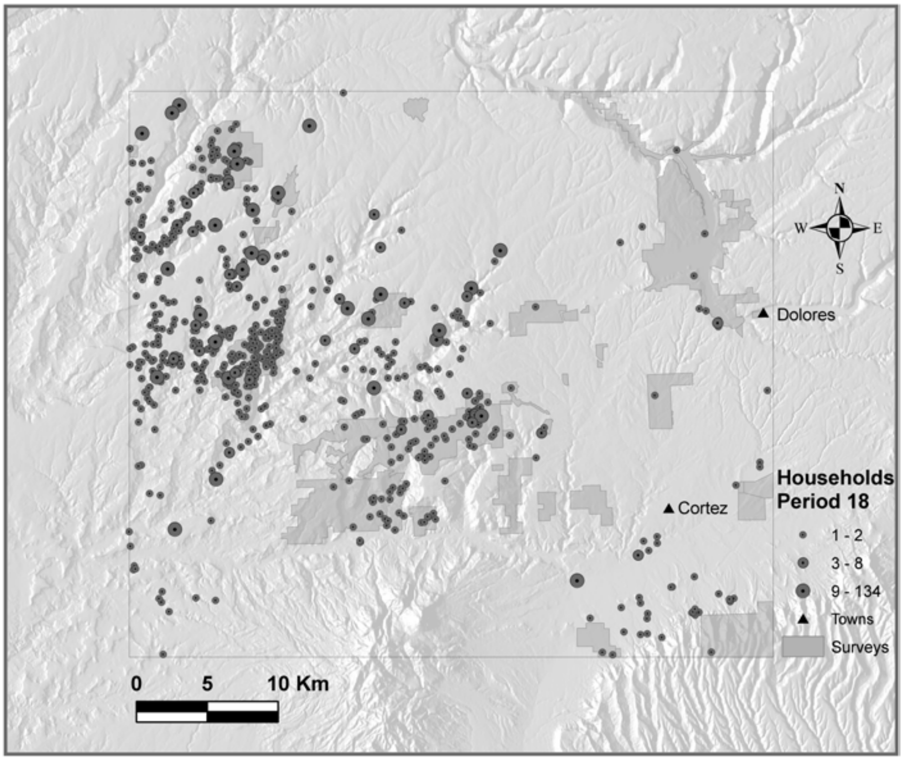

Figure 3.15. Distribution of known MP 18 (A.D. 1225 – 1260) habitation sites.

For the late 1200s, comparison of Figures 3.15 and 3.16 shows a marked decrease in the total number of habitation sites within the study area (a 56 percent decline from 711 in MP 18 to 317 in MP 19; see Table 3.1). This overall decline is apparent in numbers of all habitation site classes (Table 3.2), but dominant in the case of hamlets (58 percent decrease), slightly less so in the case of large hamlets (42 percent decline) and lowest in the case of community centers (28 percent decrease).

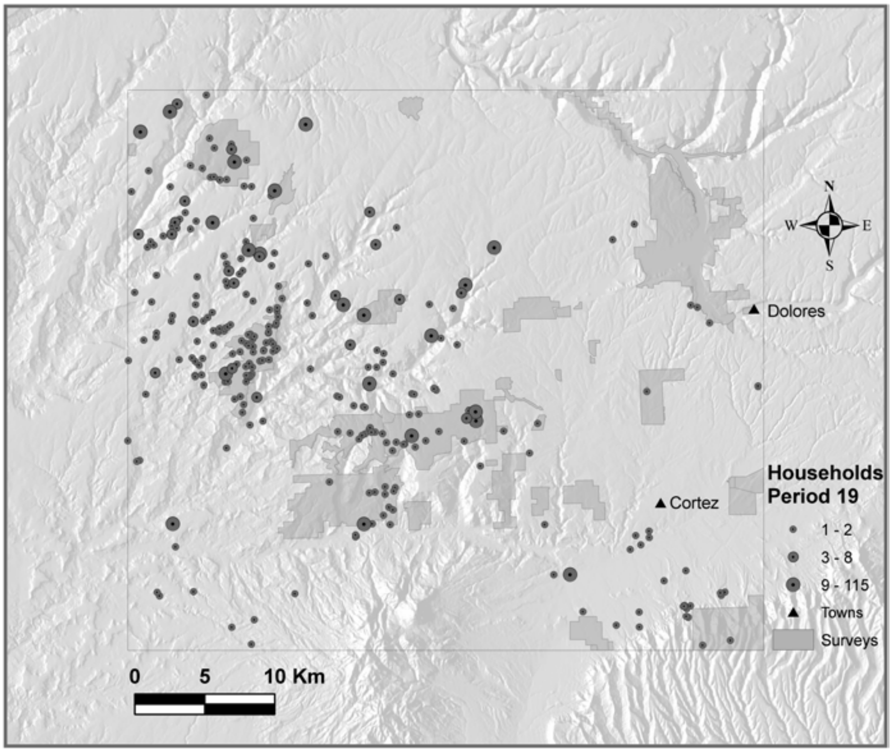

Figure 3.16. Distribution of known MP 19 (A.D. 1260 – 1280) habitation sites.

At the same time, there are increases in the average numbers of households occupying both large hamlets and community centers, at rates of eight and twenty percent respectively.

Throughout the P III period, the study area exhibits an initial steep increase in the number of households between MPs 16 and 18, with a similarly steep decrease in those numbers between MPs 18 and 19 (Figure 3.2a). During these same generations, however, community aggregation continually increased, as is evident from the plot shown in Figure 3.2b. Overall, the increase in the aggregation index from MP 16 to MP 19 is 55 percent, indicating that households had a strong interest in consolidating their settlements (Varien 1999a; Varien et al. 2006). The substantial decrease in total number of ceramic types indicates that households were standardizing design styles, and it will be interesting to learn how ceramic manufacture and trade changed (Glowacki, in preparation) during these final generations of study area occupation. As noted at the conclusion of the P II section above, I suspect this spatial constriction of residences is directly related to long-term degradation of critical natural resource supplies in the face of ever increasing demands. Competition for dwindling supplies of crucial resources is a common cause of conflict (Klare 2001), and may have led to increasing violence in the Northern San Juan region (Kuckelman 2002; Kuckelman, Lightfoot, and Martin 2000) during this time. Results of the present effort should shed light on potential resource scarcities resulting from intensive exploitation over long periods in the study area.

Summary. This chapter provides discussion of the main features of the archaeological record that are pertinent to comparisons with simulation output data. Experimenting with plausible levels of resource production and consumption over long periods provides an opportunity to observe interactions of simulated human populations with a simulated natural environment. The lessons learned from these observations are expected to be applicable to contemporary human ecodynamic problems, as well as contribute to explanations of those in the past. The following chapter begins the multi-chapter discussion of how the model is designed to provide resources model agents are required to exploit, and how well the modeled productivities match those expected, based on the data available.

CHAPTER 4: MODELING RESOURCE AVAILABILITY AND USE: OVERVIEW

Long-term modeling of resources in this project is based on the work of many others, including contributions dating back to the creation of the original Village model (Kohler et al. 2000). All resources modeled in this work are ultimately based on the reconstruction of paleoproductivity for soils of the study area. Therefore, a discussion of how potential productivity is retrodicted for the 700 years examined here must precede presentation of how I model the natural resources that are dependent on the retrodiction.

Climate and Landscape Productivity

The productivity of critical natural resources is based on area soils and varies with the amount of available soil moisture as modeled using PDSI. Palmer drought severity index values are calculated from monthly temperature and precipitation figures for each year, for each of the 139 productive soil complexes mapped within the study area. These values vary for each of the soil complexes based on the potential available moisture capacity within both the upper 6 and lower 54 inches of the 60 inch soil profile of each (see Appendix A). We model the PDSI values expected on June 1st of each of the 700 years of interest.

Historic variations in PDSI values are correlated with variation in mean tree-ring widths providing an index of ring width departures (from mean ring width) based on variation in regional climate as reported from four weather stations. The variation in PDSI values, based on modern climate is then correlated with ring-width variations as observed in long-term tree-ring series (Van West 1990). This allows prediction, or retrodiction, of PDSI values for each of the seven hundred years for which I model the productivity of natural resources.

Climatic variation influences PDSI in two respects. The more important of these is annual precipitation. In this semi-arid, upland environment, the amount of annual precipitation has a strong influence on the moisture available within soils at critical times of the growing season. Due to high levels of evapotranspiration, significantly lower moisture prior to the growing season can be detrimental to annual productivity of both agricultural crops and native vegetation. Furthermore, late summer monsoon rains are critical to maturing crops, though not as much so as winter precipitation.

Average annual temperature is also important. Although the length of growing season may not be as directly pertinent to the primary productivity of native plant species as it is to the production of maize, indirect effects are likely to result from extreme mean annual temperatures. Of particular concern is that high annual temperatures can significantly reduce soil moisture levels, bringing some soils to the permanent wilting point such that the less hardy plants die. This situation would adversely affect fuel wood production and availability of herbivore feed. At the other extreme, prolonged occurrence of winter temperatures well into the spring months can postpone the eruption of native plant shoots, ultimately causing a significant decrease in the annual production of new growth needed to support wildlife populations.

Late spring is a crucial period in the growing season. Following winter precipitation, there is usually an extended period of little to no precipitation during which moisture in the root zones of most soils significantly declines. Lack of sufficient soil moisture in the late spring, prior to the arrival of mid-summer monsoons, can stunt the growth of new shoots or, in extreme cases, kill young seedlings. Dry soil conditions in the late spring can, therefore, have a detrimental effect on the productivities of the animal populations modeled as sources of protein in the present effort. Nursing mothers require significantly more nutritious feed to successfully maintain the health and growth of their offspring (Robbins 1982). Soil moisture deficiencies can also decrease expected production of agricultural crops believed to have been the mainstay of the prehispanic Puebloan diet (Matson 1991).

Of course extremely dry spring and summer seasons greatly enhance the potential for major wild fires across the region. Periodic catastrophic forest fires can completely consume all vegetation in the area. Piñon-juniper forests in the Southwest can take up to 300 years to return to climax state following major fires (Erdman 1970).

Annual net primary productivity (NPP) of native plants, or annual new growth (Odum 1971), is the basis for the maintenance and/or increase of the standing crop of species deemed critical for long-term occupation of the region. This applies to both woody biomass used as fuels, and to population levels of the three herbivorous species used as sources of complex proteins. Significant departures from normal climatic conditions, with either too little rainfall or extreme temperatures, can severely decrease annual NPP. Sustained departures (exceeding 25 years duration) in either of these are what Dean (1995) terms “low-frequency climatic variation” that can result in dramatic reorganization of socio-cultural adaptation. “High-frequency climatic variation,” by contrast, represents environmental perturbations of less than a human generation (25 years). These shorter duration climatic downturns are expected to have been within the normal experience of older members of communities, so that strategies for dealing with them were retained within the cultural knowledge.

The paleoclimatic reconstruction used here is therefore an important component in simulating survival strategies of model agents. Climatic and spatial variability in natural and agricultural productivity due to physical properties of the landscape are assumed to be major factors in influencing the settlement decisions made by prehistoric households within the study area. Model households are implemented to make efficient decisions as to where to settle, but are only required to satisfy basic needs, not necessarily optimize returns on labor.

Agrarian peoples rely on many resources to satisfy their everyday needs. In pre-industrial societies most material possessions are made directly from natural resources easily collected from within a group's home territory. In areas supporting densely settled populations, access to many resources may be controlled by some type of socially sanctioned power, and in this context that is expected to be the community (Adler 1996, 2002). At present, however, the Village model assigns agency to virtual households; it is these agents that make decisions, so communities can only be inferred in the model context. Model households are not currently constrained by community rules, though they are able to exchange both meat and maize (supplying requirements for protein and calories respectively), forming networks potentially analogous to communities. Resource use at each model time step is calculated and recorded by each agent, so resource use is discussed on the basis of households.

Modeling Household Consumption

The archaeological record indicates that prehistoric Puebloan households in the American Southwest were highly dependent on agricultural produce (Schollmeyer and Turner 2004), principally maize (Matson and Chisolm 1991), though squash and beans contributed to the diet as well. In the current version of the Village model, households are required to obtain 70 percent of their calories from the farming and consumption of maize. This commodity is grown, using household labor, on agricultural plots within or adjacent to the household's home model cell. As with all other consumption-related activities, the production and harvesting of maize requires households to expend energy, which is calculated in calories that are added to those used for maintaining each household member (e.g., basal metabolism).

The remaining 30 percent of household calories are assumed to be obtained from the harvest of wild plants and/or animals. We assume these resources are always obtained by households, at no cost as if they are embedded in other activities. The current Village model (this dissertation is based on version 2.5) does not address wild plant production and harvest for direct human consumption. The simulated annual NPP of 93 native plant species does, however, provide forage for herbivorous animal populations on the model landscape. Model agents are required to obtain a small portion of their protein needs from the harvest and consumption of these animals.

At each (annual) model step, households calculate their resource needs based on the number, sex, and ages of household members. Once needs are calculated, agents plan the number of farming plots they require for maize production, limited to their home cell and those immediately surrounding it. Agents then search the local model world for required quantities of meat, fuel, and water. As long as families can satisfy their resource needs, they stay where they are and reproduce. Satisfaction, in this case, means agents are able to fund the caloric costs of procuring water, fuel, and meat using the calories produced via farming their plots. Finding and carrying all resources expends energy, so harvesting more distant resources is possible, but requires larger agricultural harvests to produce extra calories.

Households are also limited in the number of plots they are able to farm; they may plant one more .4 ha (1-acre) plot than there are workers. Children under 7 are not considered workers. Furthermore, households must farm plots either within the model cell in which they are located, or any of the immediately adjacent eight model cells; these nine cells are known as a “Moore neighborhood” (Epstein and Axtell 1996). Model cells are 200 meters square (4 ha) and contain nine (0.44 ha ≈ 1 ac) farming plots. Cultivating plots outside of the home cell increases the caloric cost of work at rates of 240, 200, and 92 kcal per hour for men, women, and sub adults (ages 8 to 16) respectively, charged for the additional travel time incurred.

Domestic heating and cooking is based on the use of woody species as fuel. Within the vegetation communities of the study area there are a total of 49 wood-producing species. Fuel wood is modeled based on the productivity of these woody plants that include 10 specified trees, 39 specified shrubs, and an “other” category of each.

Water, fuel, and/or meat required by households can become too scarce locally, which means either that households cannot grow enough maize to fund their collection, or may not have enough working hours left to collect them. Work hours are calculated annually, based on a maximum of 14 hours per day for all household members over age

7. In either case, households seek to relocate to a more efficient cell. This search is again conducted by model cell, with a variable parameter (set to a radius of 20 model cells in the simulations reported here) governing the size of neighborhood to search (their search radius). Agents are given free knowledge about production from the cells within the search radius and rank the 100 most efficient cells in terms of local resource availability. Efficiency of a particular location is dependent on the relative locations of all resources households must obtain – i.e., water, fuel, protein, and maize production potential. They then relocate to the most efficient cell that has as many farming plots available as they need. One aspect of the current implementation that makes simulated life easier for model agents is that, other than searching for a new home cell, no moving or construction costs are incurred.

Subsistence Studies

The study of food resources has always been an important part of human existence at least on some level. The organization of food procurement and storage are often cited as effective variables in the evolution of social organization (Jochim 1981). A number of studies of prehistoric floral and faunal use have been undertaken within the Southwest in general (Mathien 1985; Matson 1991; Szuter and Bayham 1989; Szuter and Gillespie 1994), and the Mesa Verde region in particular (Adams and Bowyer 2002; Driver 2002; Matson and Chisholm 1991; Muir and Driver 2002; Munro 1994; Shelley 1993). Ethnographic studies report on the subsistence strategies of Southwestern natives (Bailey 1940) including farming techniques (Hack 1942), faunal exploitation (Beaglehole 1936; Elmore 1953; Gnabasik 1981), and floral use (Hough 1897).

This study benefits from such research in that it indicates which resources were important to the prehistoric inhabitants of the study area. In the prehistoric faunal record, three animal species are reported as having been particularly important, and so are modeled as populations from which model households must harvest a portion of their protein. These species (mule deer, black-tailed jackrabbits, and cottontail rabbits) are all herbivores that are commonly: 1) observed inhabiting the region today (Neusius 1985a:Table 13); 2) reported in Southwestern ethnographic contexts (Neusius 1985b:Table 16); and 3) commonly found in study-area prehistoric faunal assemblages (Driver 2002; Neusius 1985c:Table 21; Shelley 1993:Table 3.1).

High-quality, complete proteins are necessary to maintain human health, and animal protein is one of the most complete protein sources available. Just as model households have caloric needs that can be satisfied only through farming, they have minimal protein needs that can be satisfied only through harvesting herbivores. The difference is that caloric needs vary according to levels of household activity, whereas protein needs are treated as a static per capita parameter. Each of the three species modeled provides a different average meat weight, and protein content varies between artiodactyls and lagomorphs. Model households are programmed to approximately optimize their choice of species in satisfying their meat protein requirement. In general, larger-bodied mammals are more efficient, so mule deer, when available, are the most efficient wild protein source on the model landscape. If deer populations are locally depleted, model households will adjust their harvest strategy to take jackrabbits or cottontails in cells closer to home before searching farther away for deer.

Reports of protein requirements for people of different ages often differentiate between a minimum or base requirement and a recommended daily intake, or optimum amount (Wing and Brown 1979:Figures 3-2 and 3-3). Children, having much lower body weights than adults, require a *minimum* of 10 g/day. Minimum requirements slowly increase with age, leveling off at approximately 30 g/day at maturity. Recommended daily allowance values, on the other hand, vary much more widely. According to Wing and Brown (1979), the daily requirement increases from 10 to 60 g/day for males from birth to maturity. The USDA (2005) recommended daily allowance for adults is 91 g/day of protein, in conjunction with a 2000 calorie/day diet.

Village model household agents are required to satisfy only a portion of their protein needs from hunting the animals provided by the model landscape. In modeling protein consumption of prehistoric populations, other archaeologists have also tended to use lower levels of recommended daily allowances likely derived from hunting. Spielmann and Angstadt-Leto (1996), for example, suggest 10 g / person / day as a reasonable estimate of quality protein obtained by prehistoric Southwestern peoples from hunting artiodactyls and lagomorphs. We assume other sources we don’t model provide additional protein to model households.

In her discussion of the diet of New Mexico’s Arroyo Hondo population, Wilma Wetterstrom (1986:Table 31) computes an average protein requirement of 19.41 g/person/day. Assuming reduced net protein utilization associated with a heavy reliance on maize agriculture, for example in her 70 percent column, that figure increases to an average of 30.6 g. In their model of game use in the Mimbres Region of southwest New Mexico, Nelson and Schollmeyer “estimate that in a diet drawing 80% of its total calories from maize, game meat would have provided…48% of the protein" (2003:84). Using the Food and Drug Administration daily reference value of 50 g per person, Nelson and Schollmeyer's model thus requires 24 g protein/day from wild game for each member of their estimated population. Our model runs reported here require 5 or 10 g of protein from hunting − lower than researchers typically suggest. Based on even these low protein requirements, model results indicate that protein supplies could become scarce in many localities, even with low human populations. In the experiments discussed here, we keep protein requirements low so consideration of protein sources is less likely to overpower that of other resources in long-term settlement decisions. Increasing the protein requirement to levels discussed by others, above, could cause severe depletion of game within large areas of the model world. This suggests that attaining adequate protein from hunting in prehistoric agricultural contexts of the American Southwest was difficult at best in many areas.

The emphasis on modeling faunal use in the present research is in no way meant to suggest that other wild food sources were not important in the everyday lives of the prehistoric Puebloan inhabitants of the Mesa Verde region. Common use of wild and ruderal plants is strongly indicated by their frequent recovery from local archaeological contexts (Adams and Bowyer 2002). The exclusion of non-maize plant foods from this study is by design. The Village model is meant to examine only the factors thought to most strongly influence household settlement distributions. Modeling the locations of various natural plant species is necessary to model both potential animal population locations and fuel wood availability. These primary producers are not, however, otherwise directly implicated in household resource procurement or settlement decisions.

It is the resources supported and supplied by the native plants (animals and fuels respectively) that are expected to influence settlement decisions. The use rates of these resources are therefore of interest.

The actual rate of faunal use by households is exceedingly difficult to estimate. There are numerous figures provided for the amounts of calories and protein required per individual on a daily basis (Nelson and Schollmeyer 2003; Spielmann and Angstadt-Leto 1996; Wetterstrom 1986; Wing and Brown 1979). But, even assuming a relatively low maximum requirement of 5 to10 g per person per day of high-quality protein obtained from hunting wild animals, as we do, there is still no way to determine the actual average number of persons per household for a given time period. Of course, ethnographic analogy is an option for estimating household size (see Lightfoot 1994), but I suggest that the sizes of households as simulated in the Village model are just as valid.

The demographic structures of simulated households result from the use of standard life-table figures (Weiss 1973), which are modified by various environmental factors such as the amounts of food harvested per year by each household. That is, scaling factors are applied to the proportional reproductive figures for simulated mothers based on the household's success in satisfying nutritional requirements through farming and hunting on the model landscape. The resulting simulated human populations interact with and modify the levels of important resources in the model world. As discussed elsewhere in this document, both the human and animal populations supported by the model landscape track those estimated from archaeological and ecological data reasonably well using most parameter combinations in the long-term simulations.

Model households are required to satisfy basic needs to survive in the model world. In the interest of parsimony, natural resource needs are restricted to the basics of sustained family life: food, water, and fuel. There are basic minima to the amounts of these resources each person needs, and these cost calories to procure, in this case returning calories, protein, water sufficient for survival, or fuels for heating and cooking.

Critical natural resource requirements are calculated as units per day per person. For each resource, sufficient amounts for each virtual family member must be harvested. Per capita resource requirements are implemented as model parameters that are easily adjusted, such that the influence of any one or more resource(s) on household settlement can more easily be investigated.

Fuel Wood Studies

Data on prehistoric resource use rates are relatively rare. Obviously some use of woody species is required in building most structures throughout the prehispanic occupation of the region, though less so with the increasing use of masonry. Based on his replication study, Glennie (1983) estimates 1.5 m^3 as the volume of construction timbers needed to build an early ninth-century pit house. Additional wood was used to construct various outbuildings found around most pit houses, which might require another .5 m^3 by an average household of this time. This equals 2.0 m^3 per household, per site, which, accepting a structure use life ranging between eight and 18 years (Varien et al. 2006:Table 3), totals roughly 4.5 m^3 of wood used for construction by each household over a 25-year generation in the Basketmaker III and early Pueblo I periods. Compared to estimated annual fuel usage per person discussed below, household consumption for construction is very low, although the specifications for the materials were relatively narrow.

As noted above for the P II period, dispersed households likely had little need to consider construction materials in their settlement decisions. With increasingly large sites, however, one might expect that easy access to building stone might influence site locations. Most large P III sites are built on or near canyon rims, where stone is normally readily available. Mark Hovezak (1992) studied the supply and demand of construction timbers in the Sand Canyon locality, and concluded its availability was not a limiting factor in late Puebloan site construction. Compared to the continuous need for fuels, the use and availability of woody species for construction is not considered a factor highly relevant to prehistoric settlement decisions. Village agents do not harvest wood for construction, so it is not addressed in this study.

Wood availability for fuel at particular settlement locations may be more relevant to settlement decisions, so an attempt is made to determine what species and amounts were important in the daily lives of the inhabitants of the prehistoric landscape of the region. Unlike construction woods, fuels are needed on a frequent (normally daily) basis, so ready access to sufficient supplies is essential. Estimates of prehistoric Southwestern fuel wood use range from 8.5 to 11.5 m^3 per household per year (Glennie 1983; Samuels and Betancourt 1982).

Glennie's (1983) higher figure of 11.5 m^3 (5545 kg) per household per year is for that required to fuel two cooking fires daily in an A.D. 800 pit house replica. This assumes no additional fuel use for heating the structure, which seems improbable since mean daily low temperatures as historically recorded at regional weather stations are below freezing for five months of the year (see Figure 2.7). At the same time, this is approximately the rate of usage for a family of five in modern Pakistan, based on a recent study (Khan et al. 2001).

The subsequent construction of deeper pitstructures used as household facilities may have reduced wood usage (Wilshusen 1999b), because heating surface structures during winter months would certainly have required more wood for fuel. Since data on fuel use in subterranean domestic structures are unavailable, it is assumed prehispanic Puebloans used wood fuels at roughly similar rates as those reported for modern agrarian peoples. Discussion of the use of fuels is provided as justification for rates required of model agents.

High reliance on fuel woods by some contemporary peoples in the developing world (Contreras-Hinojosa et al. 2003; Openshaw 1974) has led to many studies of fuel procurement strategies (Israel 2002; Saksena, Presad and Joshi 1995; Tabuti, Dhillion and Lye 2003), household and per capita consumption rates (Alam, Islam and Huq 1999; Bhatnagar, Sunita and Razia 1994; Tomé da Costa Mata and Lopes de Souza 2000; Türker and Kaygusuz 2001), deforestation (Brondeau 2001; Nash 2001; Siddiqui and Khan 1993), fuel wood crises (Tewari et al. 2003), conservation (Maharana, Chettri and Sharma 2000) and related development issues (Omer 2003).

As is increasingly apparent in many areas of the modern world, heavy reliance on wood for fuels often produces local shortages, and can lead to soil erosion and other environmental problems. Many prehistoric societies (especially those in semi-arid environments) surely faced problems of long-term fuel wood depletion on local, if not regional, scales. Degradation of natural biotic resources is more likely for a given population density in arid environments, especially in regions with low average annual temperatures. A number of studies suggest past populations may have adversely affected their environments through over exploitation of woody species (Kohler and Matthews 1988; Plog 1981; Samuels and Betancourt 1982).

Several recent studies provide a range of fuelwood use rates by rural peoples in developing countries as well as by people in prehistoric Southwestern communities. These use rates are not necessarily directly analogous to those of prehistoric Puebloans within the study area, but they provide plausible ranges for comparison. As shown in Table 4.1, annual per capita use rates range from just over 600 kg to just under 3100 kg, encompassing the estimate of 1,400 kg per year for P I peoples in the Dolores valley (Kohler et al. 1984).

Table 4.1. Estimates of Annual Per Capita Fuel Wood Consumption for Rural People.

Location	Latitude	Elevation (m)	Fuelwood (Kg)	Source
Konomani, Mali	14˚ 07´	200 - 500	629	Brondeau 2001
Oaxaca, Mexico	17˚ 30´	1950 - 2800	657	Contreras-Hinojosa et al. 2003
Thailand	15˚ 00´	500 - 1000	770	Openshaw 1974
Gambia, Africa	13˚ 30´	0 - 50	1088	Openshaw 1974
Hilkot, Pakistan	43˚ 35´	1000 - 2000	1130	Khan et al. 2001
Garhwal, India	30˚ 00´	1000 - 3100	1200	TERI 1991
Dolores, CO U.S.	37˚ 30´	2000 - 2500	1400	Kohler et al. 1984 (archaeological)
Fonseca, Brazil	20˚ 15´	500 - 1000	1482	Tomé da Costa and Lopes de Souza 2000
Sikkim, India	27˚ 30´	3500 - 5000	1504	Maharana et al. 2001
Tanzania, Africa	6˚ 00´	1000 - 2000	1633	Openshaw 1974
Southwest U.S.	35˚ 00´	1500 - 1600	3068	Plog 1981 (archaeological)

Note that increasing fuel use rates do not always correlate with increases in either elevation or latitude, as one might expect given likely decreases in temperature under such circumstances. In the present model implementation, I use the estimate of 1130 kg per capita (Khan et al. 2001). Selection of this figure from among those in Table 4.1 is based on similarities in elevation and precipitation between northern Pakistan and southwestern Colorado; it is also very close to the median of the values presented. Based on the average family size of 3.6 members per household for all years of the 128 model runs, the 1130 kg of fuel per person annually is 4068 kg annually per household, about 27 percent lower than the estimate of Glennie (1983) referenced above.

In the present study, the procurement of fuel woods is viewed as potentially important in influencing household settlement decisions. The energy required to travel long distances to get resources can eventually amount to more than a household can produce. This is as true in the model world as it is in the real world. Use of conservative resource requirements is intended to show that resource considerations do contribute to settlement decisions without overestimating their importance.

Faunal Use

The cumulative effects of increasing population densities over successive generations within a given region can lead to resource depletion. This often results in both technological and social organizational changes to maintain settlements in the same location (Carniero 2002).

Numerous studies suggest that depletion of wild game was a very real possibility in the vicinity of prehistoric horticultural communities (Cannon 2000; Driver 2002; Muir and Driver 2002; Nelson and Schollmeyer 2003; Spielmann and Angstadt-Leto 1996). Much of the evidence used to support such conclusions is based on long-term changes in faunal species procured, evidenced by changes in faunal indices. These indices are ratios of number of identified specimens (NISP) of particular taxa to those of others. The artiodactyl index, for instance, results from dividing the artiodactyl NISP by the sum of artiodactyl and lagomorph NISPs (Bayham 1982; Szuter and Bayham 1989).

A decrease in the artiodactyl index is taken to indicate a reduction in the availability of preferred large-game species (Driver 2002; Spielmann and Angstadt-Leto 1996). Calculation of faunal indices for a sample of sites within the study area shows a general long-term decrease in the artiodactyl index, and a contrasting increase in the lagomorph index (Table 4.2). This suggests a depletion of the more valuable large game (Winterhalder and Smith 2000) in the study area, and an increased reliance on small game. This is congruent with the findings of Muir and Driver (2002) for long-term trends in the zooarchaeological record of the larger northern San Juan region. During times leading up to regional abandonment, Muir and Driver (2002) find high proportions of turkey bones in many faunal assemblages. Domesticated turkey are thought to become increasing important sources of protein for these horticultural peoples (Munro 1994).

Table 4.2 is based on data from the Dolores Archaeological Program database (Wilshusen 1999) and numerous sites investigated by Crow Canyon Archaeological Center (Driver et al. 1999). Faunal collections data were used to calculate faunal indices from 40 sites that date to various Village Project MPs. Note that the overall contributions of artiodactyls and lagomorphs to faunal collections remain fairly stable (Table 4.2, column 10) based on averages for each of the Pecos periods.

Table 4.2. Faunal Indices from a Sample of Sites within the Study Area.

Site	Name	Pecos[1]	VP_MP[2]	PeakPopMP[3]	Peak#HHs[4]	ART IND[5]	LAG IND[6]	NISP[7]	%A+L/NISP[8]
5MT4797	Cougar Springs Cave	BMII	~	~	~	0.12	0.97	475	17.68
5MT4684	Chindi Hamlet	BMIII	6, 7	6	1	0.55	0.73	1221	21.46
5MT2858	Apricot Hamlet	BMIII	7	7	1	0.13	0.93	528	5.90
5MT4614	Prairie Dog Hamlet	BMIII	7	7	1	0.16	0.72	2494	26.50
5MT4545	Tres Bobos Hamlet	BMIII	7	7	1	0.28	0.47	255	23.50
5MT4613	Pozo Hamlet	PI	7	7	1	0.44	0.39	83	38.60
BM Avg					**1**	**0.28**	**0.70**	**843**	**22.27**
5MT2854	Aldea Sierritas	BMIII/PI	7, 8	8	1	0.03	0.74	3152	21.20
5MT2193	Dos Casas Hamlet	PI	7, 8	8	1	0.20	0.73	584	31.10
5MT4671	Periman Hamlet	PI	8	8	2	0.29	0.69	2752	18.20
5MT4644	Windy Wheat Hamlet	PI	7, 8	8	2	0.28	0.56	1332	21.80
5MT3868	Duckfoot Site	PI	9	9	4	0.15	0.58	5710	37.27
5MT5107	Pueblo de las Golondrinas	PI	8, 9, 10	9	4	0.60	0.35	2395	22.76
5MT2182	Rio Vista Village	PI	7, 8, 9, 10	9	8	0.48	0.51	2933	18.60
5MT2320	House Creek Village	PI	8, 9, 10	9	9	0.60	0.63	440	21.40
5MT2151	LeMoc Shelter	PI	9, 10	10	1	0.53	0.77	6870	17.00
5MT4479	Aldea Alfareros	PI	9, 10	10	2	0.35	0.31	917	20.30
5MT5108	Golondrinas Oriental	PI	10	10	2	0.57	0.67	604	11.59
5MT2161	Prince Hamlet	PI	8-10, 14, 16, 18	10	2	0.6	0.51	1497	18.70
5MT4683	Singing Shelter	PI	8, 10, 14	10	2	0.32	0.88	1617	14.00
5MT4725	Tres Chapulines	PI	9, 10	10	3	0.44	0.36	464	29.31
5MT4477	Masa Negra Pueblo	PI	9, 10, 11	10	5	0.61	0.28	2973	23.90
5MT4480	Rabbitbrush Pueblo	PI	9, 10	10	8	0.48	0.41	725	23.20
5MT23	Grass Mesa Village	PI	7, 8, 9, 10	10	47	0.46	0.52	17570	17.20
PI Avg					**6**	**0.41**	**0.56**	**3090**	**21.62**
5MT4475	McPhee Pueblo	PI/PII	7, 8, 9, 10, 11	9	5	0.32	0.60	17924	17.60

Site	Name	Pecos[1]	VP_MP[2]	PeakPopMP[3]	Peak#HHs[4]	ART IND[5]	LAG IND[6]	NISP[7]	%A+L/NISP[8]
5MT2336	Kin Tl'iish	PI/PII	8, 11	10	2	0.20	0.31	577	19.40
5MT5106	Weasel Pueblo	PI/PII	9, 10, 11	10	3	0.42	0.30	2755	4.75
5MT2235	Marshview Hamlet	PII/PIII	15	15	1	0.06	0.77	1208	14.80
5MT11338	G & G Hamlet	PII/PIII	13-17	17	1	0.24	0.88	72	29.17
5MT5152	Kenzie Dawn Hamlet	PII/PIII	16, 17	17	2	0.05	0.86	884	34.84
5MT11842	Woods Canyon	PII/PIII	16-19	18	32	0.02	0.88	1066	21.76
5MT5	Yellow Jacket Pueblo	PII/PIII	14-19	18	134	0.16	0.78	2716	54.67
PII Avg					**23**	**0.18**	**0.67**	**3400**	**24.62**
5MT3930	Roy's Ruin	PIII	17	17	1	0.00	0.95	84	23.81
5MT3967	Catherine's Site	PIII	17,18	17	2	0.00	0.88	396	23.74
5MT3936	Lillian's Site	PIII	18	18	1	0.06	0.91	241	33.61
5MT262	Saddlehorn Hamlet	PIII	18	18	1	0.04	0.82	247	48.58
5MT10508	Stanton's Site	PIII	18	18	1	0.01	0.96	990	22.83
5MT3918	Shorlene's Site	PIII	6, 17, 18	18	3	0.08	0.81	121	42.98
5MT3951	Troy's Tower	PIII	19	19	1	0.00	1.00	92	15.22
5MT10246	Lester's Site	PIII	18, 19	19	2	0.00	0.71	181	13.26
5MT10459	Lookout House	PIII	18, 19	19	2	0.02	1.00	173	25.43
5MT1825	Castle Rock Pueblo	PIII	19	19	14	0.05	0.87	1058	39.04
PIII Avg					**3**	**0.03**	**0.89**	**358**	**28.85**

[1] Period of occupation based on Pecos classification from Kidder 1927.

[2] Village Project modeling periods of site occupations.

[3] Village Project MP with peak household population.

[4] Number of estimated households at peak population based on McElmo-Yellow Jacket settlement model v. 5.4 (CCAC and WSU 2004).

[5] Artiodactyl index calculated from site faunal assemblages based on Dolores Archaeological Program database (Wilshusen 1999c) and Sand Canyon Project Site Testing Report (Varien 1999b).

[6] Lagomorph index calculated from site faunal assemblages based on Dolores Archaeological Program database (Wilshusen 1999c) and Sand Canyon Project Site Testing Report (Varien 1999b).

[7] Number of identified specimens from site faunal assemblages based on Dolores Archaeological Program database (Wilshusen1999c) and Sand Canyon Project Site Testing Report (Varien 1999b).

[8] Percent artiodactyls and lagomorphs contribute to total NISP per period.

The artiodactyl index rises from BM III to P I times, but then decreases substantially through both the P II and P III periods. The lagomorph index shows the opposite trend across these time periods. Although sample size may affect these figures to some extent, note that the largest change in the artiodactyl index occurs between the P I and P II periods, both of which have relatively large sample sizes. In contrast, the largest shift in lagomorph index value is between the P II and P III periods, which also show a large difference in sample size based on data from these assemblages. Notice also that the contributions of artiodactyls and lagomorphs to the total faunal collections rise most dramatically from the P II to P III periods. This latter finding is interesting since turkey become increasingly prevalent in faunal assemblages in the later occupations of the area (Muir and Driver 2002).

The long-term decrease in the artiodactyl index indicates lower populations of these large-bodied animals, making their capture less efficient compared to smaller herbivores. The corresponding increase in the lagomorph index suggests that even the relatively prolific jackrabbit population was also decreasing, leading to increased reliance on the even smaller-bodied cottontail rabbits.

The reasons for overall decreases in the availability of wild herbivores in the study area are likely numerous and interdependent, but I would argue that human harvesting is a prime candidate in the long term. Clearing of fields may also contribute to this decline (Nelson and Schollmeyer 2003). The results of the present study should provide significant insight into the potential of the prehispanic Puebloan communities to deplete wild sources of animal protein, since humans are the only predators we model.

Fuel Use

Of course converting forested land to farm fields also removes woody species, which, depending on methods used (such as burning), can rapidly deplete fuel wood as well. In their study of resource use in the Dolores River valley, for instance, Kohler and Matthews (1988) find that preferred, slow-growing tree charcoal decreases in hearths whereas fast-growing, shrubby fuel remains increase throughout the A.D. 800s. These authors suggest that this shift indicates deforestation in conjunction with high Pueblo I populations in the Dolores area. Kohler (1992a) suggests that Dolores-area farmers utilized an extensive area of arable lands, and that particular families retained control of their lineage's traditional fields by constructing field houses as markers of ownership. This suggests widespread clearing of forest surrounding Dolores Valley settlements, preventing normal regeneration of fuels in exchange for agricultural production.

Fred Plog (1981) presents a model of fuel harvesting for various population densities in the Little Colorado River drainage of eastern Arizona. He concludes that populations there would have experienced some level of fuel crisis within a single generation under anything less than optimal conditions (high productivity, low population density and low consumption rates).

Simulation modeling by Samuels and Betancourt (1982) indicates estimated prehistoric populations of Chaco Canyon in north-central New Mexico would have severely degraded the piñon-juniper woodland to the point that, under reasonable stocking estimates, emigration and eventual abandonment of the canyon would have been required. Preliminary results of fuelwood production and harvesting in the Village project also show significant degradation of woody species in areas surrounding major population clusters (Johnson, Kohler, and Cowan 2005:Figure 3).

Summary. This chapter has provided discussion of some of the rationale behind the construction of the current model of natural resource production on the model landscape and use by model households. With the research context now well established, the stage is set to report how the critical natural resource model is developed. Once the major physiographic features and climatic reconstructions were processed and converted to model input format, the model landscape was prepared for the addition of productive surface attributes. The most important of these is the distribution of the many soil complexes across the study area. Each of the soils exhibits various physical properties that heavily influence the types of plants, and thus animals, they support, as well as the amounts of net primary productivity of those plants under various climatic conditions. The following chapters describe how the model of critical natural resources is constructed. Naturally the discussion moves from the ground up.

CHAPTER 5: BUILDING THE MODEL: SOILS

The basis of modeling the productivity of all resources in this project is the soils that support various primary producers. Soils in the region, and particularly in the study area, vary widely in their natural properties and distributions. More fully developed soils generally support more primary production since they are often deeper, provide more nutrients, and retain more moisture. Well developed soils usually form on low slopes, where precipitation promotes the chemical breakdown of parent materials and supports flora and fauna that contribute to soil formation. Of course, soil parent materials play a key role in the properties of the soils into which they evolve. As described in chapter two, many geologic and physiographic characteristics affect local environments and associated soils.

Regional Soils

Soils in the Mesa Verde region of the Colorado Plateau derive from many parent materials including residuum, colluvium, and alluvium, as well as eolian deposition. Ramsey (2003) lists 13 general soil map units found in three main topographic settings. Beginning with the higher of these, six groups of soils occur on mountains and hills, as well as in some canyons. These groups are: 1) Typic Torriorthents – Claysprings – Uzacols; 2) Romberg – Crosscan – Rock Outcrop; 3) Sideshow – Zigzag; 4) Wauquie – Dolcan – Rock Outcrop; 5) Sheek – Archuleta – Pramiss; and 6) Northrim – Prater – Sheek.

Soils lying generally slightly lower than these occur on hills and mesas, and are represented by five groups of series: 1) Mack – Farb; 2) Barx – Gapmesa – Rizno; 3) Wetherill – Pulpit – Gladel; 4) Granath – Ilex – Ormiston; and 5) Morefield – Arabrab – Longburn. Below these are general soil map units occurring on flood plains, stream terraces and alluvial fans. There are two groups of these series: 1) Mikim – Mikett; and 2) Lillings – Ramper – Fluvents.

The 13 groups of soil series described for the general soil map units comprise many soil components supporting a variety of native plants. Various combinations of 87 of these constitute the soil complexes occurring in the study area. Detailed data relating to study-area soil complexes, particularly with respect to their primary and secondary natural resource productivities, have been assembled in Appendix B. Further information on these and other aspects of the remaining soils in the region are provided in the soil surveys for the Cortez (Ramsey 2003), Ute Mountain (Ramsey in preparation), and the Animas − Dolores areas (Pannell in preparation).

Study Area Soils

The 148 unique soil complexes within the study area are described by three separate Natural Resource Conservation Service (NRCS) soil surveys. The Cortez Area soil survey (Ramsey 2003) covers by far the bulk of study area soils, both by type and area, while the Animas-Dolores Area soil survey (Pannell in preparation) and the Ute Mountain Area soil survey (Ramsey in preparation) add about 20 percent by area, less so by type since some of the types are the same as those described in the Cortez Area survey.

Model Soil Codes

Because the three surveys use the same map unit symbols (termed 'musyms') to identify different soil types, it was necessary to assign project-specific soil numbers termed Village Project Soil Codes (VPSCs) to the study area soils. Since more than two thirds of the Cortez-area soil types are found in the study area (and since I wanted to reduce potential problems in future revisions of the Village model, possibly including an expansion of the study area), VPSCs begin with the 152 consecutive Cortez-area soil survey musym numbers, and continue with VPSCs 153-166 assigned to the relevant Ute Mountain-area soils and 167-193 assigned to the relevant Animas-Dolores-area soils. Note that although VPSCs 153-193 denote only those soils from the Ute Mountain and Animas-Dolores Area surveys that occur within the present study area, each of these surveys includes many other soils for which no project specific codes were assigned (but could be in the future).

Of the 193 VPSCs, only 148 complexes are mapped within the study area (Figure 5.1). That is, while all of the 41 soil complexes from the Dolores-Animas and Ute Mountain surveys are within the study area, not all of the 152 soils described in the Cortez area survey actually lie within project area boundaries.

Some of those missing from the 152 soils of the Cortez Area survey were intentionally removed via ArcGIS map editing for reasons that will become obvious. The first to be replaced (judgmentally with surrounding soil codes) is musym 28, representing modern dams. There were three of these substantial structures located in the project area at McPhee, Narraguinnep, and Totten reservoirs (Figure 5.1). Although the polygon areas of these features, in and of themselves, were not large in relation to the total

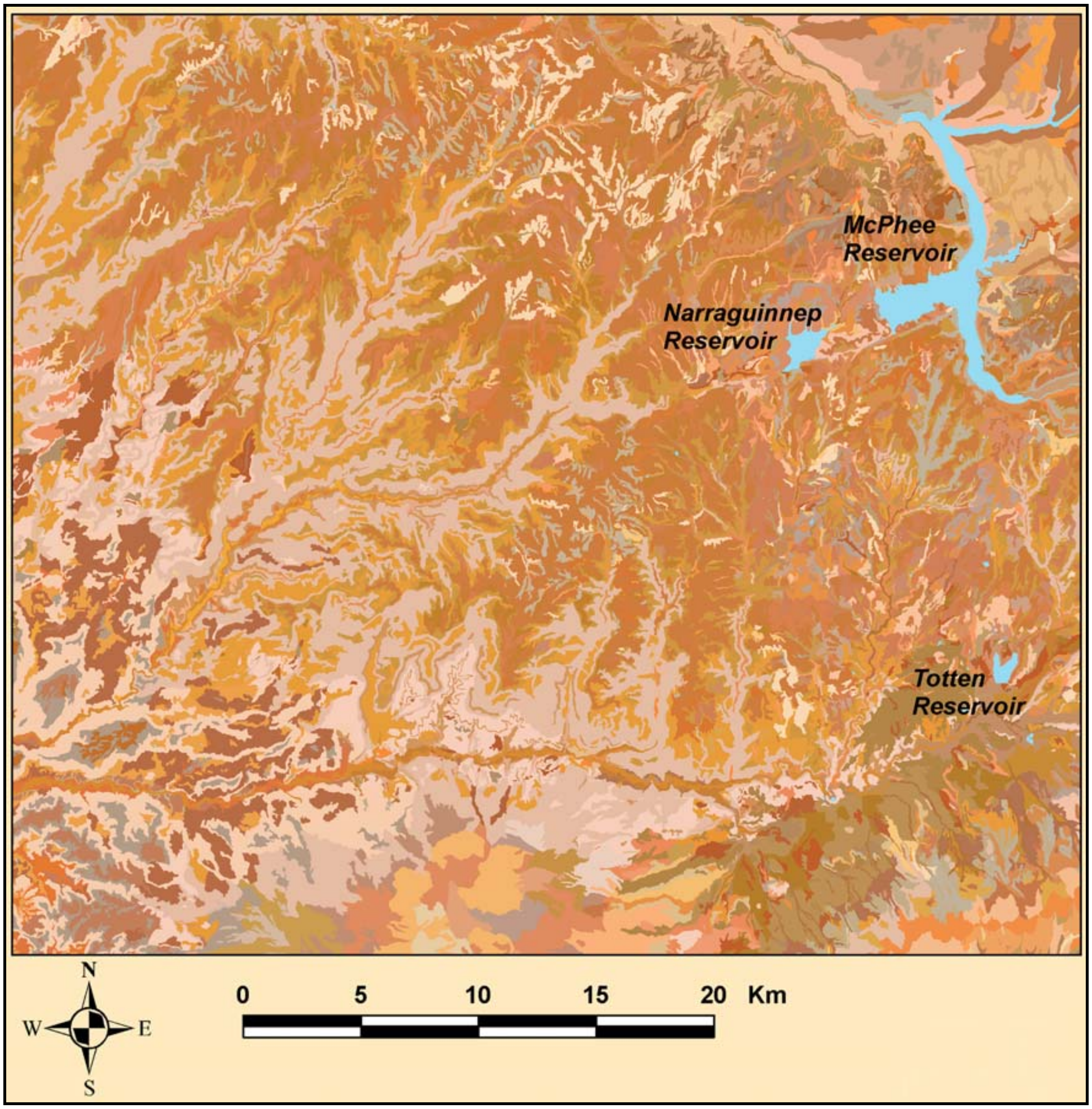

Figure 5.1. Vector map of study area soils showing major reservoirs that were converted to underlying soils.

size of the study area, it is assumed the original soils on which these structures were constructed did provide potential agricultural productivity in prehistory.

More importantly, the reservoirs themselves are coded in the soil surveys as water, which is unrealistic in terms of prehistoric adaptations. Furthermore, since water resources are modeled as a separate part of the model input (discussed above), all modern (reservoir) water should be eliminated from the soils data. I replaced the modern bodies of water with the appropriate soils as provided by the Cortez Natural Resources Conservation Service (Doug Ramsey, personal communication 2005). This resulted in the addition of 1735 ha of soils from the McPhee reservoir (not including those left as the Dolores River), 253 ha from Narraguinnep reservoir, and another 99 ha from Totten reservoir (Figure 3.1). In addition to these major bodies of modern water, 145 stock ponds are located and mapped within the study area. Although none of these is large, their combined area was considered significant enough to convert all of these to appropriate soils. Thus more than 2100 ha of modern surface water were converted to potentially productive soils.

A short discussion of stock ponds is in order here. I am well aware of various instances of prehistoric reservoirs (Wilshusen, Churchill, and Potter 1997) in the study area, and readily admit that some of the stock ponds I removed from the soils data may have originated in prehistoric times (see Connolly 1992). Nevertheless, since very few reservoirs, or “retention basins” (Crown 1987) have been seriously investigated, few dates of use, let alone construction are solid. Furthermore, even if some of these locations had retained water during some or all of our modeling periods, it is virtually inconceivable that water was the only resource provided by such areas throughout the 700 years of interest here. That is, assuming the main purpose of a reservoir as large as Mesa Verde’s Mummy Lake was water storage (Rohn 1963; Wright Water Engineers 1999), it is unlikely that the availability of other resources was not enhanced as well. Although the animal populations modeled herein could have benefited from stored water, so would their predators. The use of stored water for pot irrigation could also have increased agricultural productivity in the immediate areas, but would have had little to no effect on critical natural resources. Moreover, reservoirs were probably rarely, if ever, a sole source of domestic water. Therefore, despite the possibility that my conversion of extant stock tanks to surrounding soils negates potential prehistoric landscape modification in these locations, I felt this was the most reasonable avenue available.

A third group of polygons, represented by musym 87, was also converted to surrounding soils. This map unit symbol indicates the locations of modern gravel pits, and though few of these were large enough to recognize on the full extent map, in the interests of being thorough these 45 polygons, covering greater than 50 ha, are now modeled as dominant surrounding soils.

One organically unproductive soil code included in the full 193 VPSCs (musym 108, representing exposed rock) was not converted to surrounding soil types. Areas delineated by VPSC 108 are prominent along canyon rims in the mid- to lower reaches of Yellow Jacket Canyon, as well as those of the larger tributary canyons draining from the north into McElmo Canyon (see Figure 3.2). Soil 108 accounts for 473 4-ha model cells (1892 ha) in the model world.

Following the ArcMap editing of soil polygons, the vector data were converted to raster for export as text files to use as model input. This conversion of irregular soil polygons to square 4-ha model cells further reduced the total number of soils to 139 complexes actually used in modeling agricultural and natural resource productivity. This reduction is the result of small polygons being excluded by dominant soils within given 4-ha model cells. In Figure 5.2, soil complexes are depicted within ranges of associated native vegetation productivity as provided by the soil surveys (Pannell, in preparation; Ramsey 2003, in preparation).

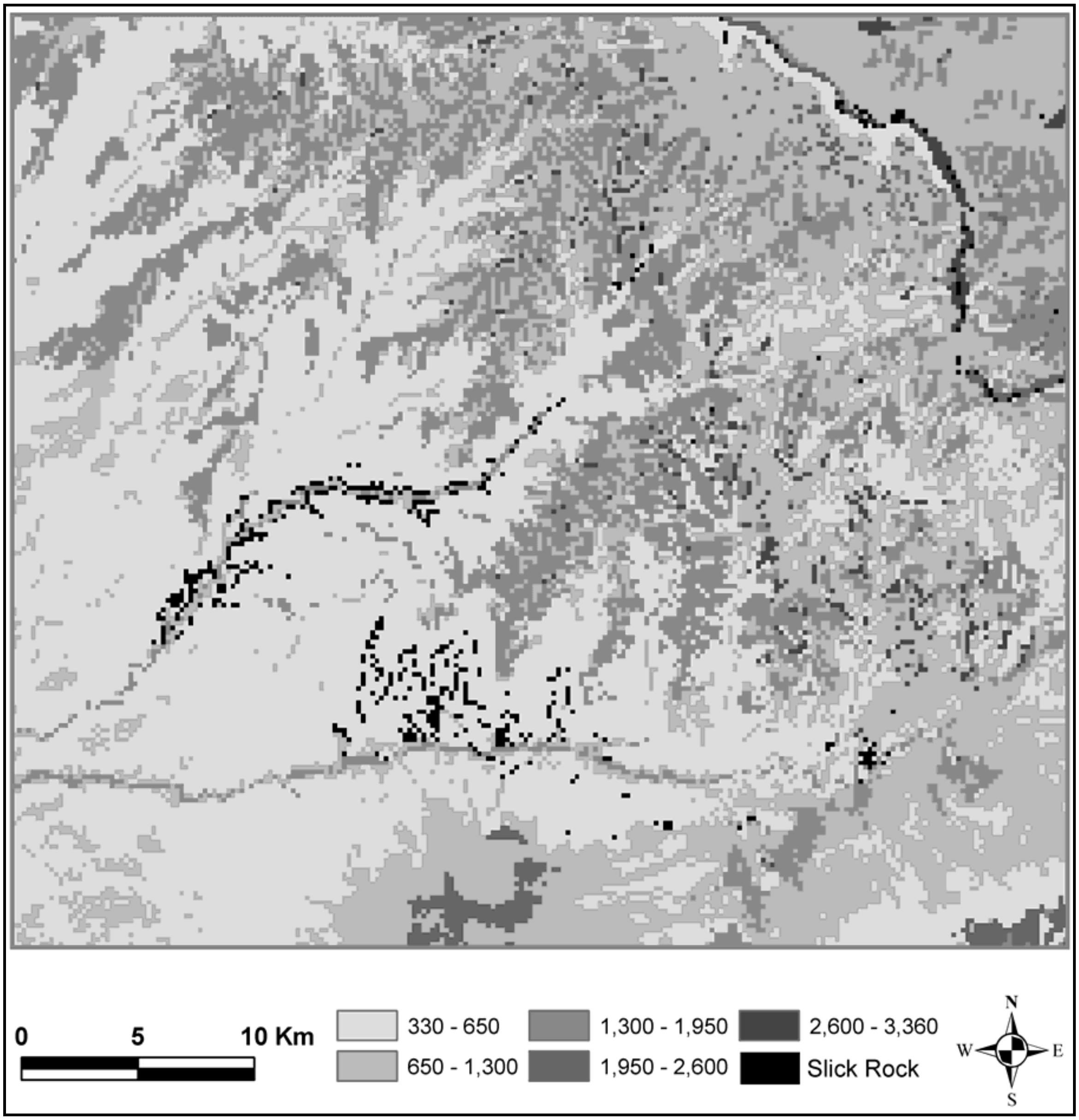

Figure 5.2. Map of study area soils in raster format used as input for the model landscape. In this image, soils are classed by kilograms of normal-year net primary productivity of native vegetation, with unproductive bare ("slick rock") rock shown in black.

Productive soil complexes within the study area include 87 components, each of which makes up some proportion of each soil complex assigned a VPSC (except for VPSC 108, bare rock). Each of these soil components is associated with one of 33 ecological settings. Since many readers will be unfamiliar with regional soil component names, Table 5.1 lists study-area soil component names with the standard soil taxonomic classifications used by soil scientists in the United States (NRCS 2003). Soil components contributing to each soil complex are provided in Appendix A.

Table 5.1. Soil Taxonomy of Soil Components Comprising Study Area Soil Complexes.

Component Name	Soil Taxonomy
Ackmen	Fine-silty, mixed, superactive, mesic Cumulic Haplustolls
Apmay	Coarse-loamy, mixed, superactive, frigid Aquic Cumulic Haplustolls
Archuleta	Loamy, mixed, superactive, frigid, shallow Typic Haplustepts
Argiustolls	Argiustolls
Awitava	Loamy-skeletal, mixed, active, mesic Ustic Haplocalcids
Barx	Fine-loamy, mixed, superactive, mesic Ustic Calciargids
Battlerock	Fine-loamy, mixed, superactive, calcareous, mesic Typic Torrifluvents
Beje	Loamy, mixed, superactive, frigid Lithic Argiustolls
Bradfield	Fine, smectitic, frigid Udic Haplusterts
Burnson	Fine, smectitic, frigid Typic Haplustalfs
Burnson, dry	Fine, smectitic, frigid Typic Haplustalfs
Cahona	Fine-silty, mixed, superactive, mesic Calcidic Haplustalfs
Claysprings	Clayey, smectitic, calcareous, mesic, shallow Typic Torriorthents
Crosscan	Loamy-skeletal, mixed, superactive, calcareous, mesic, shallow Ustic
Dalmatian	Fine-loamy, mixed, superactive, frigid Cumulic Haplustolls
Decorock	Clayey-skeletal, smectitic, mesic Typic Argigypsids
Detra	Fine-loamy, mixed, superactive, frigid Pachic Argiustolls
Dolcan	Loamy, mixed, superactive, calcareous, mesic, shallow Aridic Ustorthents
Dolores	Clayey-skeletal, smectitic, frigid Typic Paleustalfs
Falconry	Loamy, mixed, superactive, frigid Lithic Haplustolls
Farb	Loamy, mixed, superactive, calcareous, mesic Lithic Torriorthents
Fardraw	Clayey-skeletal, smectitic, frigid Typic Argiustolls
Fivepine	Clayey, smectitic, frigid Lithic Argiustolls
Fluvaquents	Fluvaquents
Fluvents	Fluvents

Component Name	Soil Taxonomy
Fughes	Fine, smectitic, frigid Pachic Argiustolls
Gapmesa	Fine-loamy, mixed, superactive, mesic Ustic Haplargids
Gladel	Loamy, mixed, superactive, mesic Aridic Lithic Haplustepts
Granath	Fine-silty, mixed, superactive, frigid Typic Argiustolls
Haplustalfs	Haplustalfs
Haplustolls	Haplustolls
Herm	Fine, smectitic, frigid Typic Argiustolls
Hesperus	Fine-loamy, mixed, superactive, frigid Pachic Argiustolls
Ilex	Fine, smectitic, frigid Calcic Haplustalfs
Irak	Fine-silty, mixed, superactive, mesic Cumulic Haplustolls
Jemco	Fine-loamy, mixed, superactive, frigid Typic Haplustalfs
Katzine	Loamy-skeletal, mixed, superactive, mesic Aridic Calciustepts
Katzine, dry	Loamy-skeletal, mixed, superactive, mesic Ustic Haplocalcids
Kucu	Fine-silty, mixed, superactive, mesic Calcidic Haplustalfs
Kwiavu	Fine-loamy, mixed, superactive, frigid Typic Haplustalfs
Lillings	Fine-silty, mixed, superactive, calcareous, mesic Ustic Torrifluvents
Littlewater	Loamy-skeletal, mixed, superactive, frigid Typic Haplustalfs
Mack	Fine-loamy, mixed, superactive, mesic Typic Calciargids
Mariano	Loamy-skeletal, carbonatic, mesic Typic Haplocalcids
Mikett	Fine-loamy, mixed, superactive, calcareous, mesic Oxyaquic Torriorthents
Mikim	Fine-loamy, mixed, superactive, calcareous, mesic Ustic Torriorthents
Moento	Fine-loamy, mixed, superactive, frigid Typic Argiustolls
Nees	Loamy-skeletal, mixed, superactive, mesic Lithic Haplustalfs
Nortez	Fine, smectitic, frigid Typic Argiustolls
Northrim	Fine-loamy, mixed, superactive, frigid Typic Haplustalfs
Ormiston	Clayey-skeletal, smectitic, frigid Calcic Haplustalfs
Pagayvay	Loamy-skeletal, mixed, active, mesic Ustic Haplocambids
Pagoda	Fine, smectitic, frigid Vertic Argiustolls
Payter	Coarse-loamy, mixed, superactive, mesic Cumulic Haplustolls
Pogo	Fine-loamy, mixed, superactive, calcareous, mesic Typic Fluvaquents
Pramiss	Fine, smectitic, frigid Typic Argiustolls
Pulpit	Fine-silty, mixed, superactive, mesic Aridic Haplustalfs
Ramper	Fine-loamy, mixed, superactive, calcareous, mesic Aridic Ustifluvents
Ravola	Fine-silty, mixed, active, calcareous, mesic Typic Torrifluvents
Recapture	Fine-loamy, mixed, superactive, mesic Typic Natrargids
Ricot	Fine, smectitic, frigid Typic Argiustolls
Rizno	Loamy, mixed, superactive, calcareous, mesic Lithic Ustic Torriorthents
Romberg	Loamy-skeletal, mixed, superactive, mesic Ustic Haplargids
Salamander	Loamy-skeletal, mixed, active, mesic Typic Calcigypsids
Schrader	Coarse-loamy, mixed, superactive, frigid Cumulic Endoaquolls
Sharps	Fine-silty, mixed, superactive, mesic Aridic Haplustalfs
Sharps, dry	Fine-silty, mixed, superactive, mesic Aridic Haplustalfs

Component Name	Soil Taxonomy
Shawa	Fine-loamy, mixed, superactive, frigid Pachic Haplustolls
Sheek	Loamy-skeletal, mixed, superactive, frigid Typic Haplustalfs
Sheppard	Mixed, mesic Typic Torripsamments
Sideshow	Fine, smectitic, mesic Aridic Haplusterts
Tesajo	Loamy-skeletal, mixed, superactive, mesic Cumulic Haplustolls
Torriorthents	Torriorthents
Towaoc	Loamy-skeletal, mixed, superactive, frigid Typic Haplustalfs
Tragmon	Fine-loamy, mixed, superactive, frigid Typic Argiustolls
Typic Torriorthents	Typic Torriorthents
Umbarg	Fine-loamy, mixed, superactive, mesic Cumulic Haplustolls
Ustic Torrifluvents	Ustic Torrifluvents
Uzacol	Fine, smectitic, mesic Vertic Natrargids
Wauquie	Loamy-skeletal, mixed, superactive, mesic Aridic Haplustalfs
Wetherill	Fine-silty, mixed, superactive, mesic Aridic Haplustalfs
Wetoe	Loamy-skeletal, mixed, superactive, mesic Aridic Haplustalfs
Winner	Fine-loamy, mixed, superactive, calcareous, mesic Cumulic Endoaquolls
Yarts	Coarse-loamy, mixed, superactive, calcareous, mesic Ustic Torriorthents
Zigzag	Clayey, smectitic, calcareous, mesic, shallow Aridic Ustorthents
Zwicker	Fine, smectitic, mesic Chromic Haplotorrerts
Zyme	Clayey, smectitic, calcareous, mesic, shallow Ustic Torriorthents

Soil Productivities

The productivities of study-area soils as modeled in the current version of the Village Project are based on a number of soil and climatic properties. The distribution and extent of soil complexes is a primary factor, as is the wide range of soil moisture retention values exhibited by these soils. These factors relate to potential productivity of both maize and the natural resources of interest here. A major influence on these factors is the topographic positions of the many soils. Elevation and slope, for instance, are of prime importance in this regard, as is aspect to a (probably) lesser extent.

Variation in topographic settings across the study area influences both soil temperatures and depositional environments. The highly productive loess, for instance, is found primarily on mesa tops (Arrhenius and Bonatti1965), where it receives substantially more solar radiation. Sunlight is the major contributor in raising soil temperatures, promoting primary productivity when soil moisture is available. Mesa-top soils are normally much less susceptible to erosion than are soils on hillsides, canyon slopes or canyon bottoms. The generally low slopes found on mesa tops allow soils to develop with little movement, increasing soil depths, supporting denser vegetation, and thus accumulating more organic materials. In fact, mesa-top eolian deposits represent some of the most widespread and agriculturally productive soils in the region, and were certainly essential to support the agrarian households whose settlement patterns this project aims to model.

Canyon walls, on the other hand, have much steeper slopes, resulting in thinner, generally poorly sorted soils. Increased erosion in steep settings retards soil development, leading to generally lower fertility and water retention. These rockier colluvial soils support less productive vegetation overall than soils located either above, on the mesa tops, or on the canyon floors below (compare the productivities shown on Figure 3.2 to topography shown in Figures 1.2 and/or 2.2).

The floors of the many canyons in the study area host various amounts of alluvial and colluvial soils, many of which are both deep and relatively productive. These generally low-slope environments can be well-watered, and commonly experience warmer daytime temperatures than other topographic settings. A potential problem for agricultural productivity in canyon bottoms is the very real possibility of substantially lower nighttime temperatures resulting from cold-air drainage (Adams 1976). Native vegetation does not seem to be adversely affected by cold-air drainage, and canyon bottoms provide good habitat for both lagomorphs and artiodactyls. Prehistoric sites are not uncommon in these settings either, but appear much more frequently atop mesas and/or on canyon rims adjacent to mesa tops.

The paleoproductivity data planes are the primary datasets used in the simulation to account for variation in productivity of both maize and native vegetation. Modeling soil productivity involves the combination of many types of data, and much analysis. The current version of the Village model includes substantial revision of paleoproductivity (from that used in the earlier version as reported by Kohler et al. 2000), resulting in the extension to A.D. 600 of the modeled period, as well as explicit inclusion of annual temperature in the productivity analyses. Nevertheless, the PDSI is still used as a basic component of the paleoproductivity modeling, and this requires calculation of soil moisture retention values as shown in Appendix A.

Calculating mean soil moisture capacity closely follows the methods used for the original soil productivity retrodiction completed by Van West (1990, 1994). The soil profile for each soil component is separated into upper and lower levels of 0 – 6 inches and 7 – 60 inches respectively. Data on moisture capacity is provided in the soil survey tables reporting physical soil properties. These important data include the available water capacity for each level of the soil profile.

> Available water capacity refers to the quantity of water that the soil is capable of storing for use by plants. The capacity for water storage is given in inches of water per inch of soil for each soil layer. The capacity varies, depending on soil properties that affect retention of water. The most important properties are the content of organic matter, soil texture, bulk density, and soil structure [Ramsey 2003:181].

Converting the soil survey data to appropriate input data for paleoproductivity modeling required calculating mean values of available water capacity for each soil within both the upper (6”) and lower (54”) levels. For the rare cases where both upper and lower levels consist of a single value, this was straightforward. In most cases, however, calculating the final values was not so readily accomplished. For a complete discussion of the steps involved, I will use a multi-component complex with multiple profile divisions per level as an example. Village project soil code (VPSC) 7 provides such a case (see Appendix A).

This soil complex (VPSC 7) comprises two components, Arguistolls and Haplustalfs, each representing 30 percent of the complex. Another 25 percent of the complex consists of rock outcrop, providing neither available water capacity (AWC) nor any productivity. The 60” profile of the Arguistolls component is initially divided into six levels, with varying available water capacities. In calculating these values for our two levels, one of these six (4 – 13”) was subdivided. Values of available water capacity are provided as a range, in (fractions of) inches of water per inch of soil. These ranges are converted to a mean value for each level, and the mean values are then multiplied by the number of inches for which the value holds. The resulting values are then multiplied by the proportion the component contributes to the complex. These values are then summed within each of the upper and lower levels to get a total available moisture capacity per level per component. The resulting totals are added to the corresponding values from additional components to get total AWC values for each level for each soil.

Results of these calculations were transferred to a table listing each VPSC and the AWC values for their upper and lower levels. These values were then used as input to

SAS “PROC CLUSTER” to perform cluster analysis on 56 soils for which historic bean production data are available (Figure 5.3).

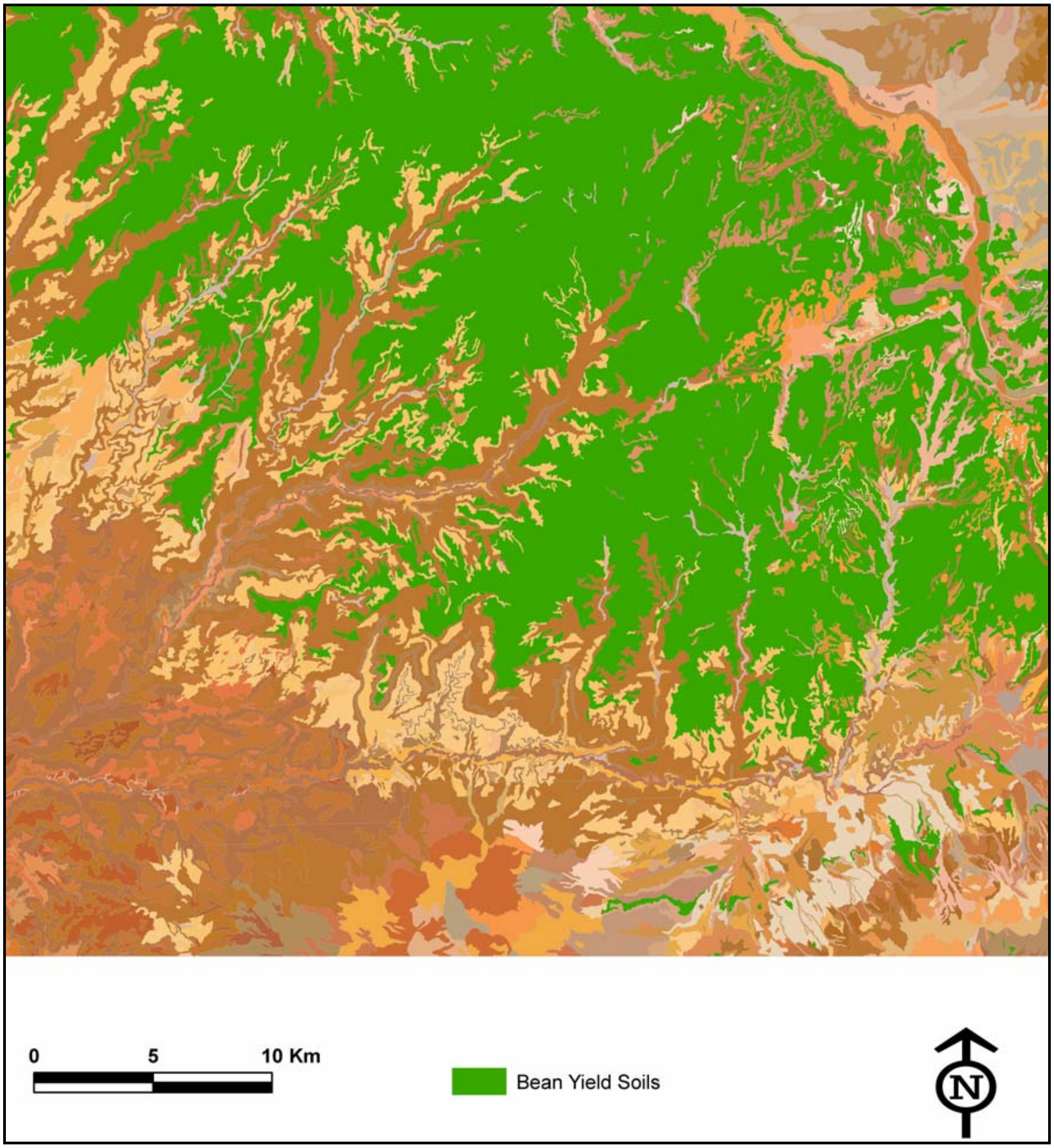

Figure 5.3. Map of study area soils for which historic bean crop yields are available.

This procedure resulted in 14 clusters of soils that are similar with respect to average water capacity and potential productivity. These data were then associated with four elevational bands coinciding with the elevations of four regional weather stations for which historic weather data are recorded. The result is 56 combinations of soil AWC and elevation (4 * 14), allowing further analyses of potential productivity for each soil depending on the elevation at which it is located. The use of four elevation bands allows more precise modeling of PDSI, since each has a different combination of mean annual temperature and precipitation (see below).

These steps provided the means to calculate the spatial component of the productivity of study area soils. A second important component is temporal variation in productivity influenced by annual differences in climate. The variations in precipitation and temperature were addressed using long-term tree-ring data from regional studies. Deviations from mean tree-ring widths were correlated with variation in temperatures (Figure 2.7) recorded at regional weather stations (Figure 2.6). Variation in available soil moisture is retrodicted using PDSI regressed against tree-ring data from the Mesa Verde Douglas-fir series (Varien et al. 2006). More detailed discussion of the paleoproductivity reconstruction is provided in Kohler et al. (2006) and Varien et al. (2006).

Calculating Net Primary Productivity

The detailed nature of the simulation of natural biomass productivity on the model landscape makes it difficult to analyze. Since so many native species contribute different proportions to the native plant communities of each of the many soils, it is difficult to determine that the simulation is accurately replicating the natural productivity of vegetation supported by study area soils. In an initial effort to examine the validity of production of critical natural resources upon the simulated model landscape, normal-year productivity of each natural species' annual NPP is calculated using Microsoft Excel™ spreadsheet functions to process soil survey data.

Although the data on "Range Production" supplied for study-area soils in each of the three soil surveys are the best available, they are nonetheless not as precise as I would like. Two factors are of particular interest in this sense. One is the fact that soil map units (musyms), as depicted spatially on the polygon maps, often represent multiple soil components. A second concern is that plants contributing to native plant communities associated with the different soil components don't constitute 100 percent of the communities, so data are missing.

Most of the soil complexes assigned a VPSC consist of multiple components. These soil components make up varying proportions of the total for their soil complex, and often have different annual NPP values and support slightly different native plant communities. In most cases, the combination of components within a given complex does not account for 100 percent of the unit. Given this, I assume that the remaining proportion of each complex is adequately represented by the components for which data are supplied.

From soil survey data on rangeland productivity I calculated the production of all critical natural resources for each soil complex for a normal year, based on the annual NPP of associated vegetation. The raw data are relatively straightforward, but conversion to data analogous to that produced by the model is not. The primary productivity reported in the soil surveys was processed for model input, and calculated outside of the model to learn what the normal-year model landscape potential actually should be.

The 139 soil complexes comprise a total of 223 soil components contributing different proportions to the total of each soil complex. In most cases the total proportion from all components within a complex is less than one, with no data on what makes up the rest of the complex. While many soils consist of some proportion of one or more non-productive components, such as bare rock, badlands, or alluvial gravels, there is almost always some proportion of each soil complex unaccounted for in the soil survey data. Furthermore, the GIS survey maps show polygons solely on the basis of map unit symbols (now VPSCs) that identify each soil complex, not specific components of complexes. That is, there is no way to delineate components for use in the model.

With the aim of being as generous as possible in providing the natural resources model agents have available, I assume the data provided for soil productivity and related vegetation species for reported components are representative of the proportions of soil complexes not accounted for. In cases where nonproductive components contribute to the complex, this gives them a share of productive potential just as unaccounted-for proportions of each complex are implied to produce. The net effect of this weighting is perhaps a slight overproduction in primary productivity.

Primary productivity values are associated with each soil component as listed in the “Rangeland Productivity” tables of the soil surveys (e.g., Ramsey 2003:Table 7). Since listed soil components generally fail to account for the total of their soil complex, they are weighted such that the total proportion of productive soil components within each soil complex equals one. By weighting each reported component upward, I make the complex complete, assuming that unreported proportions are adequately represented by those that are. Additionally, the proportions that plant species contribute to each native vegetation community are also weighted to sum to one. Again, I assume the soil productivities and associated native plant species for which data are provided (for each soil component) are representative of what occurs in the proportion of each soil (complex) polygon for which no data are reported. Therefore, the percentages provided by each soil component and those of each associated plant species, are weighted to represent 100 percent of their respective complexes and communities.

For those soil complexes with only a single component, I simply assume the proportion that component contributes to the complex is representative of the remaining unreported proportion and make that proportion equal to one. For soil complexes with multiple components, the proportion of each is divided by the sum of their proportions. The resulting figures sum to one, and are assumed to represent the entire soil complex.

Net primary productivity is given as an annual rate per area (reported in pounds / acre) for each soil component. Although these rates vary between components, the rate given for the normal-year NPP for the dominant soil component is used in the calculation for normal-year NPP presented in Appendix B, in some cases compensating for the slight overproduction noted above. These figures are multiplied by 1.12 to arrive at normal-year productivity in kg/ha for each soil complex.

In the simulation model, primary productivity is calculated based on the proportion each native plant species contributes to each soil complex, depending on the paleoproductivity value for that soil in the focal year. Weighting of plant species' contributions to the native plant communities allows the model to simulate how much of each species grows per model cell in a given year. The procedures followed in this weighting are also worthy of discussion.

Assuming that data reported for native plant species within each community are representative of those not reported, species proportions are weighted to account for missing data. That is, rarely do the proportions of each species listed as contributing to the native vegetation community add up to one. Therefore, I divide one by the sum of species proportions for each community resulting in values used as scalars for the proportion each species contributes to each community. If a combination of species in a particular class of vegetation (trees, shrubs, forbs, or grasses) is reported as totaling 20 percent of a native vegetation community, for example, the weighting maintains the relative proportion of that vegetation class in the community. Using the weighted soil component figures and the weighted values for native vegetation communities, the productivity of each species within the associated native plant community is calculated for a normal year (see Appendix B).

As an example, let's consider the case of VPSC 11, which is a complex represented by two components, each supporting a slightly different native vegetation community (Appendix B). The primary component, Barx Loam, contributes 60 percent to the complex and the secondary component, Gapmesa, contributes 30 percent. The two components thus account for 90 percent of soil complex VPSC 11. The species proportions within these two components' native vegetation communities total .57 and .62 respectively. The native vegetation communities differ slightly, both by proportions of shared species and by inclusion of different species.

To calculate the contribution to NPP of each soil component, their proportions are each divided by the sum of their proportions, resulting in weighted proportions of .67 (60/90) for Barx, .33 (30/90) for Gapmesa, and a total for the complex of 1.0. The proportions of each native vegetation community are similarly weighted, in this case the contributing proportion of the community associated with Barx is weighted from .57 to .48, and that of Gapmesa from .62 to .52, again summing to 1.0. The proportions of each plant species are then multiplied by the weighted values for their respective soil component and weighting scalar of their respective native vegetation community. Thus the dominant species within the native vegetation communities associated with both the Barx and Gapmesa components, Galleta, has its .15 proportion contribution to each community multiplied by .67 and 1.75 (the Barx proportion of the complex and the weighting scalar for the native vegetation community associated with the Barx component, respectively), and .33 and 1.61 (the Gapmesa proportion of the complex and the weighting scaler for the native vegetation community associated with the Gapmesa component, respectively). The resulting weights for this species are .175 and .081 within the two native vegetation communities respectively. These weights are then added to arrive at the actual contribution of Galleta (.256) to model cells dominated by VPSC 11 (see Table 5.2).

This same procedure is applied to all soil complexes, soil components, associated native vegetation communities and their contributing plant species. The weighted values for each plant species for each soil complex are then converted to a 2-D array that the model reads at initialization. This occurs after the model reads the soil code array, allowing each model cell to then “know” both what its soil type is, and how much of each native plant species it supports. This information is then combined with the annual, soil-specific, paleoproductivity values to provide NPP of native plants for each 4-ha model cell. This productivity is then used to model secondary productivity of both fuel wood standing crop and herbivorous animal populations.

Once these procedures were completed, the model was prepared to produce a biotic landscape based on primary productivity of each of the 93 (98 total, less five forbs that are essentially unused) plant species. The annual NPP of most of these species contributes to secondary productivity (that deriving from, and thus dependent upon, annual net primary productivity, see Odum 1971) of critical natural resources in the model world. Before moving on to the specifics of floral resources, a short discussion of how the model production compares to that calculated from "normal-year" productivity is needed.

Validating the Modeling of Critical Natural Resources

Before getting into the specifics of native vegetation within the study area, comparison of raw productivity as reported in the soil survey data and that simulated by the model is appropriate. As presented above, each soil complex has an associated "normal-year" productivity that estimates how much NPP of native plants can be expected (Doug Ramsey, personal communication 2003). These figures are actually bracketed by "favorable" and "unfavorable" year estimates as well, but our interest in is long-term average productivity across the study area. Therefore, I compare the "normal-year" productivity estimates from figures pertaining to relevant soils in the soil surveys to model output for the entire 700-year simulation.

Table 5.2. Example of Soil Component and Native Vegetation Weighting: Village Project Soil Code 11.

Component	% / Proportion	Wt. Proportion	Native Vegetation	%	Prop.	Scalar	Wt. Veg. Prop.	Wt. by Soil
Barx	60 / .6	0.666666667	Galleta	15	0.15	1.754386	0.263157895	0.1754386
			Indian Ricegrass	10	0.1	1.754386	0.175438596	0.11695906
			Muttongrass	10	0.1	1.754386	0.175438596	0.11695906
			WY Big Sagebrush	10	0.1	1.754386	0.175438596	0.11695906
			Blue Grama	5	0.05	1.754386	0.087719298	0.05847953
			N. M. Feathergrass	5	0.05	1.754386	0.087719298	0.05847953
			Winterfat	2	0.02	1.754386	0.035087719	0.02339181
			Totals:	57	0.57		1.0	0.66666667
Gapmesa	30 / .3	0.333333333	Galleta	15	0.15	1.612903	0.241935484	0.08064516
			N. M. Feathergrass	15	0.15	1.612903	0.241935484	0.08064516
			Indian Ricegrass	10	0.1	1.612903	0.161290323	0.05376344
			WY Big Sagebrush	10	0.1	1.612903	0.161290323	0.05376344
			Blue Grama	5	0.05	1.612903	0.080645161	0.02688172
			Western Wheatgrass	5	0.05	1.612903	0.080645161	0.02688172
			Winterfat	2	0.02	1.612903	0.032258065	0.01075269
			Totals:	62	0.62		1.0	0.33333333

Figure 5.4 shows the results of long-term model output of annual NPP across the study area in comparison to calculation of "normal-year" NPP productivity estimates from all relevant soils as reported in the soil surveys. Extreme productivity values are 336 and 257 kg/ha as minimums and 3360 and 3045 kg/ha as maximums (means of 1155 and 1071 kg/ha) for the soil survey and model output respectively. Note that model output is slightly lower overall than the figures from the soil surveys. Contrary to the potential for slightly overproducing noted above, this is to be expected since there are long periods within the seven centuries of the simulation with below normal growing conditions. Nevertheless, the close correspondence between soil survey and model output in mean, median, and upper and lower quartile figures suggests the model does a good job of producing valid long-term growth (in terms of annual NPP) on the model landscape.

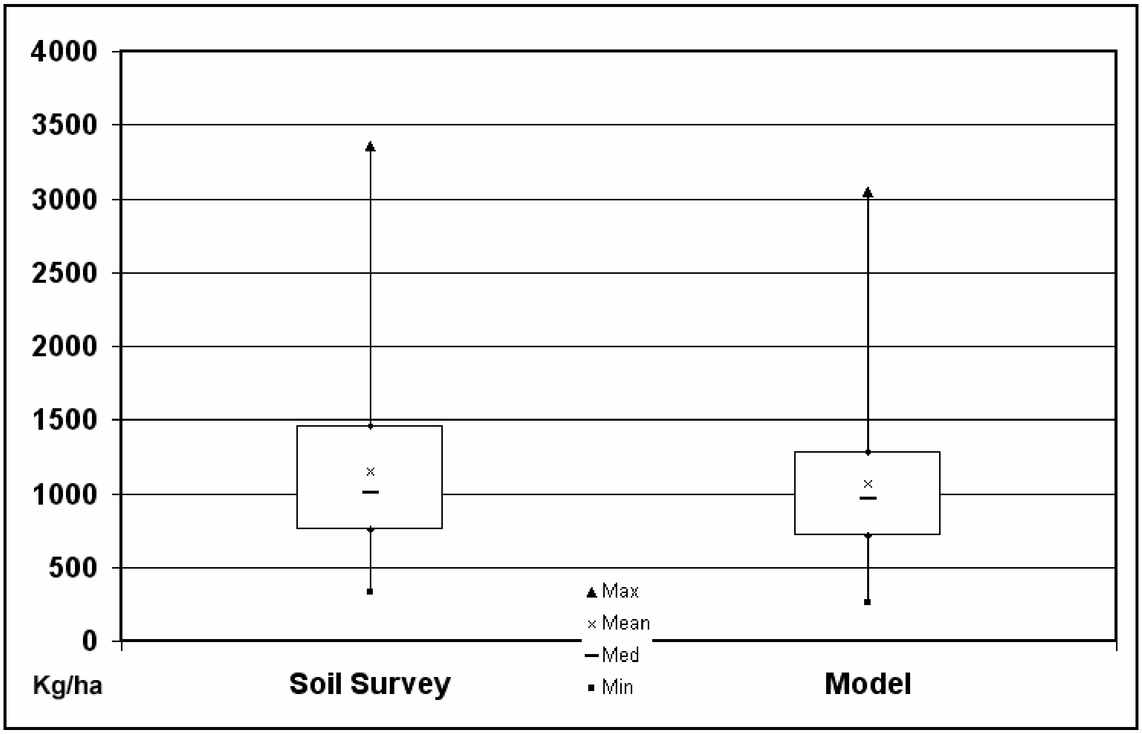

Figure 5.4. Comparison of normal-year annual NPP as reported in the soil surveys and mean long-term output from the simulation for all soils.

The results of building the soil model appear to be very satisfactory, both on a per soil basis, as well as in the long-term context across the entire study area. For a more detailed look at figures for individual soil complexes, refer to the third column of Appendix B. Now that the base data for productivity are established, we can move on to discussion of modeling vegetation as both primary and secondary productivity.

CHAPTER 6: BUILDING THE MODEL: CRITICAL FLORAL RESOURCES/FUELS

The critical natural resources model discussed in this dissertation relies primarily on the distribution and annual new growth of native plants associated with soils in local soil surveys. As discussed in the previous two chapters, each soil complex provides an annual retrodicted paleoproductivity to each model cell in which it is the dominant soil. This productivity is then distributed to modeled resources, depending on the species within the associated native plant community, and on whether or not the model cell is under cultivation by model agents. In cases when no farming is underway within a model cell, all potential productivity goes directly to the primary productivity of native species of the appropriate soil, in proportion to that species' contribution to the associated vegetation community. While under cultivation, farmed plots do not produce any natural resources. That is, the native vegetation is replaced by cultivated crops (maize), and neither fuel nor animal resources are produced or supported as long as the plot is farmed.

This chapter describes how the various classes of vegetation, trees, shrubs, and grasses are modeled, based on their natural, archaeological, and simulated occurrence within the study area. Although nine species of forbs are supported by study area soils, only one of these is a preferred food for the animals modeled here. Since that species occurs as ≤ 5 percent of the native vegetation in only three soils, each of which has very limited occurrence within the study area, forbs are neither modeled nor discussed further. Tree, shrub, and grass species' contributions to secondary productivity are important concerns, and are the main focus of this chapter. Because it is secondary production that model households seek and respond to in making settlement decisions.

Plants in the tree and shrub classes are all woody species and thus support production of both fuelwood and, potentially, animal protein. Grasses are not expected to have been used as a significant source of fuels, and so can only contribute to production of animal protein in the cases where they are a preferred food species of lagomorphs. Although some researchers have reported mule deer eating grass in the early spring, grasses make up only a very small percentage (<1 percent) of deer diets (Anderson, Snyder and Brown 1965; Collins and Urness 1983), and are not modeled as deer food here.

Trees represent one of the greatest potential contributors to natural resources used by model households. They provide preferred fuels and deer browse, and represent a significant proportion of total biomass on soils that support them. I therefore begin this discussion with the arboreal resources available within the study area.

Trees

In this study, arboreal resources are represented by 10 named species of trees, and, to a limited extent, by the category "other trees" listed in the soil surveys as components of particular native vegetation communities (Table 6.1). Some of these species provided numerous resources commonly used by the prehispanic Puebloans, notably piñon nuts and juniper bark and berries, potentially oak acorns, and any number of other materials.

The present modeling of trees as primary producers of critical resources, however, addresses only their secondary production. My usage of the term "secondary productivity" departs from that of Odum (1971), in that I consider not only the growth of animals supported by annual NPP, but also the wood it produces over the years. Thus secondary productivity as used here is in the form of woody fuels, and the artiodactyl and lagomorph browse that annual NPP of native vegetation produces. All species of trees produced wood available as fuel to prehistoric households. Tree species representing preferred browse for the animals modeled as protein sources are reported in the following chapter describing the modeling of faunal resources.

Table 6.1. Tree Species Contributing to Native Plant Communities and Modeled as Potential Supporters of Secondary Production of Fuel and Protein.

Common Name	Scientific Name
Blue spruce	*Picea pungens* Engelman
Cottonwood	*Populus fremontii*
Douglas fir	*Pseudotsuga menziesii*
Narrowleaf cottonwood	*Populus angustifolia*
Ponderosa pine	*Pinus ponderosa*
Quaking aspen	*Populus tremuloides*
Rocky Mountain maple	*Acer glabrum*
Rocky Mountain juniper	*Juniperus scopulorum*
Twoneedle pinyon	*Pinus edulis*
Utah juniper	*Juniperus osteosperma*
Other trees	

In general, trees comprise a low proportion of species in the native vegetation communities (10 of 93), though their long-term productivities were arguably more important to regional inhabitants than those of other floral species. This is primarily due to the cumulative standing crop of trees, which constitutes much more of the biomass on soils supporting trees than is made up of smaller shrubs and grass species. This is not to imply that across the study area overall standing crop of trees is greater than that of shrubs.

Biomass Distribution

The distribution of arboreal biomass can be considered in at least two ways. The first of these is the spatial distribution of different soils and their associated native vegetation communities. Many soils, due to either their physical properties or their locations, support few to no trees. This is especially true of soils located in the southwest portion of the study area, which are generally very dry and alkaline. Soils in higher portions of the study area, on the other hand, receive more precipitation, are generally well developed, retain more available moisture, and support much higher densities of trees.

In the higher, moister areas, ponderosa pine forests dominate the groundcover. At climax community states, high volumes of trees also occur on the Ute Mountain and Mesa Verde portions of the study area. In ponderosa and piñon-juniper forests, understory vegetation generally represents a small proportion of the total biomass (Everett and Koniak 1981). However, soils supporting tree species are not always dominated by thick forests.

Conversely, in the lower, drier, portions of the study area, grasses and shrubs dominate, with arboreal biomass represented primarily by widely scattered, shrubby, juniper trees. In the lowest parts of the study area, to the extreme southwest, vegetation consists primarily of grasses, saltbush and greasewood. In this much drier part of the study area, trees–primarily cottonwoods and occasional shrubby junipers–occur almost exclusively within the bottoms of drainages.

The spatial distribution of forest is somewhat variable in the long-term, but this variation probably had little to no effect on settlement decisions of prehistoric households. Changes in the spatial extent of piñon in the region coincide with long-term trends in the intensity of summer monsoons (Petersen 1988). Variation in the influx of piñon pollen at Beef Pasture in the La Plata Mountains (east of the study area) are believed to result from changes in summer monsoon strengths; stronger monsoons promote higher piñon pollen influx. Between A.D. 500 and 1300 this piñon pollen influx is shown as a bell-shaped curve, with a peak at A.D. 900 (Petersen 1988:Figure 55). This indicates a gradual increase in the strength of the summer monsoon up until the mid-point of Puebloan occupation, with a gradual decrease until abandonment.

Very gradual shifts in piñon forest extent across the study area were most likely imperceptible to generations of families living in various locations, so it is not expected that these would have influenced household moves in most cases. Moreover, I would suggest that the decrease of piñon pollen influx identified by Petersen (1988) at least partially resulted from the clearing of farm fields (e.g., Kohler 1992b; Kohler and Matthews 1988).

We must also consider how arboreal biomass is distributed on each tree; what proportion is leaves or needles, bark, live wood, and dead wood. This is especially relevant to the present study in that we are concerned with the distribution of woody biomass at the individual organism level. In aggregate, wood-producing plants are the focus of the fuel wood component of the critical resources model.

The amount of deadwood per individual tree is an important consideration in modeling both the availability of fuels in general, and firewood acquisition costs in particular. This is because model households are charged caloric costs to harvest fuels to meet their annual needs. Studies of the distributions of biomass for woody species relevant in this study (Chojnacky 1984; Miller, Meeuwig, and Budy 1981) indicate deadwood represents a relatively small proportion of the total for standing crops (Table 6.2).

Table 6.2. Mean percentages/standard deviations[1] of biomass distribution for major tree species in the study area.

Component	Pinon (%)	Juniper (%)
Wood	55 ± 5.96	53.25 ± 4.5
Bark	16.6 ± 1.14	10.5 ± .58
Deadwood	8.2 ± 3.1	4.5 ± 2.38
Foliage	20 ± 7.87	31.75 ± 6.65

[1] Mean and sd values based on dry weight as calculated by Miller, Meeuwig, and Budy 1981:Table 3.

In modeling the procurement of fuel woods this project implements two different energy costs for fuel acquisition by simulated households. A primary reason for this modeling strategy is that stone axes are significantly more effective for harvesting live (or green) wood than deadwood. This is generally the case with even the sharpest steel axes, as green wood normally is absorbent of impacts by sharp implements. Groundstone axes, in fact, have been shown to be rather ineffective in cutting deadwood (Robinson 1967).

Each load of a natural resource (green or dead in the case of wood) carried by a simulated household member is modeled as 25 kg (Lightfoot 1979), so the energy expended in transport is the same. The cost of harvesting fuels, however, is calculated as two hours of work calories for each load of live wood versus one for each load of deadwood. This is intended to account for the extra time and energy expenditure required to reduce woody elements to sizes one could return to his residence.

Resource Modeling

Modeling of fuel wood provided by trees is based on the NPP of the 10 named species (and the “other trees” category) reported as components of native vegetation communities in the soil surveys. Data on standing crop of trees within the study area are not available (all we know is which soils support trees in their associated native plant communities). We do know, however, that annual new growth of trees represents a small percentage of the total biomass of each specimen. Joseph Howell (1941) observed a 1.2 percent (of standing crop biomass) growth rate for slow-growing piñon-juniper on 39 plots in forests of the Southwest. Though based on Howell’s (1941) findings, the model growth rate is set slightly higher to account for faster-growing species. We use a 1.3 percent growth rate to stock the model landscape with arboreal standing crop, which is assumed to have been at climax state at A.D. 600, the first year of the simulation.

During an entire 700-year model run, each model cell coded with a soil whose native plant community includes trees was programmed to report the annual amount of new growth for all tree species. The resulting output matrix contained 700 rows (one per model year) of data, with each of 45,400 columns recording the weight, in kilograms, of (NPP) tree growth within the corresponding model cell.

These data were imported into MatLab™ to calculate the mean annual tree growth per model cell. The resulting mean weights are then multiplied by the inverse of

1.3 percent (76.9) to get figures for the total weight of standing crop of trees for each model cell. These figures are recorded in a text file, organized as a 200 row by 227 column matrix that the model reads (as a two-dimensional array) at initialization to stock the landscape with a standing crop of trees (Figure 6.1).

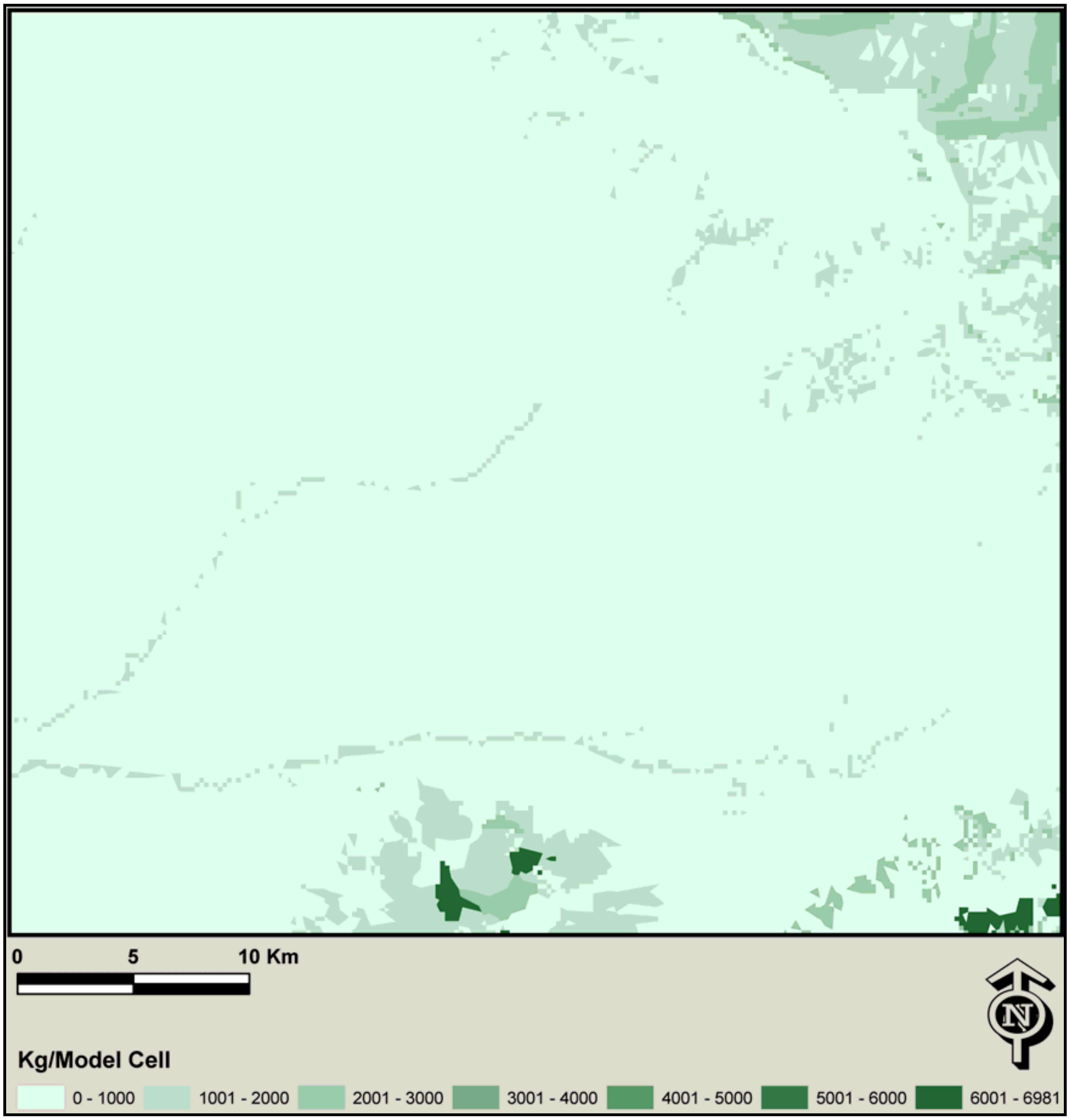

Figure 6.1. Initial standing crop of trees as modeled for the study area, shown as kilograms of biomass per 4-ha model cell.

Following initialization, biomass is added to the initial (climax) standing crop by all annual NPP of trees in the native vegetation community associated with each soil complex. To illustrate this, I’ll use the soil complex assigned VPSC 110, the most common (though minimally productive) soil in the study area (Figure 6.2).

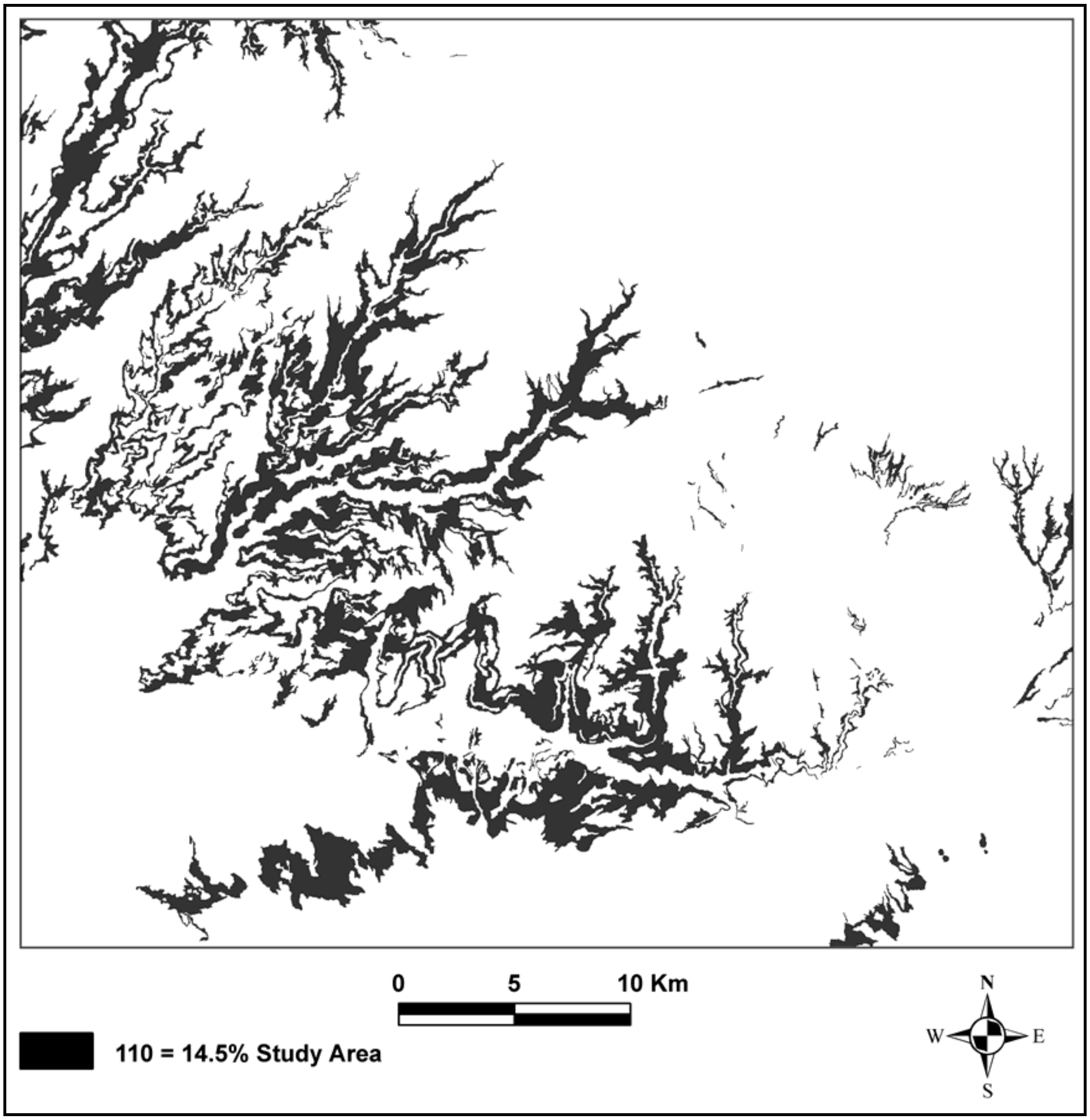

Figure 6.2. Distribution of soil assigned VPSC 110.

The VPSC 110 soil complex comprises Romberg and Crosscan components and occurs in the piñon-juniper ecological zone. For model cells coded with VPSC 110, the normal-year annual NPP is reported as 336 kg/ha, and the mean annual productivity produced by the model for all cells in which this soil occurs is 286.7 kg/ha. This NPP varies according to the paleoproductivity value for any given year and is potentially variable among all other soil complexes.

The two tree species supported by VPSC 110 are two-needle piñon (*Pinus edulis)* and Utah juniper *(Juniperus osteosperma)*, each making up (a weighted) 11.1 percent of the associated native vegetation community. The total NPP of these two species is therefore 75 kg/ha (.111 * 336 * 2) based on normal year productivity and 64 kg/ha (.111 * 286.7 * 2) based on mean paleoproductivity. As such, the model will produce an average of 256 kg (64 * 4) of tree biomass in cells coded with VPSC 110.

Using the conversion described above, the resulting standing crops for trees in model cells coded VPSC 110 are 23,070 kg based on normal-year productivity, and 19,686 kg based on long-term mean model productivity. The latter figure is thus 15 percent lower than that calculated on the basis of normal-year NPP. Nevertheless, the lower figure produced by our model is more than twice the minimum biomass for piñon-juniper reported by Samuels and Betancourt (1982, citing Howell 1941), though only about a third of what they use to show forest decimation in Chaco Canyon. At the same time, recall that VPSC 110 is the least productive soil in our study area, with its normal-year productivity of 336 kg/ha equal to only 29 percent of the mean normal-year productivity for all study area soils.

When calculating the actual annual increment of woody biomass the total NPP of arboreal species is reduced by 25 percent to account for foliage that does not eventually become woody tissue (Miller, Meeuwig, and Budy 1981). Of course the foliage biomass from tree species reported as preferred food is available as forage for the herbivores. If consumed, this primary production biomass contributes to the productivity of protein by supporting herbivore populations. If not consumed, it effectively decomposes; we do not model nutrient replenishment of soils through such decomposition.

In model cells already stocked with the climax standing crop of trees, all new NPP (less the 25 percent noted above) is added to the deadwood component of the arboreal biomass. Model cells from which fuels have been harvested have their standing crops of live wood replenished to the climax state stocking level by all available annual NPP in a given year/model step. The current model implementation caps standing crop live biomass at that set by the procedure described above for determining initial standing crop at model initialization.

Shrubs

Thirty-nine species of shrubs, as well as an “other shrubs” category, are supported by study area soils (Table 6.3). All are considered to be producers of wood for fuels. Many of these species undoubtedly provided important resources other than fuels to ancient consumers. In the present study, however, shrub primary productivity is of interest because of the secondary resource production it supports (in this case fuelwood and wild protein).

Table 6.3. Shrub Species Contributing to Native Plant Communities and Modeled as Potential Supporters of Secondary Production of Fuel and Protein.

Common Name	Scientific Name
Antelope bitterbrush	*Purshia tridentata*
Basin big sagebrush	*Artemisia tridentata tridentata*
Big sagebrush	*Artemisia tridentata*
Black sagebrush	*Artemisia nova*
Cliff fendlerbush	*Fendlera rupicola*
Cliffrose	*Purshia* spp.
Common chokecherry	*Prunus virginiana* spp.
Common snowberry	*Symphoricarpos albus*
Fourwing saltbush	*Atriplex canescens*
Gambel's oak	*Quercus gambelii*
Greasewood	*Sarcobatus vermiculatus*
Kinnikinnick	*Arctostaphylos uva-ursi*
Mormon tea	*Ephedra viridis*
Mountain big sagebrush	*Artemisia tridentata vaseyana*
Mountain mahogany	*Cercocarpus Kunth* spp.
Mountain snowberry	*Symphoricarpos oreophilus*
Oregongrape	*Berberis repens*
Rabbitbrush	*Chrysothamnus vaseyi*
Rubber rabbitbrush	*Chrysothamnus nauseosus*
Sagebrush	*Artemisia* spp.
Saltbush	*Atriplex gardneri*
Saskatoon serviceberry	*Amelanchier alnifolia*
Serviceberry	*Amelanchier*
Shadscale saltbush	*Atriplex confertifolia*
Shrubby cinquefoil	*Dasiphora floribunda*
Skunkbush sumac	*Rhus trilobata* Nutt.
Small Douglas rabbitbrush	*Chrysothamnus viscidiflorus*
Snakeweed	*Gutierrezia* spp.
Snowberry	*Symphoricarpos albus*
Squaw apple	*Peraphyllum ramosissimum*
True mountain mahogany	*Cercocarpus montanus*
Utah serviceberry	*Amalanchier utahensis*
Utah snowberry	*Symphoricarpos oreophilus utahensis*
Whortleleaf snowberry	*Symphoricarpos oreophilus*
Willow	*Salix* spp.
Winterfat	*Ceratoides lanata*
Woods' rose	*Rosa woodsii*
Wyoming big sagebrush	*Artemisia tridentata wyomingensis*
Yucca	*Yucca baccata*
Other shrubs	

In aggregate, shrubs represent a moderate proportion of the total annual biomass produced (Appendix B) across the study area (Figure 6.3).

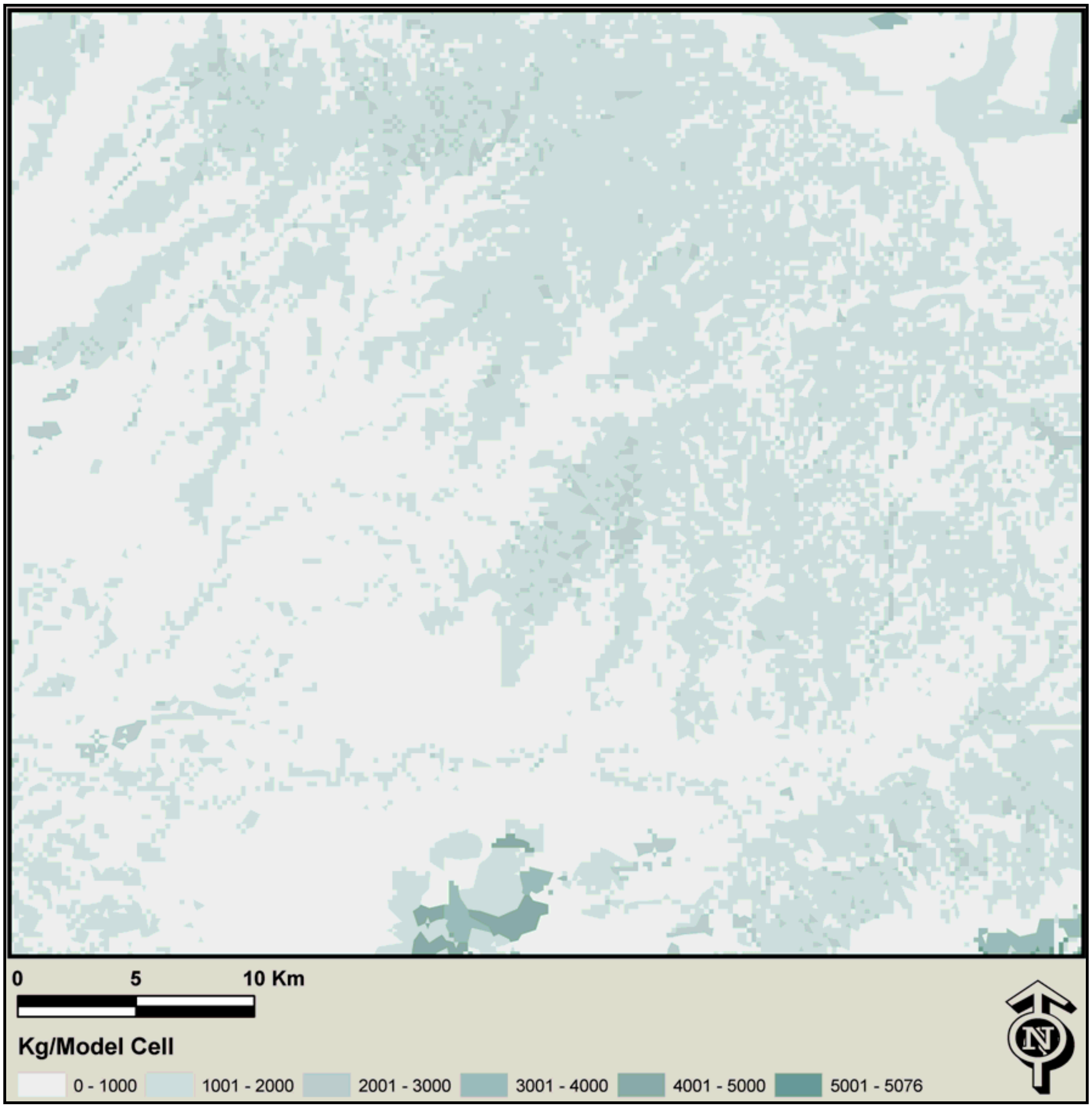

Figure 6.3. Initial standing crop of shrub species as modeled for each 4-ha model cell.

Comparison of Figures 6.1 and 6.3 readily shows that although both trees and shrubs provide some level of biomass across the entire study area, the bulk of the area that supports trees provides relatively low quantities, while that of shrubs provides moderate quantities of biomass.

The fact that shrubs out-produce trees in total NPP is more clearly demonstrated by Figure 6.4 that shows woody species productivity modeled by all soils across the study area for both vegetation classes in all 14 modeling periods. These figures can be adjusted to represent average fuel productivity by simply reducing the amounts by 25 percent, to deduct loss of foliage, as discussed above. Of course the ratios would be the same.

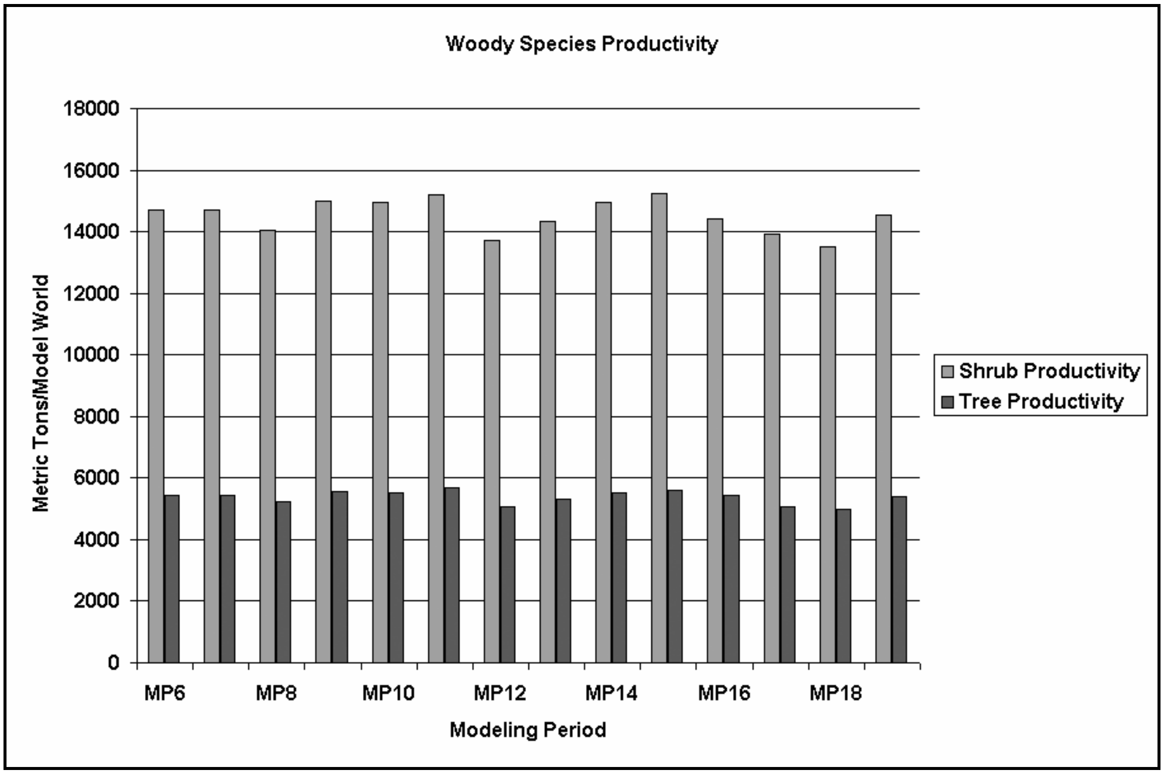

Figure 6.4. Average annual net primary productivity of woody vegetation classes aggregated across the study area, grouped by modeling period.

At the same time, because of various quantities, distributions, and productivities of soils within the study area, actual normal-year production of shrubs and trees, as classes of vegetation, is not so different. Figure 6.5 shows that shrubs do produce more annual NPP (and so contribute more to fuel production) per soil complex in normal years, but not quite as much more as Figure 6.4 suggests. Nevertheless, it is clear that shrubs, as a vegetation class, do contribute much more to the total production of woody biomass in the study area. The normal-year annual NPP (less 25 percent for lost foliage) of trees and shrubs is combined to produce fuels as shown in Figure 6.5.

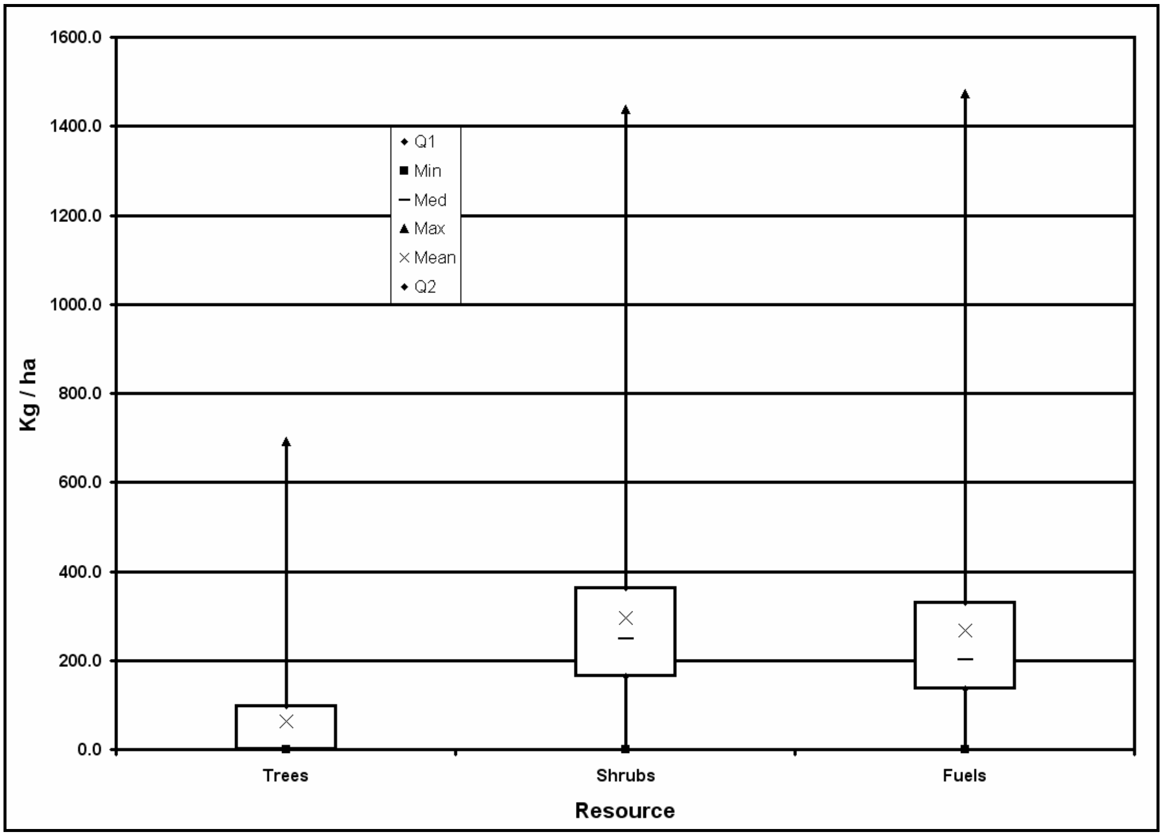

Figure 6.5. Normal-year annual NPP of trees, shrubs, and fuels for all soils.

Biomass Distribution

The biomass distribution of shrub species can be considered in the same ways as that of tree species. That is, both the spatial distribution of native vegetation communities with various proportions of shrubs and the distribution of biomass on individual specimens are important. Figure 6.3 maps the standing crop of shrubs across the study area, showing that areas supporting high productivity are mainly in the mid- to higher-elevation regions. Note that shrubs are also much more common than trees in lower elevation environments, as indicated by low to moderate levels of shrub productivity in the southwest portion of the study area. Interestingly, zones of mid- to high-productivity of shrubs, are very close to high productivity zones of trees. This is evident in areas such as those on the flanks of Ute Mountain and parts of Mesa Verde.

Reports of biomass distribution on individual plants for shrubs are uncommon in the literature. Chojnacky (1984:Table 2) provides figures for percentages of deadwood from a sample of individual specimens of mountain mahogany (*Cercocarpus*) from Nevada. Deadwood represents a mean of less than 3.4 percent (sd 3.8 percent) of the biomass for all diameters of this shrub species. That figure increases to 4.7 percent (sd 3.7) for specimens with diameters at root crown less than 8 cm (Chojnacky 1984). I suggest that although deadwood collected from smaller shrubs may have been used to start cooking and/or heating fires, larger-diameter materials made up the bulk of the fuelwoods harvested when available. Nevertheless, in lieu of additional data on shrub species' biomass distributions, the lower figure of 3.35 percent is used for the deadwood component of shrubs within the study area.

Resource Modeling

Standing crops of shrubs in each model cell are estimated in the same way as those of trees. Since standing crops are in general unknown, but growth rates are known in both an absolute sense and relative to the standing crop, we let the model retrodict the absolute productions and then multiply that production by the inverse of the relative growth rate to estimate the standing crop, at which model cells are initialized. As discussed above for trees, the model was run in its entirety with the NPP of shrub species per model cell output to an array that was then processed using MatLab™ functions to calculate the mean production of new growth per model cell. The resulting figures were multiplied by the inverse of the annual growth increment, based again on the inverse of the 1.3 percent following the findings of Howell (1941). Total shrub standing crop figures are represented as kilograms per model cell, written to a two-dimensional array in text file format, and used as input to initialize the model landscape. Conversion to a raster format map within the GIS allows display as shown in Figure 6.3.

Following initialization, shrub NPP is added to each model cell based on a combination of the following factors: the soil type; the proportion of shrubs in the associated native plant community; and the paleoproductivity value in the cell for the particular year.

To illustrate this, I'll again use the soil complex assigned VPSC 110, the most common soil in the study area (Figure 6.2). This soil complex comprises Romberg and Crosscan components and occurs in the piñon-juniper zone. Shrubs make up a weighted 27.9 percent of the species included in the native vegetation community of this soil complex (Appendix B). Normal-year NPP of VPSC 110 is 336 kg/ha, and the mean annual productivity produced by the model for all cells in which this soil occurs is 286.7 kg/ha. Thus the total NPP of the three shrub species supported by soil 110 is 93 kg/ha using the normal-year productivity figure and 80 kg/ha based on mean annual paleoproductivity. Translated to model cell production, the three shrub species produce an average of 240 kg of NPP per 4-ha model cell, during an annual model time step. Of this, 180 kg are expected to represent woody biomass, with the remainder representing foliage available for animal consumption.

Deadwood Productivity

The deadwood component modeled as part of the fuel load in each model cell is allowed to grow in each model step, provided some portion of the annual NPP remains following maintenance of live biomass standing crop of all woody species. Factors reducing the contribution of annual NPP of woody species to fuels include feeding by herbivores, woody species harvesting by model agents, and the clearing of plots for agriculture.

Actual rate of deadwood production, for a limited number of species, has been studied as part of this research. A fuelwood production/availability study was initiated by researchers at the Crow Canyon Archaeological Center in the early 1990s. Although the study has yet to be completed, I collected preliminary data from a sample of the original 20 fuelwood plots for use in this study.

The fuelwood study was initiated by establishing two 100 m * 10 m transects at different locations within the present study area. All specimens of woody plants were then mapped within 10 m segments of each transect. Each plant was consecutively numbered and tagged for future identification. Workers then collected all easily available deadwood from each plant, including that on the ground beneath the crown, recording the weights and species of deadwood recovered. “Easily available” means that resource extraction tools, like axes or saws were not used (Karen Adams, personal communication 2003). The data on available fuelwood was recorded in spreadsheet format, and some of the plots were revisited over the course of the next few years. Plants within those plots were once again harvested of both standing and downed deadwood, with weights and types again entered into the spreadsheet. Once collected, all deadwood was deposited outside of transect plots so as not to be re-counted in the future. The initial collections from the two transects were conducted between the years of 1990 and 1993.

During the summer of 2003, I revisited both of the fuelwood transects, and collected deadwood from each specimen (and beneath their crowns) located in five of the original 20, 10 * 10 m plots. Four species of woody plants were located in these plots, and all easily available deadwood was again collected, weighed, recorded, and discarded. Assuming the previously recorded deadwood collection was for all easily collected deadwood, these data allowed me to calculate average annual amounts of easily available deadwood produced by plants of each of these woody species over the 10 to 13 years that elapsed between the initial collections and mine.

There is no way to know how intensively prehistoric peoples collected fuels, I assume they expended more effort than only harvesting that which was “easily available”. Moreover, model agents are able to harvest all woody biomass from the model landscape. Therefore, in order to make a comparison between what I collected and what agents have available for collection, I have calculated mean values of deadwood produced for each of the four collected species from all soils that support them. Obviously, at some point the effort required to reduce large logs to a size useful for fuel will exceed that of traveling farther to collect more easily available fuels. So the total standing crop of fuels was likely never used.

Figure 6.6 shows that the average annual production of easily available fuels collected exceeds that of the annually produced (by the simulation) deadwood components of these species. The difference between easily collectable deadwood and that produced by the simulation is more pronounced with shrubs than trees, which is likely a result of the total accessibility of shrubs. Piñon represents the greatest fuel resource of the species collected, both by number of specimens and by weight of easily collected deadwood. Note that the means for both collected and simulated production for piñon are very similar, and that piñon is more productive than juniper, even though I was able to collect more of the latter.

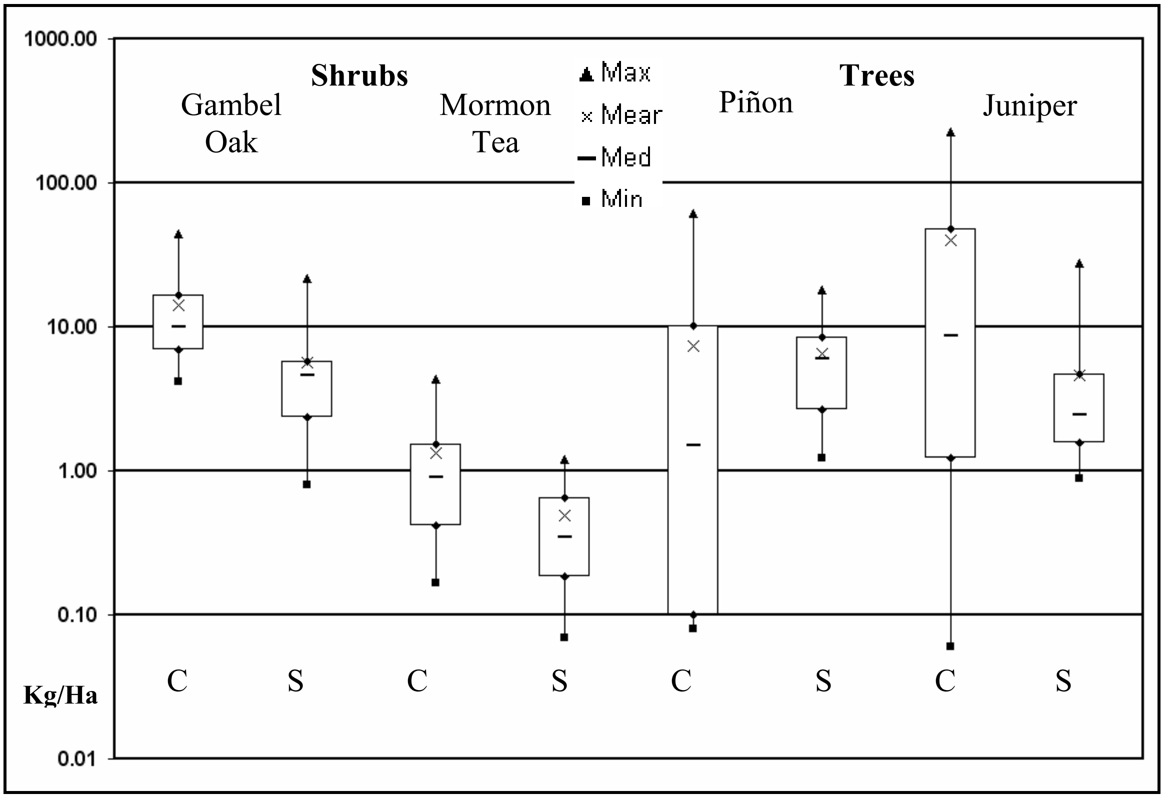

Figure 6.6. Comparison for four woody species of average annual production of easily collected (C) fuels from five 10 by 10 m plots and simulated (S) deadwood production.

The figures presented in Figure 6.6 for collected deadwood are based on a small sample of upland forest, and those for the simulated deadwood are mean annual production by all soils supporting these species on the model landscape. The interval between collections averaged 11.5 years, and it should be understood that not all deadwood collected beneath the crown of a particular specimen necessarily fell from that individual. In one case, I collected a large amount of downed piñon deadwood from beneath a numbered piñon specimen, the bulk of which was obviously derived from a nearby fallen tree.

It is my understanding that this was the procedure used during the original collections as well. The point is that although not all the deadwood collected from a particular plot necessarily originally grew there, it would have been produced nearby. It is assumed that, on average, the annual deadwood production for each of these species is representative of what could be obtained from soils on which they normally grow. Again, it is unknown how much of the total standing crop would normally be collected. Easily collected fuels, procured without the use of tools may not have been comparable to what prehistoric peoples normally collected, as far as the percent of total woody biomass available. Of course entire shrubs would be more or less easily collectable, but the larger portions of trees would probably not be.

The simulated deadwood production was averaged over the entire 700-year model run, as discussed above for productivity in general. Comparing these actual deadwood collection rates to those produced by the model shows that I was able to collect more "easily available" deadwood in a few hours that the model produces annually per species. This is not to suggest that much of what I collected was not produced over many years. It may be the case that, even though the deadwood collection plots were collected at least 10 years before my 2003 collection, a substantial amount had become easily available since the original collection (i.e. by falling from the tops of trees). Moreover, although the results of the deadwood collection study may suggest the model slightly underestimates rates of fuel production, the model does not address the often drastic reduction in fuel-loads caused by wildfires.

We do, however, subject deadwood to a four percent decay rate, such that deadwood produced in a given model step totally decomposes in 25 years if not harvested as fuel by model households. This rate of decay represents that expected of fuels that remain as standing deadwood. Downed deadwood (particularly piñon) probably has a much faster decay rate, but this rate is not known at present. In practice, downed deadwood more than five years old would provide such reduced energy that it would likely not be collected (e.g., Brisbin 1997). In this sense, we are again being generous to model agents with respect to resource productivity.

Grasses

The grass component of native vegetation communities supported by study-area soils comprises 35 identified species and an "other perennial grasses" category (Table 6.4). Again, as with the other vegetation classes, there is no doubt that some, perhaps many, of these species provided materials commonly used by prehispanic Puebloans within the study area. Since none of these grass species provides significant fuel, however, the interest here is on their contribution to supporting herbivore populations that prefer some of them as food. Since only the potential of grasses to support animals is important here, and this is restricted to lagomorphs, there is no need to distinguish between biomass allocations on individual specimens. So we don't need to allocate primary productivity between grass stems versus seeds. Animals that feed on any of the grass species are free to consume the entire plants.

In practice, in fact, there is no need to consider propagation of any native vegetation since annual NPP replenishes unused standing crop at every model time step. A more detailed discussion of standing crop of all species is provided in the concluding section of this chapter.

Table 6.4. Grass Species Contributing to Native Plant Communities and Modeled as Potential Supporters of Herbivorous Protein Sources.

Common Name	Scientific Name
Alkali sacaton	*Sporobolus airoides*
Arizona fescue	*Festuca arizonia*
Baltic rush	*Juncus balticus*
Blue grama	*Bouteloua gracilis*
Bluegrass	*Poa* spp.
Bottlebrush squirreltail	*Sitanion hystrix*
Columbia needlegrass	*Achnatherum nelsonii nelsonii*
Elk sedge	*Carex garberi*
Foxtail barley	*Hordeum jubatum*
Galleta	*Hilaria jamesii*
Indian ricegrass	*Oryzopsis hymenoides*
Inland saltgrass	*Distichlis spicata*
Kentucky bluegrass	*Poa pratensis L.*
Letterman needlegrass	*Achnatherum lettermanii*
Mesa dropseed	*Sporobolus flexuosus*
Mountain brome	*Bromus carinatus*
Mountain muhly	*Muhlenbergia montana*
Muttongrass	*Poa fendleriana*
Needleandthread	*Stipa comata*
Needlegrass	*Stipa Columbiana*
New Mexico feathergrass	*Stipa neomexicana*
Nodding brome	*Bromus anomalus*
Parry's oatgrass	*Danthonia parryi*
Pine dropseed	*Blepharoneuron tricholepis*
Pinyon ricegrass	*Piptochaetium fimbriatum*
Prairie junegrass	*Koeleria pyramidata*
Rush	*Juncus* spp.
Saline wildrye	*Leymus salinus*
Sand dropseed	*Sporobolus cryptandrus*
Sedge	*Carex bella*
Slender wheatgrass	*Agropyron trachycaulum*
Smooth brome	*Agropyron trachycaulum*
Thurber's fescue	*Festuca thurberi* Vasey
Tufted hairgrass	*Deschampsia caespitosa*
Western wheatgrass	*Agropyron smithii*
Other perennial grasses	*Poa* spp.

Each of the 139 soils in the study area supports at least one species of grass. Of course the proportions of grasses, as well as those of the other vegetation classes, are highly variable among different soil types. Compared with both the shrub and tree components of most vegetation classes, however, grasses are generally more prevalent (Appendix B), and productive as a whole, at least in terms of normal-year NPP.

Resource Modeling

Although grass species represent a mix of both annual and perennial types, all are effectively modeled as annuals. The biomass of each species is renewed within each of its native vegetation communities at every time step, at rates determined by the soil type supporting it, its contribution to the vegetation community, and the paleoproductivity of that soil in the relevant year. In contrast to the standing crops of trees and shrubs, the present model implementation does not initialize a standing crop of grasses.

Since there is no direct interest in the cumulative biomass of grasses by model households, there is no need to provide a standing crop of grass. So in this implementation, grasses are modeled based solely on annual NPP, with no biomass carried over from the previous year. For the purpose of feeding lagomorphs this is an acceptable strategy since these herbivores normally consume only new growth, as described in the following chapter. Moreover, the entire NPP of grasses is available for consumption, in contrast to the NPP of other vegetation classes.

Floral Species as Model Resources

The 139 soils distributed across the model landscape support 93 species of native vegetation. These annual and cumulative primary producers provide the biomass for the critical natural resource component for the current version of the Village Project model. As pointed out above, grasses are only annual producers, while trees and shrubs maintain a standing crop. Most biomass maintained by trees and shrubs is in the form of woody tissue, which is obviously an important characteristic of these plants.

Only 55 of the soil complexes on the model landscape support trees. Shrubs represent some proportion of the native vegetation on 132 of those 139 soil complexes, whereas all soils support at least one grass species. Reduction in the total number of soil complexes in the model world through the conversion to raster data, as described in the previous chapter, does not significantly alter the ratio of vegetation classes on the model landscape. Figure 6.7 shows that grass species (as a vegetation class) represent more than twice the percentage of all native vegetation communities as shrub species (as a vegetation class), which represent almost twice the percentages that tree species (as a vegetation class) contribute to native plant communities.

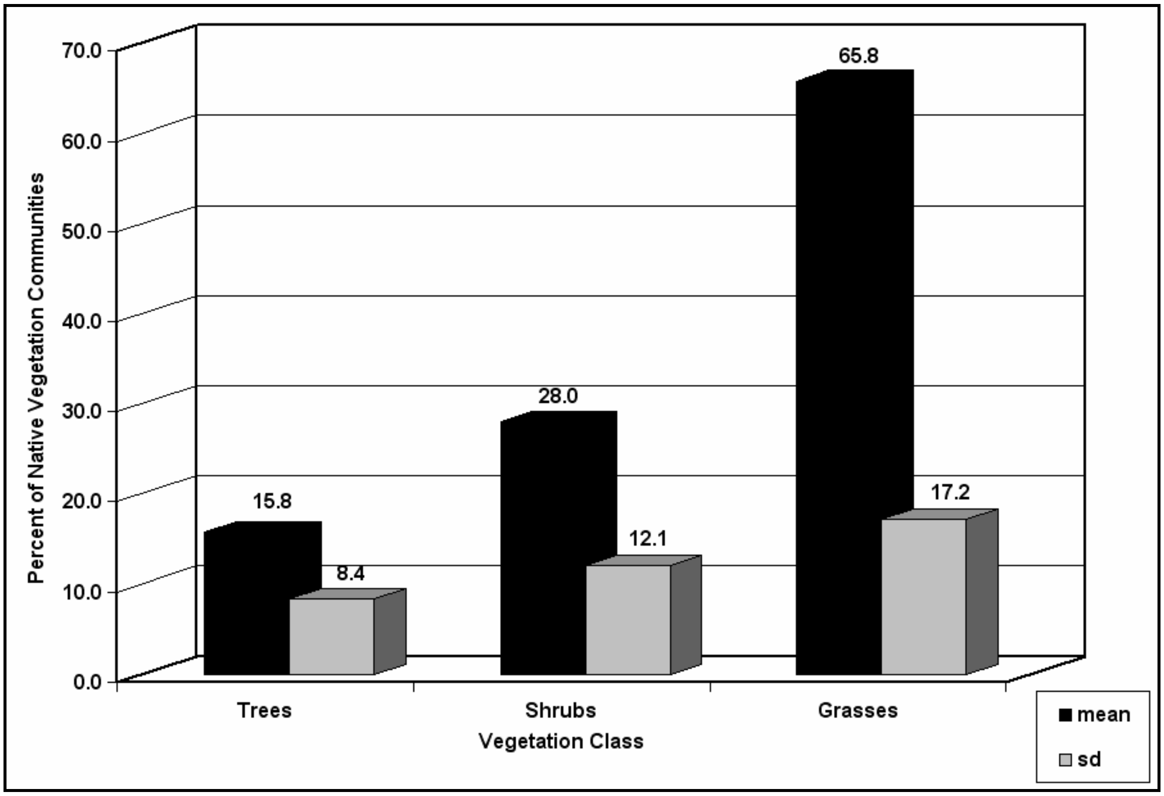

Figure 6.7. Aggregate contribution of species in each vegetation class (see Tables 6.1, 6.3 and 6.4) to all native vegetation communities (Appendix B).

Comparison of the normal-year productivities of the tree, shrub, and grass vegetation classes shows that in aggregate grasses also produce substantially more annual NPP than shrubs on study area soils, and that shrubs are more productive than trees in a normal year (Figure 6.8). Note that the tree class has the highest standard deviation from normal-year productivity on all tree-supporting soils, as is the case for percent of native vegetation community as shown above. But are these aggregate productivities consistent across the landscape?

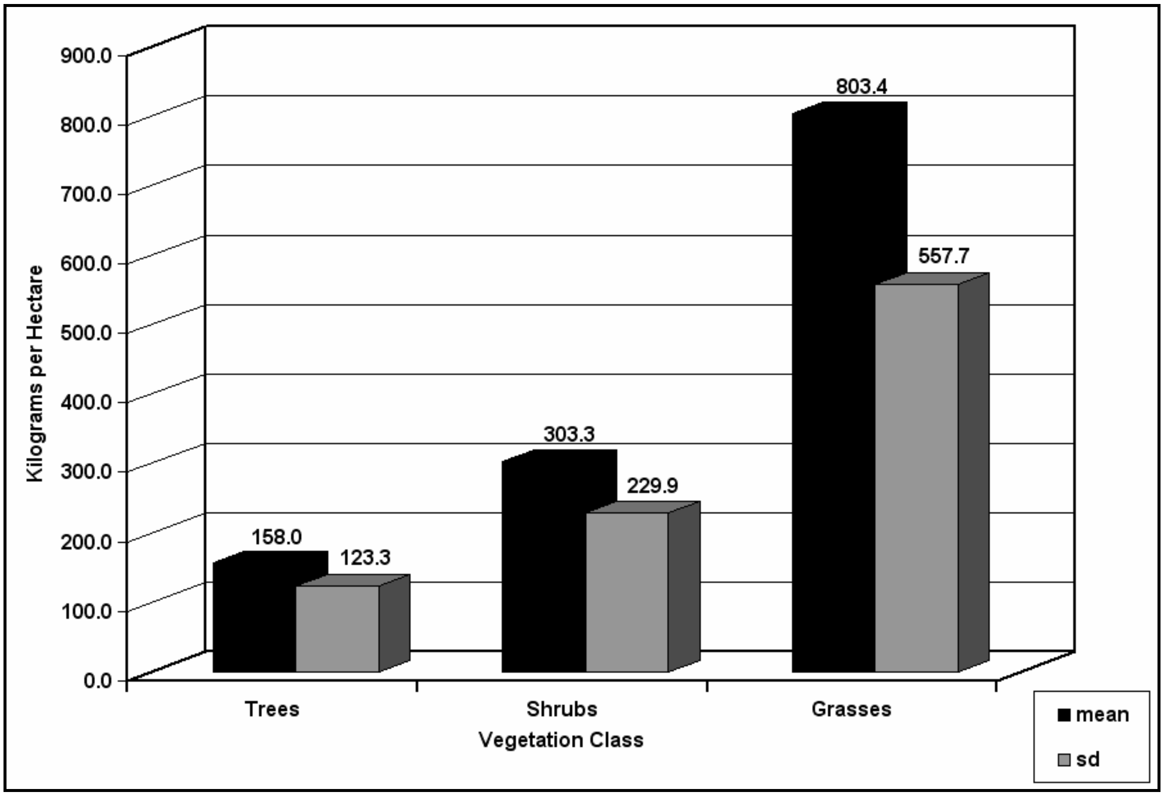

Figure 6.8. Normal-year productivity of vegetation classes for all soils on the model landscape, based on annual NPP of species within each class.

Recall from Figures 6.1 and 6.3 that higher productivities of both trees and shrubs generally occur in the northeastern half of the study area. Given that grasses contribute a low proportion of ground cover beneath piñon-juniper canopies, and that grasses are much more prevalent in the lower, drier southwestern half of the study area, the aggregate productivities may not adequately represent the vegetation distribution across the landscape. Even though the aggregate productivity of grasses is more than 2.5 times that of shrubs, this is not the case on many study area soils.

Figure 6.9 presents the normal-year productivity of vegetation classes on a per-soil basis. Note that many soils support no trees, while most support at least some shrubs and all support at least one grass species. It should therefore be realized that while lagomorph populations might thrive across the entire model world, deer and fuel woods likely will not. Tree and shrub productivity is in fact very low on many soils, while grass production is relatively high on most. Since all modeled fuel production is dependent on the annual NPP of woody species, it is clear that many soils can not supply much fuel.

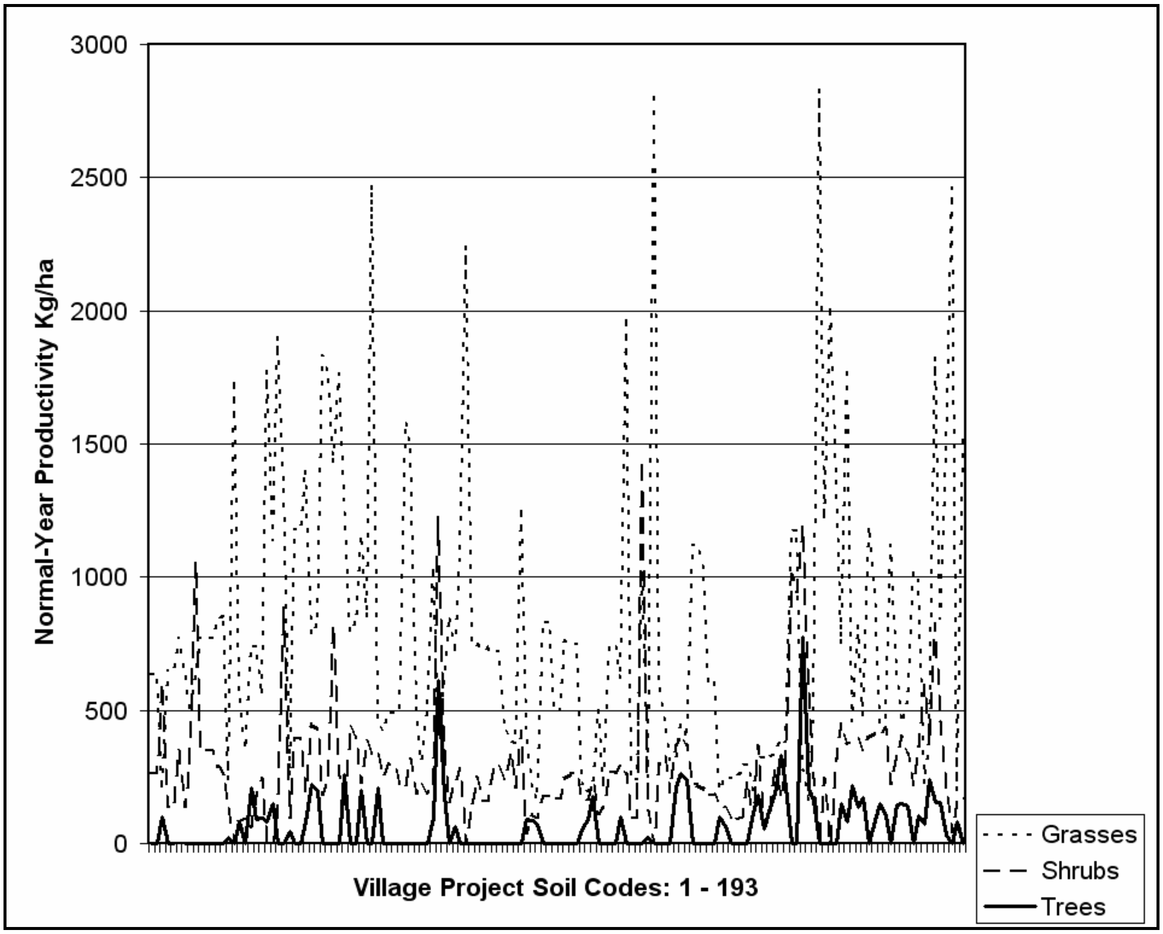

Figure 6.9. Normal-year annual NPP of vegetation classes on a per soil basis.

The contributions of each class of vegetation to native plant communities for all soils vary widely. Grasses are the dominant vegetation class on average, with shrubs more prevalent than trees. This is also the case with normal-year productivity, which is less than ideal for model households. That is, the more important, or preferred, fuels (tree species) are less productive than lesser preferred shrub species. Grasses are more common constituents of native plant communities, and more productive based on all soil productivity, but only provide resources to model households secondarily, through the potential feeding of lagomorphs.

Recall from Figures 6.4 and 6.5 that total usable standing crop of fuels is supplied predominantly by shrubs. Given this, it is interesting to note that tree species are most commonly cited as the preferred fuels of prehistoric households in the region (Adams and Bowyer 2002; Kohler and Matthews 1988), despite the fact that many soils don't support trees at all.

In the upland Southwest, temperatures are variable both diurnally and seasonally. Although subterranean structures are common throughout the Puebloan occupation of the region (and these are likely much more thermally efficient than surface structures), burning wood for heat was undoubtedly necessary for several months each year. Preparation of maize and other foods for consumption also required additional fuel when hearths were not in use for heat.

As anyone who has heated a home with wood will know, larger pieces of fuel are much better at sustaining BTU output than are smaller pieces. It is thus not surprising that tree species are prevalent components of prehistoric thermal feature refuse. An apparent preference for fuels derived from trees suggests that home heating was a primary use of fuel.

For cooking, on the other hand, small woody elements are much more efficiently procured and used. If the intent is to cook for a short period, small sticks ignite faster, burn hotter, and produce less ash, so would appear to be a preferred alternative. The fact that smaller woody elements, like shrub branches, burn more thoroughly and produce less ash may account for their less frequent recovery from thermal features (e.g., Adams and Bowyer 2002:Table 6.5).

It is important understand that in this model implementation standing crop of vegetation in each model cell is maintained as a constant distribution of species based on the native vegetation community associated with the appropriate soil complex. In other words, there are no seral stages. If a model cell composed of half piñon and half Indian ricegrass were completely burned, the next year it would grow back as half piñon and half Indian ricegrass, albeit with initially very low standing crop for the piñon. The annual NPP is determined by the combination of overall soil productivity and the paleoproductivity retrodicted for that soil in a given year (model time step). This productivity maintains the faunal populations as discussed in the following chapter.

CHAPTER 7: BUILDING THE MODEL: CRITICAL FAUNAL RESOURCES/PROTEIN SOURCES

As is the case with most neolithic peoples, once the prehispanic Puebloans of the Mesa Verde region settled into the agrarian lifestyle, they increasingly relied on agricultural production (Minnis 1985b). By far the majority of that production, at least as shown by the archaeological record, was provided by corn (Decker and Tieszen 1989). Despite evidence for the cultivation of both beans (*Phaseolus vulgaris*) and squash (*Curcurbita* spp.), it is difficult to quantify the levels of protein derived from these crops.

Maize (*Zea mays*), by itself, fails to provide many of the essential amino acids required to maintain human health. In combination with beans, some of the amino acids needed to form necessary complex proteins were certainly attainable (Spielmann and Angstadt-Leto 1996). Nevertheless, animal protein provides a very important contribution to the diet of subsistence-level farmers (Speth and Scott 1989).

The landscape production and human consumption of high-quality protein from wild animals is an important focus of the Village Project and this dissertation. We model the potential availability of meat on the model landscape based on the available annual NPP of preferred plant food species as retrodicted using paleoclimatic data. Three herbivore populations are simulated by modeling the primary productivities and distributions of plants reported as their preferred foods. The faunal species we chose to model are those whose remains are most commonly recovered from regional archaeological assemblages: mule deer (*Odocoileus hemionus*), black-tailed jackrabbits (*Lepus californicus*), and cottontail rabbits (*Sylvilagus audubonii*).

These species have different food preferences, ingestion rates, reproductive rates, and body weights. Most of the biomass they consume is annual new growth (except in times of scarcity when both mule deer and jackrabbits may rely on second-year growth). This is ideal for present purposes, since the model of vegetation discussed above is primarily concerned with annual NPP.

The animal species are modeled as populations, each of which fluctuates in response to variations in annual NPP, as well as harvest by simulated households. We do not model individual animals; animals are not agents in the same way human households are. Animal populations are modeled on a per cell basis, and vary with the amounts of plant food available, the maximum rates of reproduction of each species, harvest rates, and diffusion (in the case of deer).

Harvesting of animals by model households (hunting) is implemented such that the most efficient procurement strategy is followed. That is, agents are coded to place their habitations in locations that are approximately optimal for procuring adequate agricultural produce, domestic water, fuels, and protein. Settlement distributions of model households will thus be responsive to supply of, and demand for, these resources.

Following the same logic used in the previous chapter, I begin the discussion of faunal resources with the genus thought to have been of highest interest to the prehispanic Puebloans of the Mesa Verde region (Muir and Driver 2002; Shelley 1993). It is generally expected that populations will tend to make the most efficient choices, attempting to optimize their procurement strategies (Jochim1981). As noted above, the current model has agents attempting to satisfy their needs as efficiently as is feasible. Therefore, when mule deer are available within a reasonable distance from an agent's home cell, the best option for satisfying the annual protein requirement will be by hunting deer.

The realistic modeling of the mule deer population is more difficult than for those of jackrabbits and cottontails. The main reasons for this are the larger normal home range of deer, and the low maximum reproductive rate of these larger-bodied animals. Therefore, description of the deer model is more detailed than that of the lagomorphs, which should be relatively straightforward after the following discussion.

Artiodactyls

The Holocene hoofed mammals of the Four Corners region of the American Southwest include moose (*Alces alces*), elk (*Cervus elaphus*), pronghorn (*Antilocapra americana*), bison (*Bison bison*), mountain sheep (*Ovis canadensis*), and mule deer (*Odocoileus hemionus*). Within the study area, mule deer are the only extant representative of this order of mammals. Pronghorn may have once inhabited the lower elevations, and elk are in the alpine forests on the horizons.

Across their total range, mule deer inhabit a wide variety of environments. Populations are found in low-elevation deserts, through the mid-elevation steppe, to relatively high-elevation alpine settings (Mackie 1994a). In each of these areas, however, mule deer prefer edge zone habitats − these are places where the feeding areas (such as mountain shrub stands) and cover areas (such as thick forest) intersect. The shrub zone provides many of the plants deer browse on, and, if available, the forest zone provides the cover deer seek for security. In lieu of arboreal cover, mule deer tend to stay close to steep, rocky slopes that allow them to escape predators more effectively.

Pronghorn, on the other hand, feed primarily on grasses, and use their speed to escape predators. The majority of the study area, with its forested uplands and shrubby canyon slopes and floors is more suitable for mule deer. Pronghorn habitat is found at lower elevations, primarily in the southwest quadrant of the study area, even more so outside the study area to the south and west of Ute Mountain. Despite the presence of this habitat, pronghorn are no longer extant within the region.

The remains of mule deer dominate the artiodactyl portion of the regional archaeofaunal record. It is also a relatively common practice of zooarchaeologists to combine artiodactyl remains in their analyses and reports (Driver 2002). Therefore, this study considers only mule deer in modeling the artiodactyl population.

Following optimal foraging theory (Bettinger 1991), it is expected that these large mammals were the preferred prey of prehistoric hunters in this region. This theory proposes that the prey returning the greatest amount of nutrients for the effort expended will be the most sought after. Therefore, in habitats where deer are abundant enough to make their harvest more efficient than that of smaller prey, they should be the most desired targets. Once encounter rates of deer drop below the threshold at which harvesting lagomorphs becomes more efficient (in terms of meat returned per energy expended), hunting deer is expected to become less attractive than hunting lagomorphs. In such cases, the archaeofaunal record should reflect a gradual shift in species selection. Such a shift should trend from higher to lower body mass species, as is, in fact, reported for the Northern San Juan region (Muir and Driver 2002).

Based on the distribution of preferred deer browse, deer will be more populous in some parts of the study area than others (Figure 7.1).

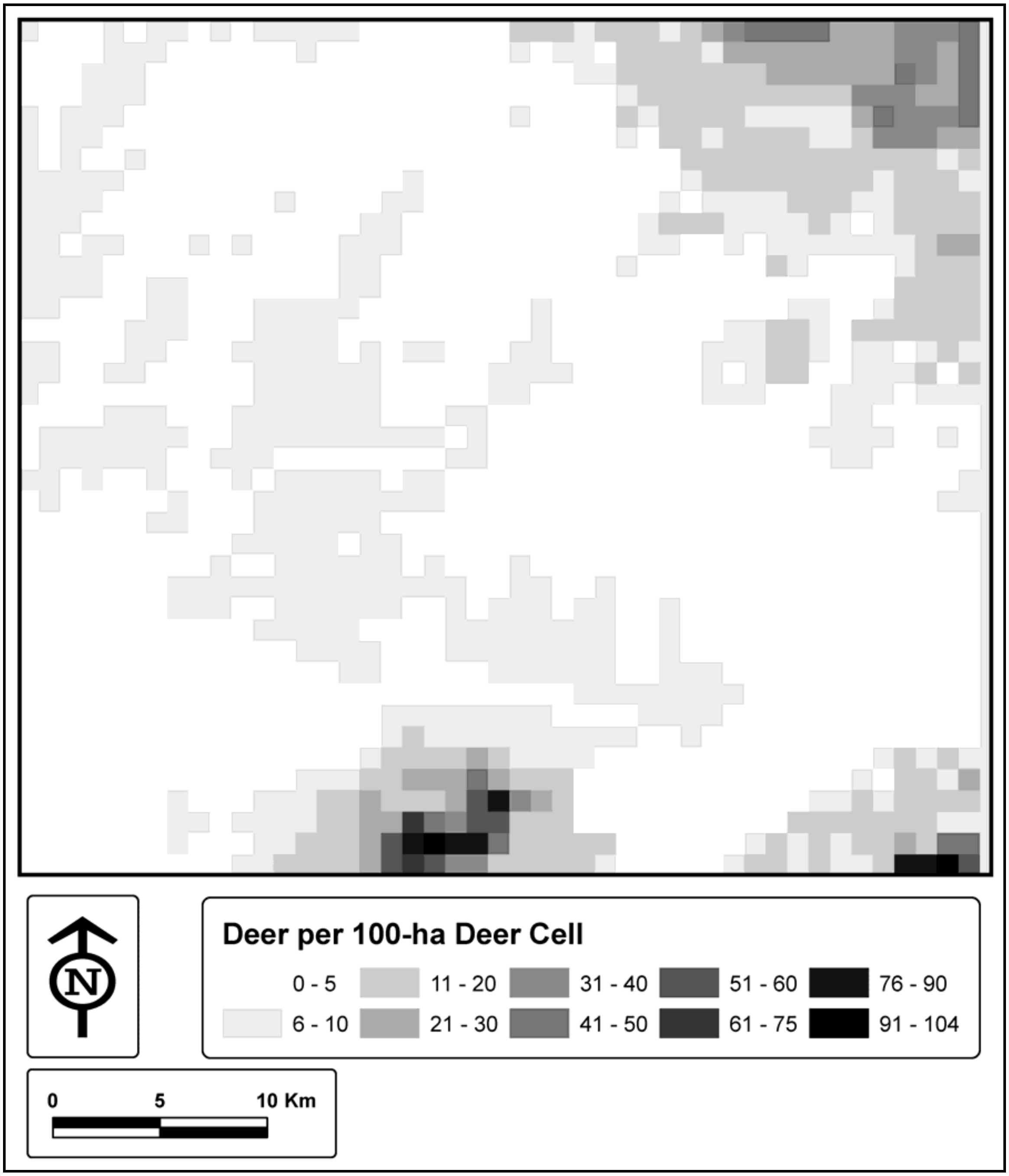

Figure 7.1. Map of long-term mean mule deer population density across the study area (without hunting).

Although on an individual basis deer, on average, are not relatively abundant across most of the study area, model results do indicate this is the preferred prey species of model households. The observant reader will notice that the map of deer distribution on the model landscape is at a different resolution than that of other resources. There is a good reason for this as discussed below.

For the present however, note that deer are primarily found at higher elevations, on the foothills of the San Juan Mountains to the northeast, on Mesa Verde proper in the southeast, and on and around Ute Mountain. The main reason for this distribution is that deer food is generally more abundant at higher elevations. “The areas most heavily populated with deer tend to be areas with greater precipitation, lower evapotranspiration rates, and decreased soil moisture deficits” (Short 1979:6). Their preferred food species tend to grow well in more mesic environments. At the same time, populations concentrate to a lesser extent along the canyons. As pointed out above, canyons provide the combination of browse, steep slopes, and cover that mule deer prefer. In the present context, however, it is only the availability of annual NPP of preferred browse to which modeled animal populations respond.

The productivity figures for fauna also differ from those of flora, discussed above, in that here we see the average number of individual specimens supported within the cells of the model world(s). The plural on worlds here refers to the fact that the deer-producing landscape is modeled at a coarser grain than that of other resources.

The main reason that faunal species are counted by individuals, even though they are modeled as populations, is that both the quantities of plants they ingest, and the needs of model households that feed on the animals, are more readily calculated on an individual basis. Individuals of each faunal species are modeled at an average rate of ingestion, body weight, edible meat weight, and protein content. In the present effort, the focus is only on the amount of protein individuals of each species can potentially provide.

Modern Mule Deer Ecology

Mule deer are the largest subspecies of black-tailed deer and are found only within North America. This species is the most widely distributed subspecies of black-tailed deer (Mierau and Schmidt 1981), ranging west from the 100th meridian and north from central Mexico to the northern borders of British Columbia and Alberta (Mackie et al. 1982).

Although mule deer can be highly mobile, they prefer areas where their needs can be met within a short distance (Mackie 1994; Mierau and Schmidt 1981:Table 8; Robinette 1966). This is the case across much of the study area. Depending on the habitat, mule deer can occupy large home ranges, but generally maintain discrete populations (Mackie 1994a) and normally migrate between summer and winter ranges when the distribution of fresh browse requires it. In prime habitat, mule deer normally have quite restricted home ranges. In a study of home ranges in central Utah, for example, Robinette (1966) found mule deer spent most of their time within a quarter-mile radius. This finding provides some support for our decision to model deer populations on a 1 km^2 cell basis, as shown in Figure 7.1.

These herbivores inhabit a range of environments, and consume a wide variety of plants (Anderson et al. 1965; Austin et al. 1984; Boeker et al. 1972). Mule deer feed primarily on fresh browse, produced as annual new growth primarily by shrubs (Medin and Anderson 1979). Forbs can also contribute significant proportions of mule deer food (Smith 1952) when available. Grasses are normally only eaten during early spring, before preferred plants sprout significant new growth, so provide a limited food supply (<1 percent) to mule deer populations (Krausman et al. 1997). Native vegetation communities associated with study area soil components include 21 named species of shrubs and trees, as well as an “other” class of each, that are preferred mule deer foods (Table 7.1).

Table 7.1. List of Preferred Mule Deer Browse Species Supported by Study Area Soils.

Native Vegetation	Latin Name
Antelope bitterbrush	*Purshia tridentata*
Basin big sagebrush	*Artemisia tridentata tridentata*
Big sagebrush	*Artemisia tridentata*
Common snowberry	*Symphoricarpos albus*
Gambel's oak	*Quercus gambelii*
Kinnikinnick	*Arctostaphylos uva-ursi*
Mountain big sagebrush	*Artemisia tridentata vaseyana*
Mountain mahogany	*Cercocarpus Kunth* spp.
Mountain snowberry	*Symphoricarpos oreophilus*
Rocky Mountain juniper	*Juniperus scopulorum*
Rocky Mountain maple	*Acer glabrum*
Saskatoon serviceberry	*Amelanchier alnifolia*
Serviceberry	*Amelanchier alnifolia*
Snowberry	*Symphoricarpos albus*
True mountain mahogany	*Cercocarpus montanus*
Utah juniper	*Juniperus osteosperma*
Utah serviceberry	*Amelanchier utahensis*
Utah snowberry	*Symphoricarpos oreophilus utahensis*
Whortleleaf snowberry	*Symphoricarpos oreophilus*
Willow	*Salix* spp.
Wyoming big sagebrush	*Artemisia tridentata wyomingensis*
Other shrubs	
Other trees	

The feeding rate for mule deer is reported as a mean of 21.9 g (Alldredge et al. 1974:Table 3) of vegetation per day per kilogram of body weight. Based on a sample of 39 male and 48 female wild mule deer, ages 1 to 18+ years, taken as part of a feeding study, Alldredge et al. (1974:Table 1) recorded an average weight of approximately 60 kg, which is consistent with figures reported by Hanley and Hanley (1982) and Hobbs and Swift (1985). Taking feeding rate and average body weight into account, average daily intake for mule deer is 1.31 kg of browse. Of course, expectant and nursing mothers require more food than average to support offspring for at least half of each year.

Mule deer reproduce annually, mating in the fall, after feeding heavily all spring and summer. Bucks compete for territory and mating opportunities, often sparring to drive off competitors, and following does for days by way of courtship. Once mating has occurred, bucks usually depart, leaving does to spend the winter in groups of females (although in some habitats, winter conditions force deer to congregate in low-lying areas where food is available, i.e., not buried in snow).

Fawns are born in the mid-spring, following nearly seven months gestation (Hobbs 1989). Female mule deer may bear young as early as yearlings, but normally by the time they reach two years of age. If the productivity of the local habitat is unusually low while a female is growing to maturity, pregnancy may be delayed until the third year (Robinette et al. 1955). Litters are usually one fawn annually, commonly two, and occasionally three (Jensen and Robinette 1955). In general, the fawn to doe ratio is approximately 1.4:1 in an average year (Krausman 1994). Overall, based on recent studies (Medin and Anderson 1979; McCullough 1997), the mean maximum rate of mule deer population growth ($r_{\max}$) is .4.

Mule deer population levels fluctuate naturally in a semi-cyclic manner. A number of factors contribute to this, including: climatic variations that determine annual NPP of browse; snow pack that can cover food plants and require substantially more energy in locomotion (exhausting deer and making them easier prey); and occurrences of diseases that can lead to local depletions. Of course predation rates by wild and human hunters can also be a major contributor to herbivore population fluctuations (Gill 1999).

Population densities are also highly variable, mostly dependent on available food supply. Observations from the mountains of eastern Oregon (primarily Ponderosa pine forest) report deer densities of 2.8 to 3.6 per km^2 (Agar et al. 2003), while densities in piñon-juniper forest are reported as 10 per km^2 (Short, Evans, and Boeker 1977). This range of mule deer population densities compares favorably with long-term densities of 2.1 to 6.3 per km^2 observed for populations living on the breaks of the Missouri River in eastern Montana (Hamlin and Mackie 1989).

There are, of course, many other observations of mule deer in the literature, concerning both individuals and populations. For our purposes here, however, this sets the stage for discussing how we simulate artiodactyls in the model world. Additional information concerning deer is provided at the end of the chapter along with discussion of animals as resources available to model agents.

Population Modeling

The model of mule deer population on the simulated landscape is based on modern ecology, including their average daily intake, mean body weight, and rate of population growth. Of course the NPP of those plants mule deer feed on varies according to the paleoproductivity reconstructed for each model year, as well as the soil on which each plant species grows. In providing browse for our deer population, the model produces annual NPP of the trees and shrubs listed in Table 7.1 just as it does for all other plant species as discussed in the previous chapter.

Deer can not access all new growth provided by their preferred food plants. There are two main reasons for this: deer do not normally climb trees, which limits the amount of new growth they can reach; and, at some point, the amount of new growth remaining on a particular plant is so small as to make its consumption too costly in terms of energy expenditure. For these reasons, we limit the amount of new growth our model deer can eat to half of what is produced (Wallmo et al. 1977).

Mule deer population on the model landscape is seeded in the same way that tree and shrub standing crop is initialized at the start of each model run. In those cases we ran an entire simulation without household agent interaction, and reported the annual NPP of each plant species from each model cell. In the case of animal populations, the preferred browse species are provided to each herbivore population (at various percentages of the total, which for deer is 50 percent of annual NPP). The numbers of animals supported in each model cell in each model time step are written to a text file that is then processed to calculate a mean productivity of preferred browse, and then of each faunal species for each model cell. The resulting figures are used to initialize animal populations across the model world.

In the case of deer, we produce a second model landscape, such that the deer population “lives” in a coarser world. Since deer need more space to survive than all other species modeled, we combine the productivity of deer food produced by blocks of

25 of our regular 4-ha model cells into 1800 1-km^2 "deer cells," Note from the discussion above that deer population densities are often about seven per km^2. This necessitates use of a coarser-grained landscape on which to grow and hunt deer, since each regular 4-ha model cell would only support about ¼ deer.

Within each 1-km^2 deer cell the deer population is initialized as $N_{t.}$ At each model step, $N_{t+\Delta t}$, the annual NPP of preferred deer foods determines the carrying capacity K, for the population within each deer cell. The mule deer population thus fluctuates annually, based on K and the logistic growth function of Gurney and Nisbet (1998:Eq. 3.65) reproduced below as equation 1, where $\gamma \equiv e^{r\Delta t}$.

$$N_{t+\Delta t} = \frac{KN_t}{N_t + \gamma(K - N_t)} \tag{1}$$

The .4 $r_{\max}$ rate of intrinsic population growth works in conjunction with available deer food to regulate the number of deer on the model landscape. Across the entire 1800 km^2 model world, we initialize the deer population at 7650 individuals. Figure 7.2 shows how, even in the absence of predation, the model world deer population fluctuates broadly, ranging between approximately 7700 and 16850 individuals through the 700 years of the simulation.

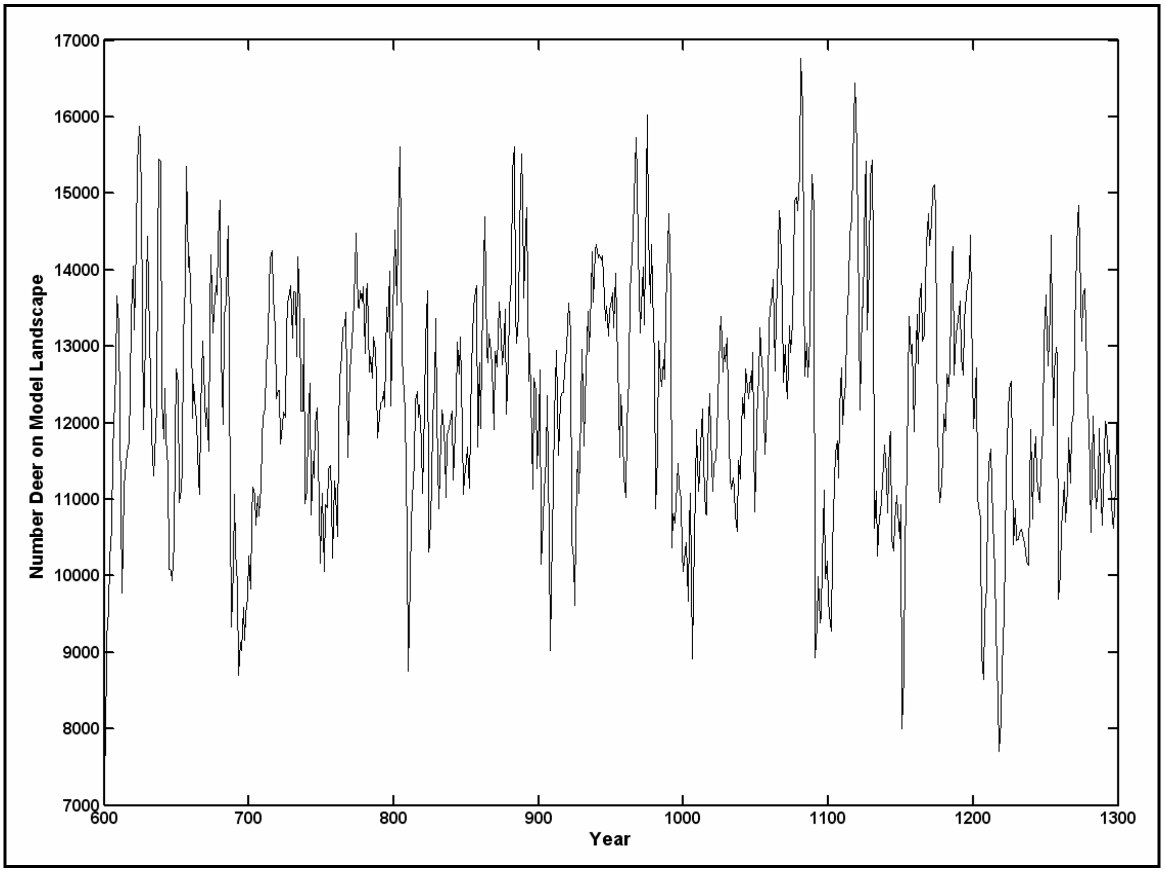

Figure 7.2. Long-term mule deer population fluctuation across the study area based on carrying capacity of food sources and the 0.4 intrinsic rate of growth of the species (with no human or other predation).

At the deer-cell level, populations fluctuate between 2.7 and 11.8 per km^2 throughout the entire model run (Figure 7.3), with a mean density of about 7 deer per km^2. This population density is comparable to those reported by modern mule deer population studies (Agar et al. 2003; Hamlin and Mackie 1989; Short, Evans, and Boeker 1977) discussed above.

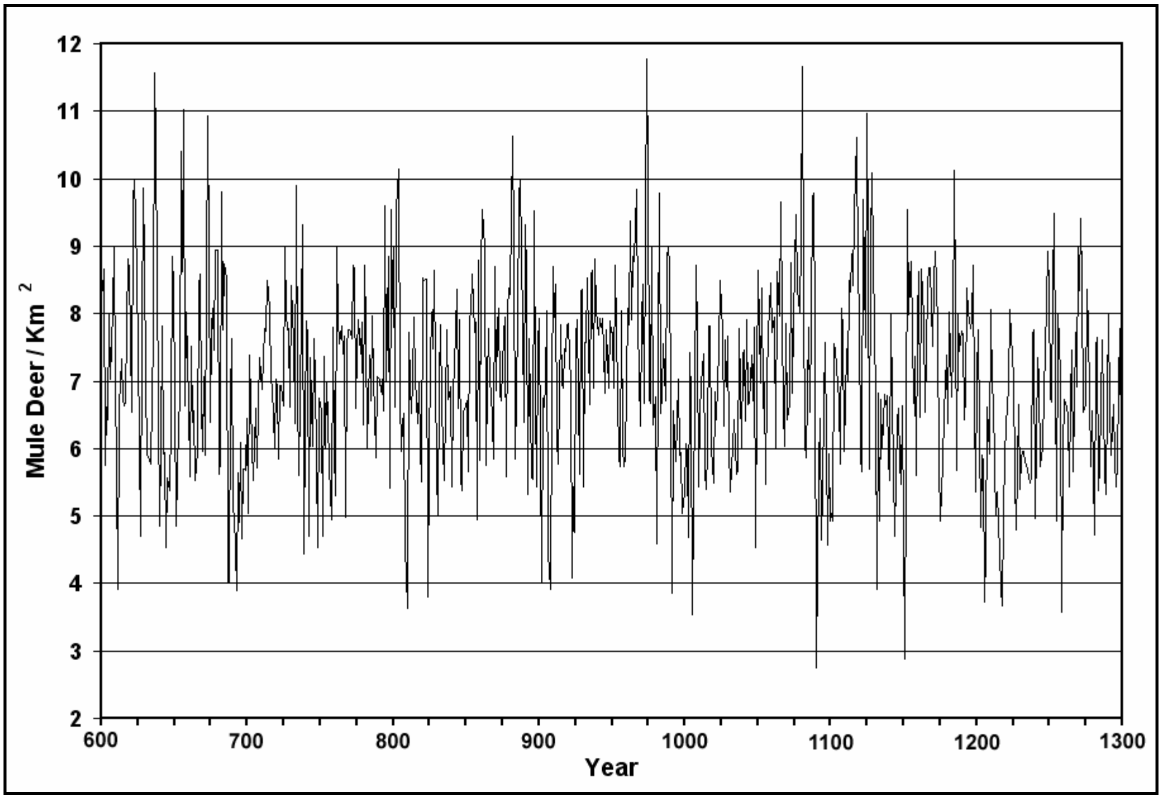

Figure 7.3. Long-term mule deer population fluctuation within 1-km^2 deer cells for the entire 700-year simulation based on annual NPP of food plants and daily intake of 1500 g per individual.

It is important to consider local density in accurately modeling the deer population. Low numbers of animals per deer cell might be problematic in the long term due to either high levels of harvest, extremely low *K*, or a combination of both, within a particular deer cell or group thereof. Given the low (.4) $r_{\max}$ of deer, once households are allowed to hunt deer it is very conceivable that local populations could be quickly depleted to a point of no return. To overcome this potential problem, we provide a routine that allows deer to move from deer cells with population at or above carrying capacity, to those in which deer populations are below what the annual NPP of preferred browse species will support. This allows local populations to distribute themselves much like they might in the real world. Even though deer may find areas supplying all their material needs, they are still likely to disperse when leaving their natal group, or to wander in search of mates. Deer are thus expected to roam freely on the landscape, in search of browse, and to disperse into under-utilized areas. We use a diffusion routine to improve the realistic nature of the model world.

The movement of deer between deer cells is implemented using an implicit discrete diffusion equation solved using a preconditioned conjugate gradient iteration (Golub and Van Loan 1983). This allows deer to diffuse annually from well-populated to under-populated deer cells, promoting a more even distribution. Cowan et al. (2006) provide a more thorough discussion of the deer diffusion routine.

If deer within a particular deer cell exceed the amount of annual NPP of preferred browse needed to support them, even after dispersing, the population is decremented in that cell, as governed by the logistic growth function (Gurney and Nisbet 1998) and the .4 r_{max} used for mule deer. This results in a decline in local deer population, tracking the carrying capacity provided by annual NPP of preferred browse with a lag. Of course the carrying capacity is dependent on the paleoproductivity of soils within deer cells, and is variable for each model time step. If deer browse in a particular cell is very poor for several years, and then very good, the growth function smoothes the long-term population trend to some extent; the annual NPP of browse can change more rapidly than the deer population that tracks it. The diffusion routine promotes further smoothing of deer populations, considered regionally.

Simulated numbers of mule deer on the model landscape appear to correlate well with those expected in the real-world upland Southwest. Population densities, though fluctuating in the long-term, fall within those observed by researchers in many areas of the west. Absent hunting pressure, the model produces no major population declines, and overall supports a stable deer population expected to provide an important source of high-quality protein for model households. Additional sources of animal protein are supplied by the modeling of lagomorph populations as described in the following section.

Lagomorphs

We also model populations of black-tailed jackrabbits and desert cottontails. Each of these species exists in the study area and is common in archaeological assemblages in the Greater Southwest (Speth and Scott 1989; Spielmann and Angstadt-Leto 1996) and in the Mesa Verde region (Driver 2002; Muir and Driver 2002; Neusius 1985a).

Based on both number of identified specimens (NISP) and minimum number of individuals (MNI), lagomorphs "constitute the largest number of remains in the Wallace Ruin assemblage" (Shelley 1993:108), a finding typical of many Mesa Verde region assemblages (Muir and Driver 2002; Neusius 1985c). This is certainly not unexpected, since according to our simulations these species are much more prevalent across the study area. This finding is based on the high occurrence and productivity of plants that lagomorphs prefer as browse. As pointed out in Chapter 6, grasses are the most prominent vegetation class, and are supported by all soils. Grasses are also favored food for lagomorphs, so these animal populations live in most portions of the study area. Like all of the resources modeled, spatial and temporal variation in localized lagomorph production can be substantial.

Jackrabbits and cottontails are modeled at the normal, 4-ha, model-cell level. As with the mule deer population, each lagomorph population is dependent on the annual NPP of plants preferred as food. Although the jackrabbit population is less productive in terms of individuals, their larger body weight is expected to make them more efficient to exploit than the smaller-bodied cottontails. After summarizing the pertinent facts of jackrabbit ecology and how we model them, I present a similar discussion for cottontails and conclude this chapter with a section covering animals as the protein-providing model resources.

Jackrabbits

The black-tailed jackrabbit (*Lepus californicus*) is a member of the hare family, and hares are synonymous with jackrabbits in the following discussion. This species of hares occurs across a large portion of the American west, "from Iowa to the Pacific Coast and southward into northern Mexico" (Lechleitner 1958), and is a dominant member of the mammalian class in many drier regions.

Hares common in the Upland Southwest prefer open habitats, and feed on a variety of grasses and shrubs. Twenty-six of their preferred food plants are supported by study-area soils, providing various amounts of foods to the hare population in the model world. Somewhat unexpectedly, soils on mesa-tops and in the deeper canyon-bottoms support more of the vegetation that hares prefer, allowing higher population densities than in the drier saltbush-greasewood habitat in the low-lying southwest region of the study area (Figure 7.4). Interestingly, the greatest productivity of hare-food plants is in the Dolores River canyon in the northeast portion of the study area, where both hares and rabbits contribute significantly to Dolores area faunal assemblages (Neusius 1985c).

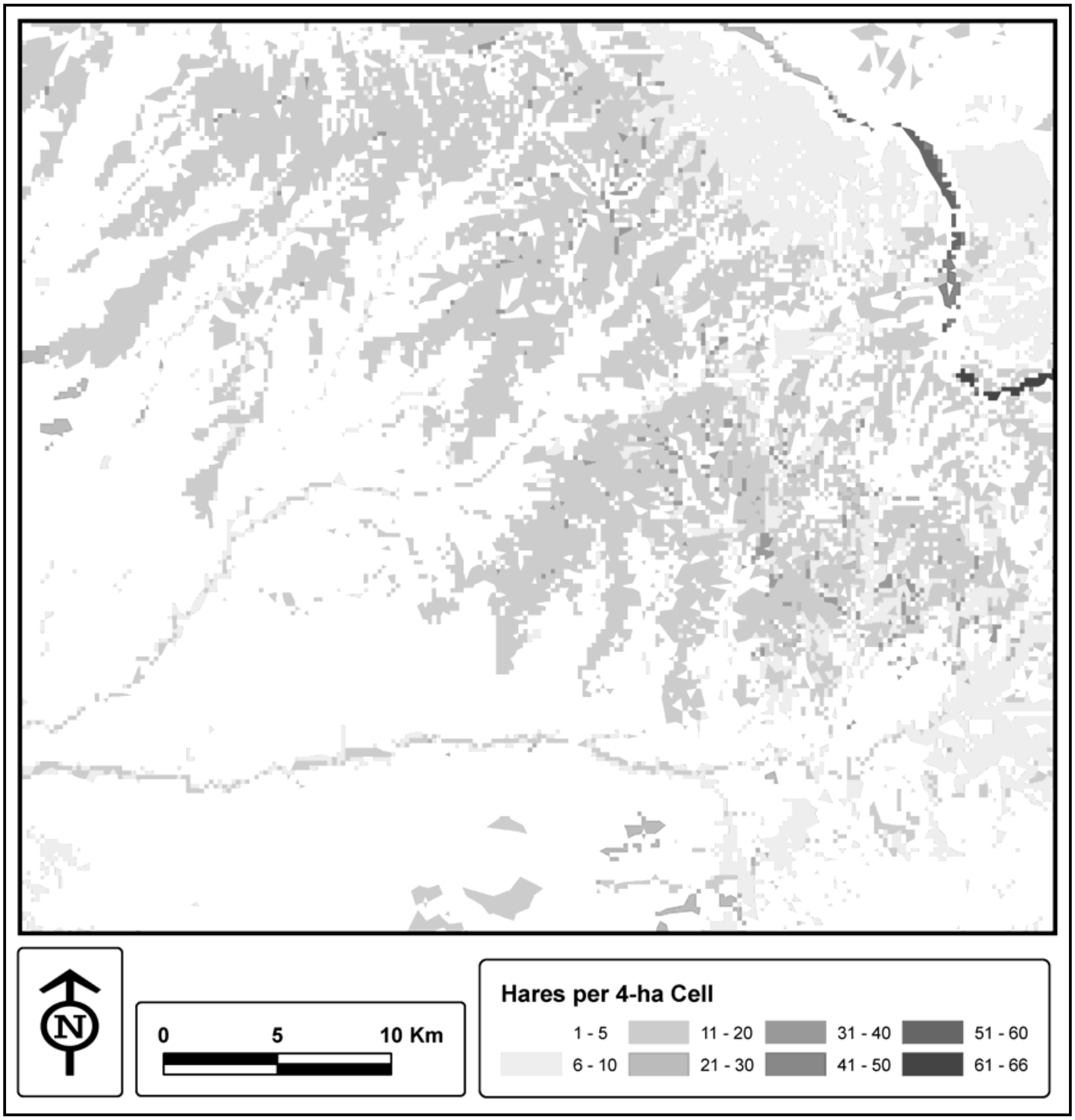

Figure 7.4. Map of long-term mean jackrabbit population across the study area (without hunting).

Modern Ecology. Black-tailed jackrabbits are the second smallest by weight, though most widely distributed, of seven species of the genus *Lepus* in North America (Myers et al.

2006). They inhabit a range of environments ranging from low-elevation saltbush deserts to mid-elevation shrub-covered steppe. Preferred habitats are areas of widely-scattered to dense shrub stands, primarily sage and greasewood, though the saltbush community is also commonly selected.

French et al. (1965:Table 4) reported most movements of 208 jackrabbits in southeastern Idaho were less than .5 km (.3 miles), and all but one were less than 1.6 km (1 mile), though some short-distance seasonal migration has been observed (but not quantified) for this species in northern Utah's Curlew Valley (Smith 1990). Although some long-distance migration has been reported, these hares prefer to stay relatively close to their place of birth, and are able to return there following displacement by environmental crises such as floods (Lechleitner 1958). Home ranges are generally between 15 and 20 ha (37 and 49 acres) (French et al. 1965; Lechleitner 1958; Nelson and Wagner 1973).

Population densities for this species vary widely, primarily in response to food supply. Estimates for hare densities in the western United States range from a low mean of .11/ha in southwestern Idaho (Knick and Dyer 1997) to .3/ha (Smith 1990), and 1.2/ha (Gross et al. 1974) in northern Utah. Converting these figures to those relevant to the model landscape is easily accomplished by multiplying by four to get densities per 4-ha model cell, the spatial scale at which lagomorphs are modeled.

These hare eat a wide variety of grasses, and browse on many shrubs. As is for mule deer, new growth is the preferred food, though second-year growth is consumed when new growth is unavailable (Currie and Goodwin 1966). A total of 24 plants, plus two “other” categories, preferred as food by hares contribute to study-area native vegetation communities (Table 7.2).

Table 7.2. List of Preferred Black-tailed Jackrabbit Browse Species Supported by Study Area Soils.

Native Vegetation	Latin Name
Basin big sagebrush	*Artemisia tridentata tridentata*
Big sagebrush	*Artemisia tridentata*
Black sagebrush	*Artemisia nova*
Blue grama	*Bouteloua gracilis*
Elk sedge	*Carex garberi*
Fourwing saltbush	*Atriplex canescens*
Foxtail barley	*Hordeum jubatum*
Greasewood	*Sarcobatus vermiculatus*
Indian ricegrass	*Oryzopsis hymenoides*
Mesa dropseed	*Sporobolus flexuosus*
Mountain big sagebrush	*Artemisia tridentata vaseyana*
Mountain brome	*Bromus carinatus*
Needleandthread	*Stipa comata*
Sagebrush	*Artemisia* spp.
Saltbush	*Atriplex gardneri*
Sand dropseed	*Sporobolus cryptandrus*
Scarlet globemallow	*Sphaeralcea coccinea*
Sedge	*Carex bella*
Shadscale saltbush	*Atriplex confertifolia*
Slender wheatgrass	*Agropyron trachycaulum*
Western wheatgrass	*Agropyron smithii*
Winterfat	*Ceratoides lanata*
Wyoming big sagebrush	*Artemisia tridentata wyomingensis*
Yucca	*Yucca baccata*
Other perennial grasses	*Poa* spp.
Other shrubs	

The average daily intake rate for black-tailed jackrabbits is 122 g per individual per day based on an average body weight of 2.3 kg (Haskell and Reynolds 1947). Juvenile hares are weaned by six weeks of age (Smith 1990) and grow to full size very quickly. By 25 weeks of age the daily consumption of juveniles equals that of adults (Haskell and Reynolds 1947:Figure 3).

Black-tailed jackrabbits reproduce much more rapidly than mule deer, but are not quite so prolific as cottontails. The breeding season lasts from late January through late June (French et al. 1965:Table 1), fully half of each year. Jackrabbit gestation is approximately 43 days (Lechleitner 1958). The average litter size of these hares is two (Haskell and Reynolds 1947). Mature mothers can produce five litters annually (Gross et al. 1974) although in years with local food shortages the breeding season may end early. On a regional scale, breeding seasons are often longer in areas with warmer climates (French et al. 1965), though litter size commonly decreases later in the season. Based on a number of studies, the average intrinsic rate of natural increase ($r_{\max}$) of these hares is 1.75 (French et al. 1965; Haskell and Reynolds 1974; Lechleitner 1958; Wooster 1935).

As is the case with many other wildlife species, hare populations fluctuate widely over long periods of time (Clark and Innis 1982; Woodbury 1955). Factors affecting mortality and natality rates are commonly associated with climatic variations leading to cyclic differences in production of food supplies. Of course predation is also a prominent influence on population levels, and the current simulation of jackrabbits takes both these factors into account, though humans are the only predators modeled.

Population Modeling. The simulation of the jackrabbit population on the model landscape is very similar to that described above for deer. Mean productivity of preferred food plants is calculated for an entire 700-year model run, with no human interaction. This productivity is then combined with average daily jackrabbit intake of 122.5 g

(Haskell and Reynolds 1947), the 70 percent forage access we allow for lagomorphs, and the 1.75 $r_{\max}$ for this species to determine long-term population fluctuations for the entire study area as plotted in Figure 7.5

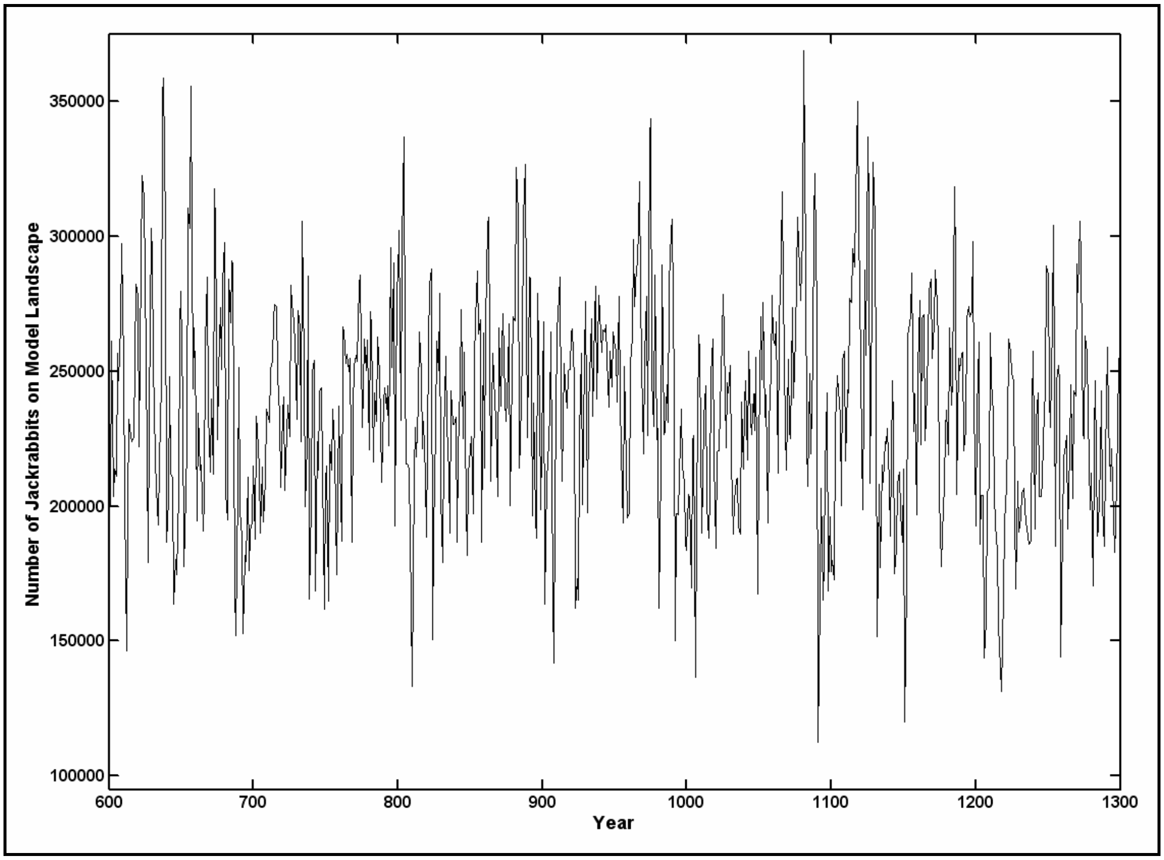

Figure 7.5. Long-term jackrabbit population fluctuation across the study area based on carrying capacity of food sources and the 1.75 intrinsic rate of growth of the species (with no human or other predation).

The results of this procedure are used to seed the model world with a population (based on the long-term mean) of 200,000 hares distributed to each model cell based on its annual NPP of preferred hare foods. Annual variation in preferred food supply, smoothed through the growth function, leads to populations ranging from approximately

115,000 to 365,000 individuals summed across the 1800 km^2 study area. On a per hectare basis, the population density ranges between .64 and 2.0 hares, figures slightly higher than those of 11/ha, 3/ha and 1.2/ha reported from long-term studies of populations in the real world by Knick and Dyer (1997), Smith (1990), and Gross et al. (1974) respectively. Within each 4-ha model cell there is substantial variation in the percentages of native vegetation communities that plants preferred as lagomorph foods represent, depending on the dominant soil type. This leads to a wide range in numbers of hares supported within each 4-ha model cell. Figure 7.6 shows long-term population trends at the 4-ha model cell scale. This mean number of approximately 5.5 hares per cell turns out to be rather problematic for the implementation of hunting as discussed in the final section of this chapter.

The simulation of black-tailed jackrabbits on the model landscape appears to correlate well with the expected productivity in the real-world upland Southwest. Population densities, though fluctuating in the long-term, fall within those observed by researchers in many areas of the west. The home range of jackrabbits is generally small enough that the lack of diffusion is assumed to have little impact on the reality of the simulation versus reality. In lieu of hunting pressure, the model produces no serious population crashes, and overall supports a population expected to provide an important source of high-quality protein for model households. A third source of animal protein is supplied by similarly modeling desert cottontail populations as described in the following section.

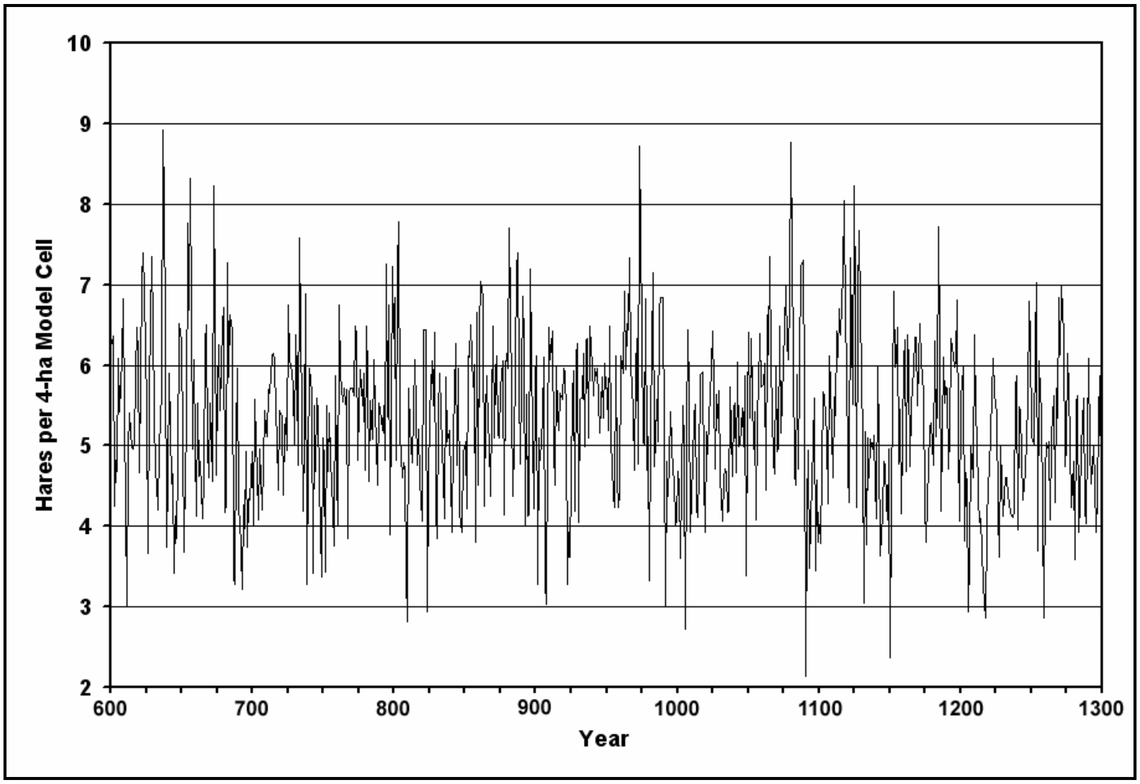

Figure 7.6. Long-term black-tailed jackrabbit population fluctuation within 4-ha model cells for the entire 700-year simulation based on annual NPP of food plants and daily intake of 122.5 g per individual.

Cottontails

The desert cottontail is also a member of the Lagomorph Order, in this case belonging to the genus *Sylvilagus*. The desert cottontail (synonymous with rabbits in this document) is one of two species of this genus recognized in the Mesa Verde region (Neusius 1985a:Table 11), the other being *Sylvilagus nuttalii*, the mountain cottontail (Myers et al. 2006). Desert cottontail are, however, much more common in the region and contribute the bulk of the cottontail remains in area faunal assemblages (e.g., Shelley 1993). Skeletal materials are too similar to distinguish these two species (Grayson 1988; Neusius and Flint 1985; Shelley 1993:Figure 3.1), so I only consider desert cottontails here.

The desert cottontail is one of seven species of *Sylvilagus* reported in North America (Myers et al. 2006). “This species can be found throughout much of southwestern North America, from northern Montana down to central Mexico, and as far west as the Pacific coast” (Ciszek 1999), and throughout the study area (Figure 7.7).

Comparison of Figures 7.4 and 7.7 shows that rabbits are more populous than hares across most of the study area. Also readily apparent from inspection of Figure 7.7 is that although preferred food plants of rabbits are predominantly found on mesa tops, they occur within riparian areas as well. The lower elevations of the southwestern portion of the study area provide some of the preferred plant foods of cottontails, while high elevations provide very few of these.

Modern Ecology. Home ranges of various cottontail species vary widely, ranging from less than 2 ha (1 acre) to more than 6 ha (15 acres), but average somewhat less than 2 ha (5 acres) (Ingles 1941, citing Allen 1939; Dalke and Sime 1938; Trippensee 1934), or about half of a 4-ha model cell. As with jackrabbits, cottontail populations are modeled at the regular model cell level. Cottontail population densities range between .2 (Chapman and Wilner 1986) and 6 (Giuliano, Elliott, and Sole 1994) per hectare.

Desert cottontail are supported on the model landscape by the annual NPP of 30 species of grasses and shrubs, as well as the “other” category of grasses, as listed in Table 7.3. These rabbits show a strong preference for grasses in their diets (Ciszek 1999) though forbs and some shrubs are also eaten (Ingles 1941). All of their feed is expected to be annual new growth, as trials have indicated they only eat green biomass (Ingles 1941).

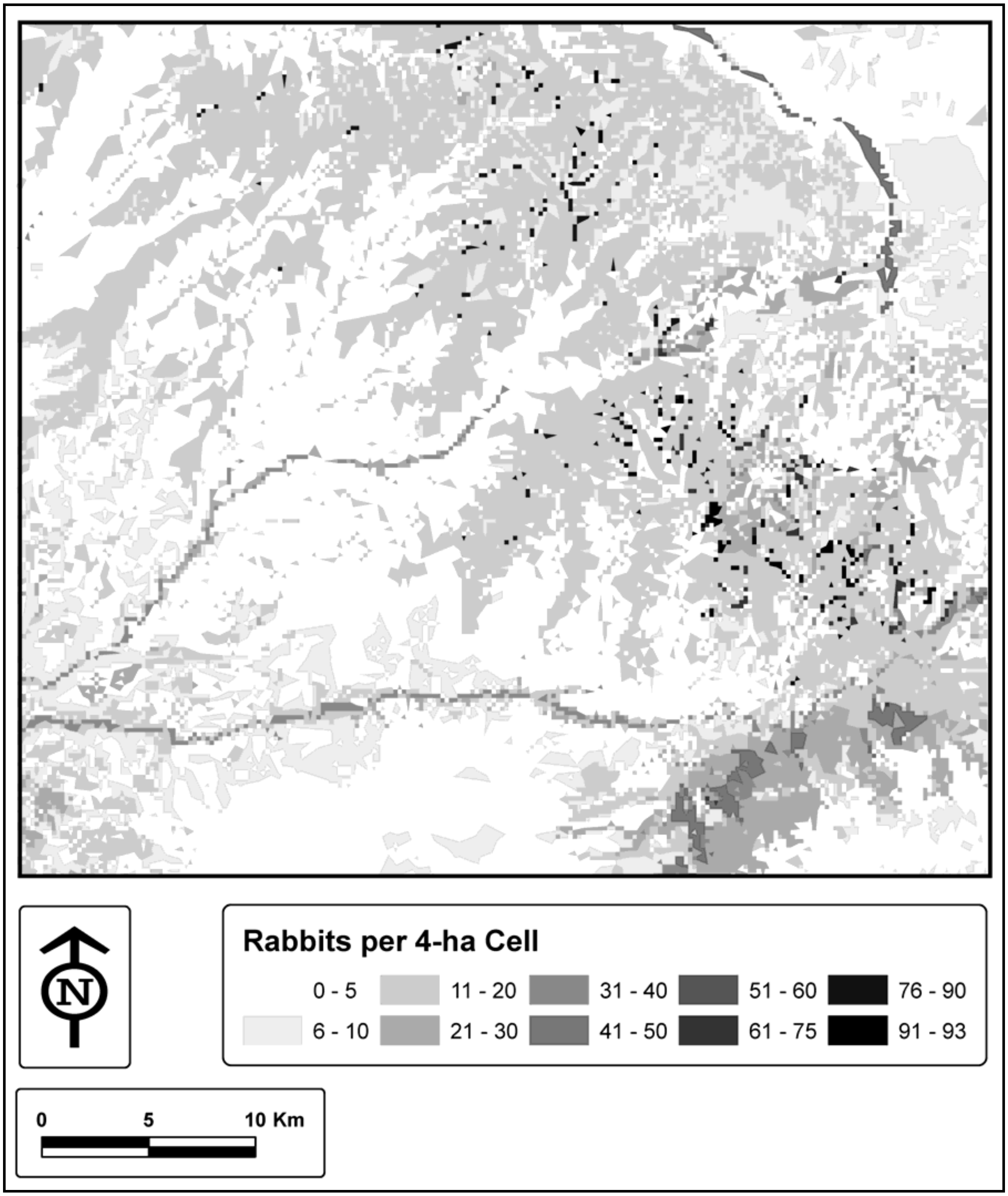

Figure 7.7. Map of long-term mean cottontail rabbit population distributed across the study area (without human or other predation).

Table 7.3. List of Preferred Cottontail Rabbit Browse Species Supported by Study Area Soils.

Native Vegetation: Type	Latin Name
Alkali sacaton	*Sporobolus airoides*
Antelope bitterbrush	*Purshia tridentata*
Basin big sagebrush	*Artemisia tridentata tridentata*
Big sagebrush	*Artemisia tridentata*
Black sagebrush	*Artemisia nova*
Blue grama	*Bouteloua gracilis*
Fourwing saltbush	*Atriplex canescens*
Galleta	*Hilaria jamesii*
Greasewood	*Sarcobatus vermiculatus*
Indian ricegrass	*Oryzopsis hymenoides*
Inland saltgrass	*Distichlis spicata*
Mesa dropseed	*Sporobolus flexuosus*
Mountain big sagebrush	*Artemisia tridentata vaseyana*
Mountain brome	*Bromus carinatus*
Oregongrape	*Berberis repens*
Rabbitbrush	*Chrysothamnus vaseyi*
Rubber rabbitbrush	*Chrysothamnus nauseosus*
Rush	*Juncus* spp.
Sagebrush	*Artemisia* spp.
Saltbush	*Atriplex gardneri*
Sand dropseed	*Sporobolus cryptandrus*
Scarlet globemallow	*Sphaeralcea coccinea*
Sedge	*Carex bella*
Shadscale saltbush	*Atriplex confertifolia*
Slender wheatgrass	*Agropyron trachycaulum*
Small Douglas rabbitbrush	*Chrysothamnus viscidiflorus*
Western wheatgrass	*Agropyron smithii*
Willow	*Salix* spp.
Winterfat	*Ceratoides lanata*
Wyoming big sagebrush	*Artemisia tridentata wyomingensis*

Of the species listed as preferred foods (Table 7.3) only 11 are grasses (plus an "other perennial grasses" category), 3 are forbs, and 16 are shrubs. Nevertheless, it is expected that grasses make up the majority of rabbit foods (Giulianoet al. 1994) and these are prevalent across the study area as noted above.

In contrast to jackrabbits, cottontails prefer more closed habitats that offer protective cover from predators (Ingles 1941). Much of the study area provides cover suitable for rabbits, particularly within canyon environments. Piñon-juniper forest also provides good cover potential, but understory species in these pygmy forests are generally very sparse (Everett and Koniak 1981), so food supplies may be restricted in forest zones. The current model implementation, however, only considers annual NPP of preferred plant foods in modeling herbivore populations.

The average daily intake rate for rabbits is 190 g, and the average adult body weight is 895 g (Ingles 1941). Although rabbits are smaller than hares, and thus provide less protein per individual, they also consume more of the species preferred as foods to convert plant biomass to animal protein than hares. At the same time, the 2.3 $r_{\max}$ observed for cottontails (Myers 1964), gives this species a distinct advantage over the other herbivores modeled here. Therefore, although expected to be the least sought after by model agents, in cases where they are hunted, cottontails have the lowest probability of being over-hunted.

In much the same manner as that of jackrabbits, cottontail populations fluctuate on both an annual basis and in long-term cycles. Naturally the same factors influence these changes in population levels for most herbivore species, to greater or lesser extents. The annual NPP of preferred plant foods and human predation are those this effort addresses with respect to cottontail population variations, both spatial and temporal. The following section describes how we implement the model of cottontail population within the Village Project.

Population Modeling. The Village Project model world is designed to include the production of protein potentially supplied by cottontail rabbits by modeling a dynamic population of this species using the same logistic growth function (Guerney and Nisbet 1998) as used for the other herbivore populations (equation 1 above), inserting the higher intrinsic rate of increase for this species. In the absence of simulated human hunting (or any other predation), annual population levels of rabbits are influenced by a combination of the productivity of preferred plant food biomass, the feeding rate (190 g/day) of individual rabbits, and the 2.3 r_{max} of this population. As implemented for the hare population, rabbits are allowed access to 70 percent of the annual NPP of their preferred food plants.

To initialize the population of cottontails, we once again run the simulation without household participation, output the preferred plant food productivity for each model cell, and calculate the mean production of forage over the entire 700 years of the model run. The resulting figures are applied to calculations of numbers of rabbits potentially supported within each model cell, and the long-term mean population is used to seed the model world with cottontails. The initial study area population of this species is 375,000, spread across the 1800 km^2 study area at densities represented in Figure 7.7.

During each model run, the rabbit population fluctuates from the initial level based on the NPP of plants that support this species. Long-term variations range between approximately 170,000 and 620,000 individuals as plotted in Figure 7.8. This represents a mean density ranging between .94 and 3.4 individuals per hectare. Note that although the range of population fluctuation for rabbits is greater than that of hares, which is much greater than that of deer, the absolute magnitudes of these fluctuations are very similar. In all cases the initial (mean) populations are right at 80 percent of the ranges of long-term fluctuations.

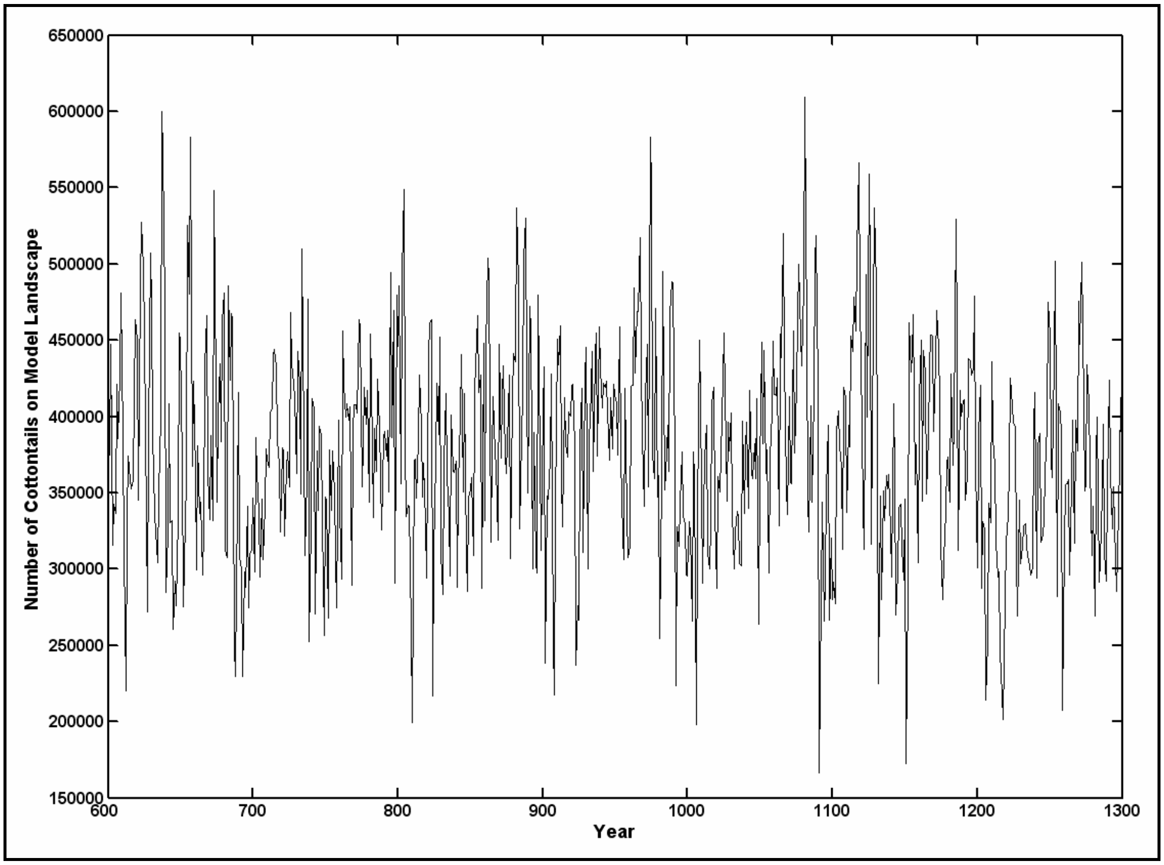

Figure 7.8. Long-term cottontail rabbit population fluctuation across the study area based on carrying capacity of food sources and the 2.3 intrinsic rate of growth of the species (with no predation).

Multiplying these figures by 4 results in population densities ranging between 3.8 and 13.8 rabbits per 4-ha model cell. These figures are very near those expected based on normal-year NPP of preferred plant foods as plotted in Figure 7.9. As is the case with jackrabbits, even these lower densities allow for sustained populations (due to high reproductive rates and even sex ratios) within each model cell, at least barring over-exploitation by model households. Although the mean per-cell population of rabbits (approximately 8.5 individuals) is larger than that of hares, this too is a problem in the present model implementation of lagomorph hunting. I elaborate on this in the conclusion of this chapter.

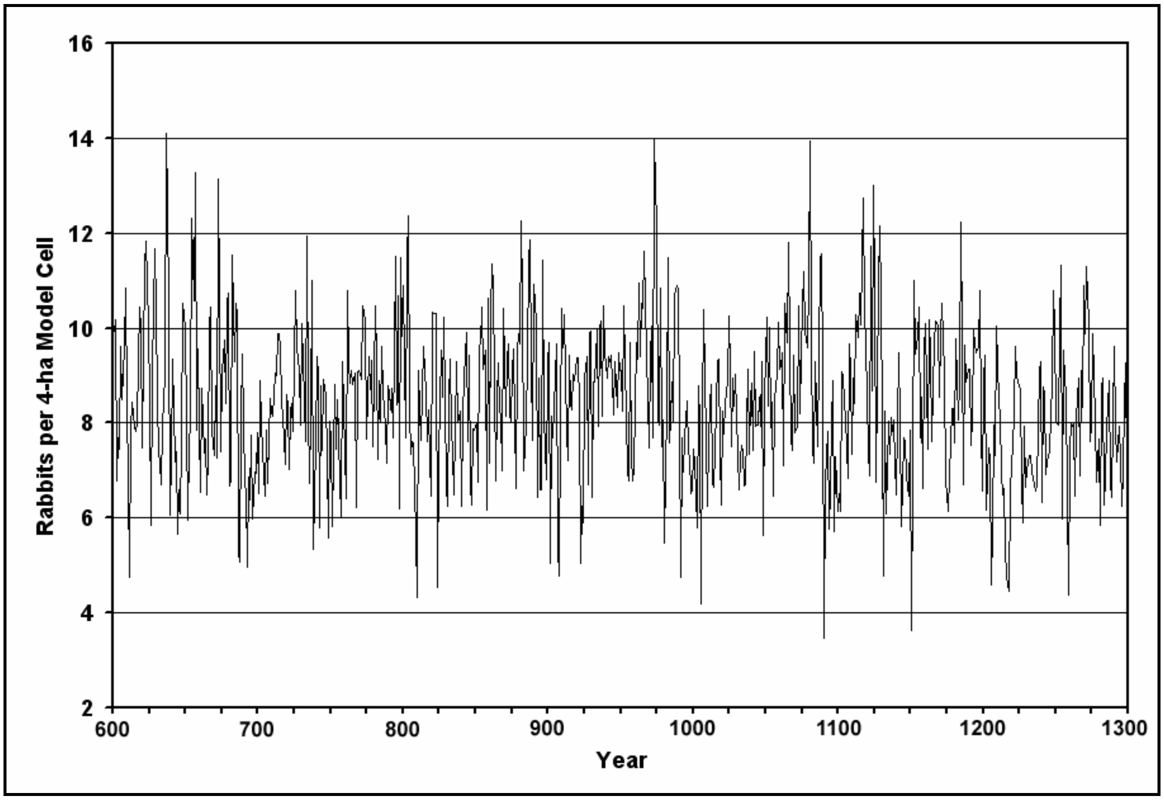

Figure 7.9. Long-term cottontail population fluctuation within 4-ha model cells for the entire 700-year simulation based on annual NPP of food plants and daily intake of 190 g per individual (without predation).

The simulation of cottontail rabbits on the model landscape appears to correlate well with that expected based on the productivity of preferred plants in the real-world Upland Southwest. Population densities fluctuate in the long-term, but fall within ranges observed by researchers in many areas of the west. Without household agent hunting pressure, no serious population crashes occur during the 700-year simulation. Overall the model landscape supports a population expected to provide a third source of high-quality protein for model households. As opposed to those of artiodactyls, the higher density and $r_{\max}$ of lagomorphs makes population mobility unnecessary for population maintenance, so no diffusion between model cells is implemented.

Now that the bases of the simulation of animals intended to supply high-quality protein have been described, I can discuss how these should act as model resources. The final section of this chapter presents additional facts about each faunal species (Table 7.4) and how they perform in providing protein on the model landscape.

Fauna as Model Resources

To supply model households with meat sources to satisfy their required protein, we simulate dynamic populations of three species of herbivores. The mule deer population is simulated at the 1-km^2 deer-cell level, based on the combined productivity of deer food plants in blocks of 25 4-ha model cells, and subject to diffusion. Both hare and rabbit populations are modeled within each 4-ha model cell, based on its annual NPP of food plants. Spatial and temporal variation in the amount of edible meat, and the protein it provides, is expected to influence household settlement decisions.

The simulation of animals on the model landscape relies on productivity of soils, constitutents of associated native vegetation communities, long-term paleoclimatic reconstruction, and many characteristics of each animal species. In the modeling of protein resources these species-specific characteristic values are used in various ways as detailed in other sections of this work. A list of useful characteristic facts associated with populations and/or individuals of each of these faunal species is provided in Table 7.4.

Table 7.4. Important Characteristics of Herbivore Populations Modeled in this Project.

Parameter/Population	Deer	Hare	Rabbit
Home Range/Hectare[a]	~ $1km^2$; <100	<20; <16	3.01 +/- .25
Density/Hectare[b]	3.2; 4 - 8; 10	<0.3; 0.11; 0.2-1.02	.02 - 2.5; 6
Daily Ingestion Rate[c]	1500; 22g/Kg	122.5g	190g
Average Weight[d]	60 Kg	2.3 kg	895
Sex Ratio[e]	83:100 ; 50/50	50/50	50/50
Litter Size[f]:Season[g]	1.4:1	2:5	3:3-4
Annual Intrinsic Rate of Increase[h]	.33; ~.4	1.5;	2.3
Life Span[i]	~10 years	2.5 - 7 yrs	600 days
Annual Mortality Rate[j]	40-50%; 29% (fawns); 52% (bucks)	80%	86.50%
Protein:Kcal/100g Meat[k]	30 g:158	33g:173	33 g:173
References:			
a	Robinette 1966; Mackie 1994a	Lechlietner 1958; French et al. 1965	Dixon et al. 1981
b	Ager et al. 2003; Mackie 1994b; Short et al. 1977	Smith 1990; Knick and Dyer 1997; Gross et al. 1974	Chapman and Willner 1986; Giuliano, Elliott and Sole 1993
c	Hobbs and Swift 1985; Alldredge et al. 1977	Haskell and Reynolds 1947	Ingles 1941
d	Hobbs and Swift1985; Hanley and Hanley 1982	Haskell and Reynolds 1947	Ingles 1941
e	Connolly 1981; Moen 1994	Gross et al. 1974	Sowls 1957
f	Krausman 1994	Haskell and Reynolds 1947	Ingles1941
g	Medin and Anderson 1979; McCullough 1997	Gross et al. 1974	Ingles 1941; Sowls 1957
h	Medin & Anderson 1979; McCullough 1997	Wooster 1935; Lechleitner 1958	Myers 1964
i	Mackie 1994b	French et al. 1965; Haskell and Reynolds 1974	Bothma et al.1972:1213
j	Anderson et al. 1974; Krausman 1994; Connnolly 1981	Gross et al. 1974	Lord 1961
k	USDA 2005	USDA 2005	USDA 2005

Artiodactyls are expected to be the preferred suppliers of protein, since their larger body weight translates into more efficient protein procurement for model households. This, of course, depends on local population densities of all three species modeled, since hunting areas of low deer density will return less protein per energy expended than will hunting areas supporting high densities of lagomorphs.

Deer meat provides 300 g of protein per kg of edible meat, and edible meat constitutes 60 percent of total body weight (Simms 1987). Sixty percent of the average 60 kg deer is 36 kg, so each deer can provide 10800 g of protein. At modest requirements for meat protein of 5 and 10 g per person per day, each deer can supply protein for an average 4-person household for 540 and 270 days respectively. So, in lieu of storage, a household of four would have to successfully hunt two deer annually to satisfy their protein requirements. Protein is storable, however, so each 4-person household must only harvest approximately 2 deer every three years. At a minimum hunting success rate of 30 percent, households should need to stage a deer hunt no more than twice annually. These requirements are obviously quite conservative, but can be adjusted upward in future experiments based on insights gained from the results of model runs reported below.

At an average body weight of 2.3 kg, an edible meat weight of 60 percent of body weight (Simms 1987), and 330 g of protein per kg edible meat, each jackrabbit can supply 455.4 g of protein. Applying required use rates of 5 and 10 g of protein per person per day, one hare can support a household of four for 22.8 and 11.4 days respectively. Since model agents are only allowed to harvest lagomorphs in batches of 10 (intended to represent a successful rabbit drive), one successful hare hunt will supply the daily per person requirements of 5 or 10 g of protein for a 4-person household for 228 or 114 days respectively. Thus less than two successful hare hunts per year are required to obtain 5 g of daily protein, and just over three successful hunts are needed annually to satisfy a 10 g daily protein requirement. Considering the 30 percent minimum hunt success rate, the 4-person household must then make at most six hare-hunting trips annually to satisfy a 5 g/person/day protein need, and about 10 to procure protein at the 10 g/person/day requirement.

Cottontail rabbits have an average body weight of 895 g, and we use the same 60 percent edible meat weight percentage as for the other animals. These lagomorphs also supply 330 g of protein per kg of edible meat, so each rabbit harvested provides 177.2 g of protein. Like the hunting of hares, rabbits are harvested in lots of 10 individuals, so a successful rabbit hunt returns 1772 grams of protein, enough to satisfy a 4-member household with 5 g per person of daily protein for 89 days, and that same household with 10 g of daily protein per person for 44 days. Based on a minimum 30 percent success rate of hunts, the low and high daily protein requirements can thus be satisfied by 12 and 27 hunting attempts, respectfully, annually.

All hunting trips are based on four hours of effort by hunters. In the case of deer hunts, a single member of a simulated household conducts the hunt. In hunting lagomorphs, a household must supply a hunting party of at least two members. Assuming adult males conduct hunts, each hunt expends a minimum of 240 kcal * 4 hours, for a total additional (beyond basal metabolism) cost of 960 kcal invested in each hunt for deer. As shown above, each household must attempt two hunts annually to supply required protein by harvesting deer. This then costs an extra 1920 kcal annually for hunting, not much more than that (1872 kcal) expended during one day (of a total of 91.25 annually) tending maize (Kohler et al. 2000:Table 3).

If a particular 4-member household finds it more efficient to satisfy the protein requirement by harvesting hares, the additional annual caloric costs are approximately 11520 kcal to get 5 g protein per person daily and 24000 kcal to obtain 10 g protein per person per day. These higher costs account for the minimum of two household members required to hunt lagomorphs, again spending four hours per attempt, with a minimum 30 percent chance of success. The caloric expenditures for relying on rabbits for protein requirements are even higher.

Focusing on rabbits as the sole protein source by a four-person household accrues the following caloric costs. At two members and four hours per hunt, each hunt costs an extra 1920 kcal. Assuming the poorest success rate of 30 percent, each year 12 hunts are required to obtain 5 g protein per person per day and 27 hunts are needed to return 10 g protein per person per day for a four-member household. The additional annual caloric expenditure of hunting rabbits then ranges between 23040 and 51840 kcal.

Of course all these hunt costs are in addition to basal metabolism, and the costs of travel during the hunting trips. Depending on local availabilities, however, it is obvious that hunting deer to provide required protein should be a much more efficient strategy than hunting lagomorphs. At the same time, it is likely that some locations support such low densities of deer, while providing adequate amounts of arable soils, domestic water, fuels, and lagomorphs, that some households are bound to hunt lagomorphs more often than deer.

There are, however, some problems with hunting lagomorphs in the current model implementation in which hunting households harvest these animals in lots of 10 (an estimated return for a successful rabbit drive). As shown in Figures 7.6 and 7.9, long-term mean numbers of both lagomorph populations at the model-cell level are below the 10 animal per hunt harvest rate. Combined with the less-than-perfect knowledge of total animals per cell that hunters are allowed, it is clear that many model cells can not provide lagomorphs as protein sources available to model agents. A further problem with lagomorph hunting and harvesting in the current model version results from an error in coding the search routine. A one-line misplacement of a method closing brace effectively excluded most of the cells from being searched for these animals. It is therefore extremely interesting that lagomorph harvests do, in fact, exceed those of deer when averaged for all 128 model runs, as discussed in the final chapter.

The results of many model runs are analyzed to determine which combination of parameter values result in the best goodness-of-fit between observed and simulated household locations. Once the best-fitting simulation is determined, additional analyses are performed on results of that run, and variations of that best-fitting run, as discussed in the following chapter.

CHAPTER 8: MODEL IMPLEMENTATION, OUTPUT, AND ANALYSES

The current version of the Village Project simulation (Villa 2.5) is an extremely ambitious effort involving numerous research problems and providing a wide array of results available for analyses. A variety of adjustable parameters allow the same basic model to experiment with many different influences on model agent responses to the simulated environment. We chose to vary a small number of these parameters in 128 simulations (Table 8.1) that produced abundant output data for the analyses reported below.

Model runs on which this research reports all begin with the same initial conditions. The base layer of the model world is of course a constant, with terrain, soil, and water sources all in the same locations. Standing crops of vegetation and animal populations are initialized at the same densities for each simulation. The same number of household agents (200) are seeded onto the model landscape at the start of each run. We also used the random number seed for each of these runs. Once begun, however, differences in parameters we varied soon start to influence model outcomes.

The seven parameters whose values we change in this version of the model are the amount of protein required, the penalty for not getting that much, the presence or absence of exchange, agent travel speed, harvest adjustment affecting the amount of production, the paleoproductivity data plane used, and the degree of soil degradation. These are defined in the next section.

Table 8.1. Village Model Version 2.5, Parameter Values Varied for 128 Model Runs Addressed in this Study.

Run #	Protein (g)[1]	Protein Penalty (0, 1)[2]	COOP/ Economy (0, 4)[3]	Travel Speed[4]	Harvest Adjust (1, .8)[5]	Prin1 vs. Almagre[6]	Soil Degrade (1, 2)[7]
1	5	0	4	10	1	P	1
2	5	0	4	10	1	P	2
3	5	0	4	10	0.8	P	1
4	5	0	4	10	0.8	P	2
5	5	0	4	20	1	P	1
6	5	0	4	20	1	P	2
7	5	0	4	20	0.8	P	1
8	5	0	4	20	0.8	P	2
9	5	1	4	10	1	P	1
10	5	1	4	10	1	P	2
11	5	1	4	10	0.8	P	1
12	5	1	4	10	0.8	P	2
13	5	1	4	20	1	P	1
14	5	1	4	20	1	P	2
15	5	1	4	20	0.8	P	1
16	5	1	4	20	0.8	P	2
17	10	0	4	10	1	P	1
18	10	0	4	10	1	P	2
19	10	0	4	10	0.8	P	1
20	10	0	4	10	0.8	P	2
21	10	0	4	20	1	P	1
22	10	0	4	20	1	P	2
23	10	0	4	20	0.8	P	1
24	10	0	4	20	0.8	P	2
25	10	1	4	10	1	P	1
26	10	1	4	10	1	P	2
27	10	1	4	10	0.8	P	1
28	10	1	4	10	0.8	P	2
29	10	1	4	20	1	P	1
30	10	1	4	20	1	P	2
31	10	1	4	20	0.8	P	1
32	10	1	4	20	0.8	P	2
33	5	0	4	10	1	A	1
34	5	0	4	10	1	A	2
35	5	0	4	10	0.8	A	1
36	5	0	4	10	0.8	A	2
37	5	0	4	20	1	A	1
38	5	0	4	20	1	A	2

Run #	Protein (g)[1]	Protein Penalty (0, 1)[2]	COOP/ Economy (0, 4)[3]	Travel Speed[4]	Harvest Adjust (1, .8)[5]	Prin1 vs. Almagre[6]	Soil Degrade (1, 2)[7]
39	5	0	4	20	0.8	A	1
40	5	0	4	20	0.8	A	2
41	5	1	4	10	1	A	1
42	5	1	4	10	1	A	2
43	5	1	4	10	0.8	A	1
44	5	1	4	10	0.8	A	2
45	5	1	4	20	1	A	1
46	5	1	4	20	1	A	2
47	5	1	4	20	0.8	A	1
48	5	1	4	20	0.8	A	2
49	10	0	4	10	1	A	1
50	10	0	4	10	1	A	2
51	10	0	4	10	0.8	A	1
52	10	0	4	10	0.8	A	2
53	10	0	4	20	1	A	1
54	10	0	4	20	1	A	2
55	10	0	4	20	0.8	A	1
56	10	0	4	20	0.8	A	2
57	10	1	4	10	1	A	1
58	10	1	4	10	1	A	2
59	10	1	4	10	0.8	A	1
60	10	1	4	10	0.8	A	2
61	10	1	4	20	1	A	1
62	10	1	4	20	1	A	2
63	10	1	4	20	0.8	A	1
64	10	1	4	20	0.8	A	2
65	5	0	0	10	1	P	1
66	5	0	0	10	1	P	2
67	5	0	0	10	0.8	P	1
68	5	0	0	10	0.8	P	2
69	5	0	0	20	1	P	1
70	5	0	0	20	1	P	2
71	5	0	0	20	0.8	P	1
72	5	0	0	20	0.8	P	2
73	5	1	0	10	1	P	1
74	5	1	0	10	1	P	2
75	5	1	0	10	0.8	P	1
76	5	1	0	10	0.8	P	2
77	5	1	0	20	1	P	1
78	5	1	0	20	1	P	2
79	5	1	0	20	0.8	P	1

Run #	Protein (g)[1]	Protein Penalty (0, 1)[2]	COOP/ Economy (0, 4)[3]	Travel Speed[4]	Harvest Adjust (1, .8)[5]	Prin1 vs. Almagre[6]	Soil Degrade (1, 2)[7]
80	5	1	0	20	0.8	P	2
81	10	0	0	10	1	P	1
82	10	0	0	10	1	P	2
83	10	0	0	10	0.8	P	1
84	10	0	0	10	0.8	P	2
85	10	0	0	20	1	P	1
86	10	0	0	20	1	P	2
87	10	0	0	20	0.8	P	1
88	10	0	0	20	0.8	P	2
89	10	1	0	10	1	P	1
90	10	1	0	10	1	P	2
91	10	1	0	10	0.8	P	1
92	10	1	0	10	0.8	P	2
93	10	1	0	20	1	P	1
94	10	1	0	20	1	P	2
95	10	1	0	20	0.8	P	1
96	10	1	0	20	0.8	P	2
97	5	0	0	10	1	A	1
98	5	0	0	10	1	A	2
99	5	0	0	10	0.8	A	1
100	5	0	0	10	0.8	A	2
101	5	0	0	20	1	A	1
102	5	0	0	20	1	A	2
103	5	0	0	20	0.8	A	1
104	5	0	0	20	0.8	A	2
105	5	1	0	10	1	A	1
106	5	1	0	10	1	A	2
107	5	1	0	10	0.8	A	1
108	5	1	0	10	0.8	A	2
109	5	1	0	20	1	A	1
110	5	1	0	20	1	A	2
111	5	1	0	20	0.8	A	1
112	5	1	0	20	0.8	A	2
113	10	0	0	10	1	A	1
114	10	0	0	10	1	A	2
115	10	0	0	10	0.8	A	1
116	10	0	0	10	0.8	A	2
117	10	0	0	20	1	A	1
118	10	0	0	20	1	A	2
119	10	0	0	20	0.8	A	1
120	10	0	0	20	0.8	A	2

Run #	Protein (g)[1]	Protein Penalty (0, 1)[2]	COOP/ Economy (0, 4)[3]	Travel Speed[4]	Harvest Adjust (1, .8)[5]	Prin1 vs. Almagre[6]	Soil Degrade (1, 2)[7]
121	10	1	0	10	1	A	1
122	10	1	0	10	1	A	2
123	10	1	0	10	0.8	A	1
124	10	1	0	10	0.8	A	2
125	10	1	0	20	1	A	1
126	10	1	0	20	1	A	2
127	10	1	0	20	0.8	A	1
128	10	1	0	20	0.8	A	2

[1] Protein requirement in grams per household member per day.

[2] Protein penalty applied for failure to obtain protein requirement; zero is no penalty, one is a 10 percent decrease in household mother's fertility and a 10 percent increase in household member mortality relative to the elevated rates that are applied if households are exceeding caloric requirements.

[3] Agent cooperation in exchange networks, both generalized and balanced reciprocity. Zero is no exchange, four is both types of exchange.

[4] Travel speed of agents when obtaining resources, the number of model cells crossed per hour, so 10 is 2 km/hr, 20 is 4 km/hr.

[5] A divisor on productivity applied to maize production to account for climatic variation, an adjustment of .8 results in a 25 percent increase in productivity.

[6] Paleoproductivity data plane used to assign productivity to soils based on paleoproductivity reconstruction. P is the first principal component derived from analyses of both Almagre Mountain (Graybill 1984) and the San Francisco Peaks (Salzer 2000) tree-ring data, A is based solely on the Almagre Mountain bristlecone data (see Kohler et al. 2006 and Varien et al. 2006 for more detail on paleoproductivity reconstructions).

[7] Soil degrade factor applied to soil maize potential to account for nutrient depletion from long-term cropping without fallow (see Kohler et al. 2006).

Each of these parameters affects the household agents in different ways, and, as we shall see, various combinations of values lead to different goodness-of-fit between model household locations and those observed in the archaeological record.

Parameter Values and Effects

The protein requirement controls, to some extent, the amount of hunting model agents must do to remain in a healthy state in the model world. We keep the protein requirement at a very modest level, relative to what others have suggested prehistoric maize farmers likely required (e.g., Nelson and Schollmeyer 2003; see more discussion in Cowan et al. 2006). The rates of protein intake we require for each member of model households is 5 g daily in half the model runs, and 10 g per day in the other 64 simulations.

In the present implementation, the 5 and 10 g protein requirements are effectively reduced by 35 percent from what I intended, due to a miscommunication between Village Project personnel. This reduction is the result of failure to calculate the amount of protein provided by each animal. The source of the error is that protein supplied by each animal is currently based on their total body weight, instead of the proportion of each that is actually edible. Estimates of edible meat weight per total body weight range from 50 percent (White 1953), to 65 percent (Wing and Brown 1979).

My intent was that agents be allowed the 65 percent (of total body weight) figure for edible meat weight from all three species; this was not implemented correctly, but will be in future versions of the simulation. The current version provides protein based on the entire body weights of successfully hunted animals. This effectively makes getting the protein agents need 35 percent easier than if protein content of animals were based on edible meat weight, as intended.

The unintended increase in protein supply may be offset by two factors. The first is that hunters often pursue the largest animals to provide the greatest return on their hunting efforts (Jochim 1981). Returns from killing larger animals may not be limited to nutrients either, since human behavioral ecologists argue that hunters often seek to bag the largest individuals in order to show off (e.g., Hawkes 1991), thereby increasing their evolutionary fitness by enhancing their access to reproductive opportunities. Therefore, calculating protein based on average body weight, that includes juveniles, probably under-estimates the normal returns from hunting.

The second factor is that animals of the past were often larger, on average, than they are in most modern contexts. Shelley (1993:Table 4.10) reports the artiodactyls recovered from Wallace Ruin provided an edible meat weight of 50.28 kg, 84 percent of the total average body weight used here for mule deer. Assuming that prehispanic Puebloan hunters did generally select larger individuals, our failure to calculate protein based on edible meat weight may not be as detrimental to model results as it seems.

The protein penalty parameter varies whether, and how, we "punish" agents who fail to meet their protein requirements. If we use a value of zero, failure to obtain required levels of daily protein has no consequences on the survival of model agents. When set to the value of 1, however, agents that are producing more than adequate amounts of maize (and thus are in State 2, see Kohler et al. 2000, 2006) are penalized for not harvesting adequate amounts of meat to acquire their protein. When agents fail to get enough daily protein, protein penalty 1 decreases the natality rate of the "mother" of the household (assuming there is one, which is usually the case) by 10 percent. This obviously lowers the birth rate, potentially lowering a household's viability. Further adverse effects to these households' survival are imposed by this protein penalty as it also increases the mortality rate of all household members by 10 percent. In other words, this penalty returns State 2 households to base levels of reproductive fitness, based on the standard life table of Weiss (1973). As is the case with all the parameters we vary, half of the total 128 simulations use protein penalty 1 and half use the other current protein penalty value (0).

The "COOP" parameter values of 1 and 4 switch (off or on, respectively) an option for households to exchange resources with each other when the need arises. In the current version, household exchange is limited to either maize or meat, with no exchanges across these domains. There are two separate networks of exchange (Kobti

2004), the first based on a generalized reciprocity network (GRN), and the second on a balanced reciprocity network (BRN) as described by Sahlins (1972). When COOP is switched to four, model agents who suffer shortages of either calories or protein are able to initiate exchange with local households to meet their needs. Agents first attempt to obtain foods through the GRN, but when unsuccessful will go to the BRN.

Agent travel speed is a fourth model parameter adjusted within the simulations reported here. When moving across the model landscape in resource procurement activities, agents move at speeds of either 10 or 20 model cells per hour. At 200 meters per side, there are five model cells per km (all movement is calculated orthogonally), so the lower speed is 2 km per hour, and the higher rate of travel is equivalent to 4 km per hour. This, of course, affects the efficiency with which agents can obtain distant resources, since they are charged calories for moving about the landscape.

The current implementation also includes a harvest adjustment parameter that has two values. The values are 1 and .8, and act as divisors on maize yields that fluctuate both spatially and temporally. Harvest adjust value of one does not affect the productivity of farm plots, but when set to .8, the harvest adjustment increases maize yields by 25 percent on all farm plots in all years of the simulation. This parameter is designed to allow us to experiment with various levels of maize productivity, and to determine whether higher yields improve the goodness-of-fit of model settlement patterns with those indicated by the archaeological record.

Two paleoproductivity data planes are implemented in the current version of the model. The Almagre (A in Table 8.1) reconstructs paleoproductivity of study-area soils based on high-elevation Bristlecone pine tree-ring data (Graybill 1984) from Almagre

Mountain on the east slope of the Colorado Rockies. The principal component (Prin1= P in Table 8.1) reconstructs paleoproductivity based on the first principal component of analyses using both the Almagre Mountain and San Francisco Peaks tree-ring data sets (Salzer 2000). For a thorough discussion of the creation of the paleoproductivity reconstructions, see Kohler et al. (2006).

The final parameter value that is adjusted in the 128 simulations is the soil degrade factor. This parameter reduces the productivity of farming plots, by slowly decreasing the annual harvest by up to 30 percent for soil degrade 1, and up to 60 percent when the soil degrade factor is set to 2, relative to their base values. The implementation of this parameter is designed to account for soil nutrient depletion on farm plots that are continuously planted for many years, along with other causes for reduced returns that might include soil erosion and weed invasion.

The output from the simulation provides a wealth of information available for analyses. A total of 59 files are produced for each model run. Some of the output is written as a series of 200 row by 227 column matrices. The numbers in each of the 45,400 elements of these files record values relating to household occupation for each model cell, recorded for each of the 14 modeling periods. There are 4 sets of these files for each of the 14 MPs output for each model run, resulting in 7,168 files with 45,400 values each.

The first two of these data sets represent the numbers of years per model cell in hamlets and large hamlets for each of the 45,400 model cells, during each MP. This is the number of years varying numbers of agents lived within a particular cell in that model period. Each value in the files for hamlet occupations, for instance, is the number of years in that MP that the corresponding model cell hosted either 1 or 2 agents. The analogous files for large hamlets record the number of years that each model cell was occupied by three to eight simulated households. A third set of matrices reports the number of years community center-sized settlements (of more than 8 agents) occupied each model cell in a given MP.

A fourth set of 14 matrices is output for each model run. These files record the total number of household years accumulated for each model cell during each MP, regardless of how many agents occupy the cell at any time. A value of 15, for example, can result from 15 agents occupying a cell for 1 year, 1 agent occupying a cell for 15 years, or any combination of number of agents and years of occupation that sum to 15. One of these files is written for each MP for each model run. This last set of matrices (named “H_Yrs”) is used for the analyses of how well the distributions of simulated households compare to those households observed in archaeological record.

Goodness-of-Fit Analyses

The results of the simulations can be analyzed along many dimensions, and only a few are considered here. A major goal of the Village Project is to investigate which environmental factors (natural and/or social) are most influential on long-term household settlement decisions. Therefore, it is imperative that we track the changes in residential locations that households occupy in adapting to the model world.

The accumulated household years recorded for each model cell in all MPs are used in correlation analyses to determine which model run produces the best match of simulated to observed settlement patterns. Producing data from the archaeological record for the study area comparable to that from the simulations required additional GIS computation. Recall from Chapter 3 that the settlement data originally input to the GIS from the Monument-McElmo settlement model consists of numbers of households at known points within each MP. In MP 6, for example, there are 1480 known habitation sites and a total of 1572 households recorded (Table 3.1). The conversion of the points at which these sites are plotted (based on UTM coordinates as shown in Figure 3.3), to raster maps used in the model, combines observed numbers of households (possibly from different sites) into the 4-ha model cells. To compare these data with simulated settlement patterns, these values must be multiplied by the number of years prehistoric households are estimated to have been occupied (Varien and Ortman 2005), since the simulation data in the H_Yrs files are in household years. This figure is eight for all hamlet households in MP 6 (see Varien et al. 2006:Table 3), so multiplying the observed number of households in small sites by eight produces values analogous to those recorded in the "H_Yrs" matrix files for MP 6 output by each model run.

The H_Yrs files contain the data used to determine which model runs achieve the best fit with the observed archaeological data. The 45,400 values provided in both the simulation-produced files, and those created from observed data, are converted from 200 row by 227 column matrices to 45,400 row by 1 column vectors. The resulting files for each MP are then appended to create 635,600 row by 1 column vectors used for correlation analyses. The 128 simulated household-year arrays are then concatenated to a set of four arrays of observed data to create a matrix 132 columns wide by 635,600 rows long.

The first four vectors (columns) of the 635,600 * 132 matrix used in the correlation analysis are based on observed archaeological data. The first of these columns lists the MP to which subsequent data (moving to the right across each row) relates, so there are 45,400 entries for each modeling period. The second column lists the number of households within each of the 45,400 model cells for each of the 14 MPs from the McElmo-Yellow Jacket database. The third and fourth columns contain household numbers smoothed over the Moore neighborhood of each focal (model) cell. Two smoothing techniques were applied to the observed numbers of households within each model cell. These smoothing procedures were used experimentally to determine whether simulation results would correlate more or less strongly with the observed data after smoothing.

The first smoothing operation used the "point density" function of the ArcGIS Spatial Analyst toolbox. The resulting values represent the number of observed households within each model cell divided equally among itself and the eight adjacent (surrounding) 4-ha model cells. For a focal cell containing 90 household years, for instance, those household years are divided equally among the nine cells that include the focal cell and its eight adjacent neighbors, such that each gets a value of 10, representing 10 years of household occupation. Once converted to the analysis array, the original value of 90 is then listed as nine values of 10.

A second smoothing technique used the "kernel density" function of the ArcGIS Spatial Analyst toolbox. This routine spreads the number of households in a cell in a weighted manner, such that the focal cell maintains a higher value, and surrounding cells split some proportion of the original value. The values in the eight adjacent cells are not all the same, because the kernel density function differentially weights the distributed values based on the distance from the point of origin (the site coordinates) to the surrounding cell centers. So, if a site is located near the southwest corner of the cell in which it is located, the adjacent cells to the south, southwest, and west get higher values than those to the southeast, east, northeast, north and northwest. The kernel density smoothing technique thus spreads the same 90 household years used in the example above unequally to the nine model cells in the focal cell's Moore neighborhood.

Conversion of the 1834 observed and simulated household settlement (200 by 227) matrix files to 132 (635,600 * 1) vector files was accomplished using the MatLab™ software package. The text files were read into MatLab workspaces and processed through a number of routines before being exported as single-field text files ready for input to the SAS statistical package for Pearson correlation (PROC CORR) analyses. The output from these analyses indicates which model runs produce the best fit between model household locations and those observed in the archaeological record, both overall (for the entire 700-year occupation) and for each of the 14 MPs. Results of these analyses are presented in the following chapter.

Aggregation Index Analyses

The data on simulated household occupation per model cell output for each MP by each model run, as described above, are not totally congruent with the observed archaeological data provided by the McElmo-Yellow Jacket settlement model. Figure 3.2 shows total and momentized numbers of households and calculated aggregation indices based on counts provided by the McElmo-Yellow Jacket settlement model and Varien et al.

(2006:Table 3), not household years as output by the simulation. Additional mathematical procedures were therefore applied to the observed data to make these data sets comparable to the model output, in order to calculate aggregation indices for valid comparison of observed and simulated data. Using MatLab I calculated a second set of aggregation indices for the observed households based on the numbers of occupation years in each modeling period. These figures were produced by a number of steps (see Appendix C), using the same data files of observed households per MP as those used as model input (the raster map versions of the site location/size data presented in Figures 3.3 through 3.16 above).

The 14 text files were read the into MatLab workspace matrices, and the numbers of households in hamlet- and large hamlet-sized sites were copied to a new matrix, those of community centers to two duplicate, but separate matrices (the first labeled "N" for numerator, the second labeled "D" for denominator), for each MP. The values in the resulting 42 matrices represent the total numbers of households in each model cell for hamlet- and community center-sized sites. The values in each of these matrices were then summed into a single number of households in each site size class (hamlets or community centers) for each MP, resulting in 42 values (3 for each MP). The total household numbers calculated from the "N" matrices for community centers were then divided by 9, the fewest number of households required to constitute a community center. Each of the 42 values calculated by the above processes were then multiplied by the figures for estimated years of household use life (which vary, depending on site size class and MP as presented in Varien et al. 2006:Table 3). The resulting figures from the hamlet-sized sites were then added to those of the community center-sized "D" values to get total household years, comparable to the simulated data output in the “H_Yrs” files for each MP. Finally, the figures calculated from the community center “N” data were divided by the total household years figures to produce aggregation indices for each modeling period that are comparable to what can be calculated from the simulated output.

Calculating aggregation indices of simulated households used a similar procedure, but required less computation. The first step is to import the data files that record total years of household occupation in each model cell in each MP into the MatLab workspace. These data are recorded in the “H_Yrs” files for all households and the “CC_Yrs” files for community center households. Each of these 28 files (per model run) is read into MatLab as a 200 by 228 matrix (an extra vector is appended to the right side of the matrix, due to carriage returns being read as entries). After removing the empty 228th vector, the values in each cell are added to get the total numbers of household years in all model cells. The total numbers of household years recorded in both matrices from each MP are obtained by summing the columns, transposing the resulting 227 by 1 array and summing the results. The results of these operations are then added to get the total number of household years simulated in all model cells for each modeling period. Finally, the aggregation index is calculated by dividing the total community center household-year figures by the total number of household years for each MP.

Faunal Index Analyses

The harvest of animals as sources of protein is an important topic in this work. As discussed in chapter four, the local archaeofauna record indicates a long-term decrease in the harvest of preferred large game (Muir and Driver 2002). Similar arguments have been made for many other prehistoric localities in the Greater Southwest (Cannon 2000; Nelson and Schollmeyer 2003). Given the high human population densities in the prehistoric Mesa Verde region, it seems likely that sources of meat protein were over-exploited in at least some localities during some times. Table 4.2 (above) supports this notion, showing long-term decline in the artiodactyl index and a corresponding increase in the lagomorph index.

Faunal indices calculated on the basis of results produced by the simulations are not strictly comparable to those calculated from prehistoric faunal assemblages. This is because the former are based on mean numbers of animals harvested per year by all model households, and the latter are based on the discarded skeletal remains of animals harvested by prehispanic Puebloans and recovered through archaeological excavation. Nevertheless general trends in these indices can be taken to indicate changes in the availabilities of preferred sources of wild meat (Jonathan Driver, personal communication 2005).

The remaining two files output by the model include data useful in analyzing resource use and availability for each year of the simulation. The "cell_stats" files record the total numbers of deer, hare, and rabbits, as well as standing crops of live and dead wood maintained within all model (and deer) cells (in aggregate) on an annual basis. These data allow analyses of long-term changes in the availabilities of the resources of interest in this study. Processing of these data is straightforward, consisting of graphing long-term changes. An example is provided in the following chapter.

The final output file is labeled the "agent_stats" file, and records the most data of all output files. Each record in the "agent_stats" files provides annual data about a model household. There are 54 fields in these files, recording model year, agent number, agent x and y location, number of household members, their ages, number of births, number of deaths, hours devoted to work, mean distances traveled to obtain fuel and water, calories expended in procuring various resources, numbers of animals hunted, and exchange activities.

Since these files record statistics for each household every year, they are typically a million lines long, and contain so much data that in raw form are difficult to analyze. Attempting to open a single "agent_stats" file, for instance, is impossible in Microsoft Office programs. I was able to open one in a text editor, but unable to accomplish much, other than look at it. In order to facilitate analyses, it was necessary to calculate summary statistics for all model runs, transforming individual agent data for each year into mean data output by all agents in each year. The summary statistic procedure (achieved by Tim Kohler using SAS), results in two files (named "mean_a_s") that are each small enough to open fully in a standard spreadsheet program.

The mean agent statistics files provide the data needed to calculate faunal indices. For each year of all 128 simulations, the mean numbers of animals harvested by all agents are provided. The first step was to add the numbers of animals taken to get figures analogous to the number of identified specimens (NISP) commonly used by zooarchaeologists (Grayson 1984; Lyman 1994). The numbers of rabbits and hares taken were also summed to allow calculation of the lagomorph index. The lagomorph index is calculated by dividing the number of rabbits by the sum of rabbits and hares, in this case those harvested annually by model agents. The artiodactyl index is calculated by dividing the number of deer by the total number of animals harvested.

Once the faunal indices were calculated for all years of all model runs, I separated the results to a new worksheet, placing the indices calculated for each of the 700 years from each of the 128 simulation runs on a single line. This allowed me to produce mean faunal indices for each year based on those of all 128 runs. In contrast to the low temporal resolution provided by the archaeological records of the sites listed in Table 4.2, the resulting data are for each of 700 years from A.D. 600 through A.D. 1299. The results of these analyses are presented in the concluding chapter, where they are compared with data gleaned from the archaeological record to support conclusions about the use of faunal resources by model agents.

Analyses of Mean Costs

The costs to model households of procuring natural resources can be calculated in two ways. Two fields in the “agent_stats” files provide figures for distances traveled by households to obtain water and fuel. These data are concatenated into the “mean_a_s” files and used to calculate the mean annual distances model households go (each way) to get these resources. In order to do so, the annual values from each model run are transferred from a single field to 128 fields with records for each model year. The records are then averaged, producing a mean annual distance traveled to reach these resources.

A second set of fields that are transformed from the large “agent_stats” files to the “mean_a_s” files are those that list the mean caloric costs of obtaining water, fuel, and meat. These data also list annual records for each model run, and so must be transferred to a separate field for each run. The records within the 128 fields are also averaged, providing mean values for amounts of calories expended annually by all model households during each model run. Analyzing these data allows me to compare the costs of procuring different resources, as well as changes in those costs to the average household through model time.

The results of the analyses presented in this chapter are discussed in the final chapter below. Along with this discussion I include various graphics presenting the data. Conclusions are provided on what the results of output analyses can inform us about the use of resources by household agents. Finally, the influences of resource considerations on household settlement decisions are presented, and discussed in relation to the questions this research set out to investigate.

CHAPTER 9: RESULTS AND CONCLUSIONS

The suite of simulation runs presented in the previous chapter ran on a number of computers, each using different platforms, running at different speeds, but producing the same types of data. The results of each simulation are written to a run-specific folder with the various data types contained in one of the 59 output files. Following the analysis procedures described above allows us to compare results of different runs, as well as present average long-term trends produced by combinations of data from all runs.

The primary analyses are designed to determine which combinations of parameter values result in model households obtaining the best goodness-of-fit of simulated settlement patterns with those observed for prehistoric sites. We are initially interested in settlement system correlations for the entire 700-year period of study, but will eventually look at those within selected MPs. Results of the first set of analyses indicate that only one of the 128 model variations obtains a positive correlation of simulated settlement with that of the observed archaeological record for the entire 700 years.

Goodness-of-Fit Results

The correspondence of simulated settlement patterns with those of the observed archaeological data is tested using Pearson Product Moment Correlation between observed and simulated occupation in each model cell in each MP. The results of the statistical analyses are reported for each of the 128 model runs for the entire 700-year simulation and for each of the 14 MPs. For each model run, three columns of figures are output by the SAS "Proc Corr" procedure. Three values are provided in each column for each simulation. The first value is Pearson's r, the correlation coefficient. The second value is the *p* value, and the third value is the number of observations on which the previous two values are based. The three columns correspond to the unsmoothed, uniform-smoothed, and kernel-smoothed observed data respectively.

Of the 128 simulations, only model run 111 achieves a positive correlation for the entire model run, though other runs achieve stronger positive correlations with observed settlement within particular MPs. For the purposes of the natural resource portion of the current modeling effort, the overall best-fitting simulation provides the basis for further testing of parameter influences. Interestingly, the positive correlation occurs with the unsmoothed values of household locations, so it initially appears that the smoothing provides little if any improvement over the original (unsmoothed) observations.

Run 111 returns the only positive Pearson product moment correlation, a value of .0006 ($p > |r|$ .8608) based on 85194 observations. This is not a particularly strong correlation, only slightly higher than some of the negative correlations, but positive nonetheless. Of the 128 original runs, the next best fit for the entire length of the simulation is - .00081 ($p > |r|$ .7950), achieved by model run 39. One of the incremental runs based on run 111 achieved a slightly weaker negative correlation, but more on those runs below.

The combination of parameter values under which run 111 ran are presented in Table 9.1. These results are somewhat surprising, since the combination of parameter values is neither harsh nor lenient for model households. In fact this combination seems to balance out negative and positive effects. The low protein requirement combines with the protein penalty to prompt households to make some effort at hunting, though little is likely required in most locations. Although households are not allowed to exchange maize or meat, travel speed is high so neither farming plots in adjacent model cells nor venturing farther afield to hunt or collect fuels incurs the highest possible costs. The harvest adjustment value of .8 slightly increases returns on crops, the soil degrade factor is at the lower rate, and the use of the Almagre-based paleoproductivity dataplane does not consider the combined effects of temperature from both high-elevation influences.

Table 9.1. Parameter Values for Simulation Run 111.

Protein per capita (5g, 10g)	Protein penalty (0, 1)	COOP (0, 4)	Travel Speed (10, 20)	Harvest Adjustment (1, .8)	Prin1 vs. Almagre	Soil Degrade (1,2)
5	1	0	20	0.8	A	1

Comparison of the long-term settlement patterns generated by model run 111 with those of the observed archaeological record (Figure 9.1), shows that despite many fewer household locations overall, the simulation does match the observed data relatively well. Notable similarities in locations of residential clusters on these raster maps are in the vicinity of the Dolores River Canyon, and on the southwest ends of mesas. More dispersed settlements are scattered across the study area, on the mesa tops in particular.

Obvious discrepancies are also visible, primarily along the northern border of the study area, as well as in the vicinity of Ute Mountain in the south-central area. These simulated household locations are most likely related. Recall that the model landscape is a torus world, so the edges are connected. Agents are therefore capable of seeing and moving from one edge of the study area to the opposite edge in a single step. This leads to two potential relationships between the clusters of households on the northern border and those around Ute Mountain. The first is that the soils in the northern area are relatively highly productive for agriculture, but not for deer. Households may have initially clustered in the north for the farming potential, and moved to the higher elevations in the south to exploit high deer populations. Conversely, model agents may have initially sought deer in the south, but found that farming was too unproductive and so moved into the area across the (virtually unknown) border, landing them in the north on arable soils.

Another potential factor responsible for the simulated households locating along the northern study area border where very few real sites are known is that the northern area is predominantly private land, little archaeological survey has been conducted there, and so few sites are recorded. Similarly, the land on and surrounding Ute Mountain is Ute Mountain Ute tribal territory, and access has been restricted for many years on much of this. Particularly in areas not associated with infrastructure improvements (such as irrigation canals), little to no archaeological work has been accomplished. This is not the case on the east and south flanks of Ute Mountain, but these areas are outside of the study area.

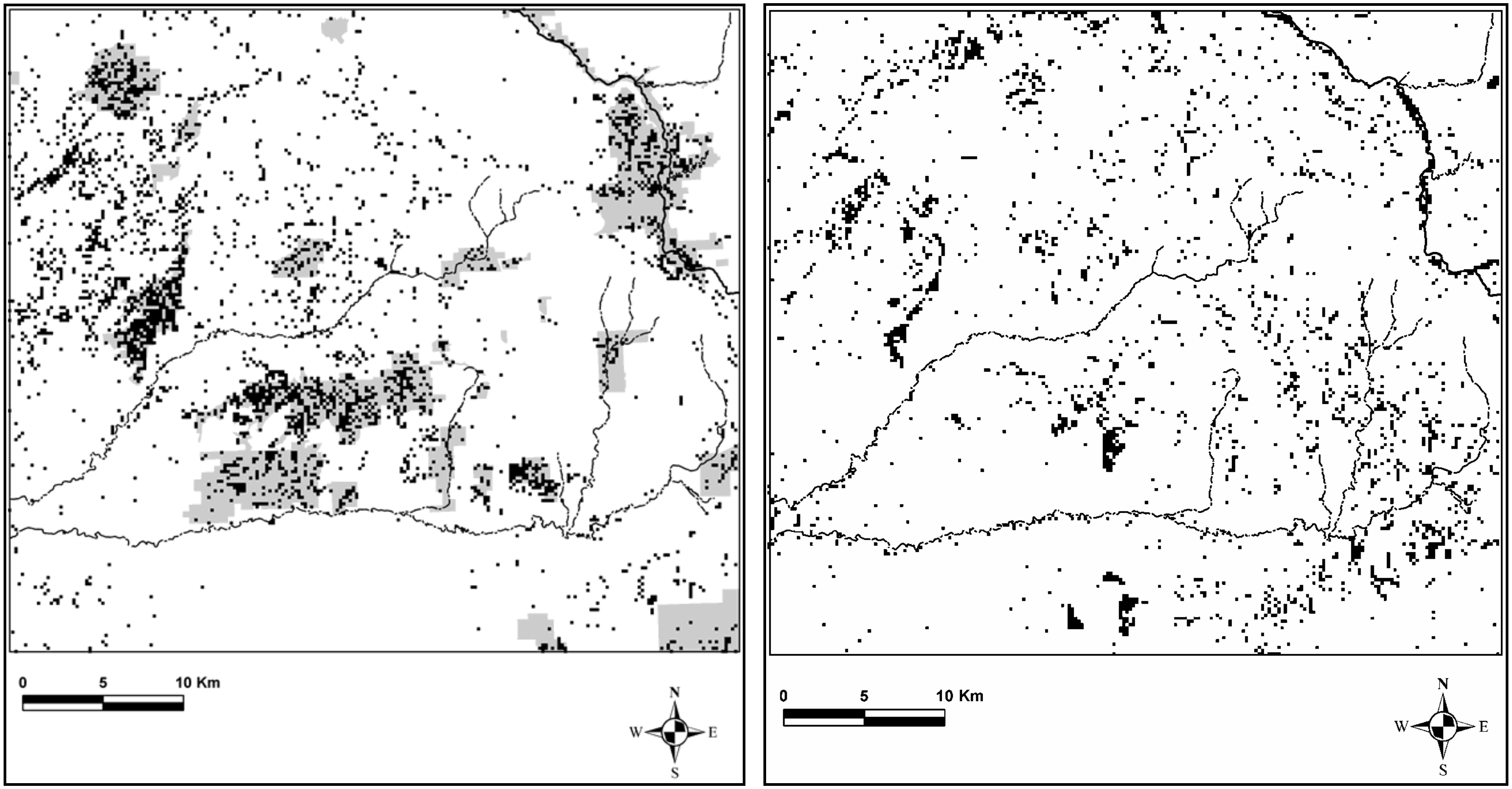

Figure 9.1. Comparison of observed site locations (left, with block-survey areas in grey) and household locations produced thoughout the 700-year simulation by model run 111 (right).

Regardless of how the combination of parameter values came to influence the simulated households of run 111 to most closely correlate with observed settlement, the positive results led us to make run 111 the basis of a series of additional experiments. These derivative runs are seven in number, and all are designed to test the influence(s) of different combinations of resource options enabled or disabled as shown in Table 9.2.

Table 9.2. Combinations of Factors Used in Incremental Runs Descended from Run 111.

Run	Agriculture	Water	Protein	Fuels	Population
111_02	Yes	No	No	No	Capped
111_03	Yes	Yes	No	No	Capped
111_04	Yes	No	No	Yes	Capped
111_05	Yes	No	Yes	No	Not Capped
111_06	Yes	Yes	No	Yes	Capped
111_07	Yes	Yes	Yes	No	Not Capped
111_08	Yes	No	Yes	Yes	Not Capped

Values for the tunable parameters (where appropriate) are the same as those used for run 111 shown above. Because the number of factors influencing households is fewer in these incremental runs, household populations tend to grow beyond realistic levels. Therefore populations in four of these were capped at the highest level reached in the original run 111.

Ranking the simulations based on run 111 parameter settings (hereafter referred to as the incremental runs) by their overall goodness-of-fit with the observed data provides insight into which combinations of independent variables (the natural resources) lead to what relative levels of correlation with the observed household settlement data. The reader should understand, however, that the importance of these factors may vary depending on the parameter choices in place. Run 111, for example, makes very modest protein demands. Higher protein requirements would likely increase the importance of protein in an "incremental run" of this sort. Table 9.3 lists these incremental runs in order of the best, that is, weakest negative correlations, with the observed data. All of our simulations require agriculture as the primary source of agent food, so only additional resources are listed.

Considering lower absolute values of negative correlation as closer-fitting to the observed data, we see that adding water and fuels (run 111_06) to the agricultural base provides the best fit with the observed data. The second strongest correlating run is 111_07, which adds water and protein to the base agricultural resource. Following this is run 111_05, which adds only protein acquired through hunting model animals. Run 111_03 is next, adding only water to the required agricultural resource. Run 111_08 follows the water-only incremental run by adding fuels and protein to the agricultural resource base. Next is run 111_02, which adds no resources to the agricultural base. Finally, run 111_04 obtains the strongest negative correlation, by adding only fuels to the agricultural base.

Table 9.3. Incremental Runs Ranked by Best Fit (Weakest Negative Correlation). Entries in Each Cell are *r*, *p*, and n.

Run #	Resource(s) Added to Agriculture	Unsmoothed Correlation	Uniformly-Smoothed Correlation	Kernel-Smoothed Correlation
111_06	Water Fuels	-.00177 .6052 85,194	-.01317 <.0001 108,283	-.00707 .0232 103,107
111_07	Water Protein	-.00279 .4150 85,194	-.00835 .0060 108,283	-.00438 .1593 103,107
111_05	Protein	-.00475 .1656 85,194	-.01316 <.0001 108,283	-.00826 .0080 103,107
111_03	Water	-.00571 .0958 85,194	-.01610 <.0001 108,283	-.01392 <.0001 103,107
111_08	Protein Fuels	-.00597 .0815 85,194	-.01172 .0001 108,283	-.01048 .0008 103,107
111_02	None	-.00714 .0373 85,194	-.02012 <.0001 108,283	-.01718 <.0001 103,107
111_04	Fuels	-.00776 .0236 85,194	-.02184 <.0001 108,283	-.01772 <.0001 103,107

The results of the correlation analyses can be better visualized by examining Figure 9.2. Here, the full suite of variables is included in run 111 (the best fitting run) shown in the top box along with the *r* and *p* values for the correlation with the unsmoothed observed data. The row of boxes below shows the incremental runs featuring the base agricultural resource (maize) and two additional natural resources, along with the corresponding correlation statistics. The lines and values between the boxes show the differences in correlation between the runs with more variables included (run 111 in the first instance) and those below that included one less resource.

The runs with the most improvement in fit, or least decrease in positive correlation, are indicated by the bold lines acscending from the boxes of runs below to those with the same and additional resources above.

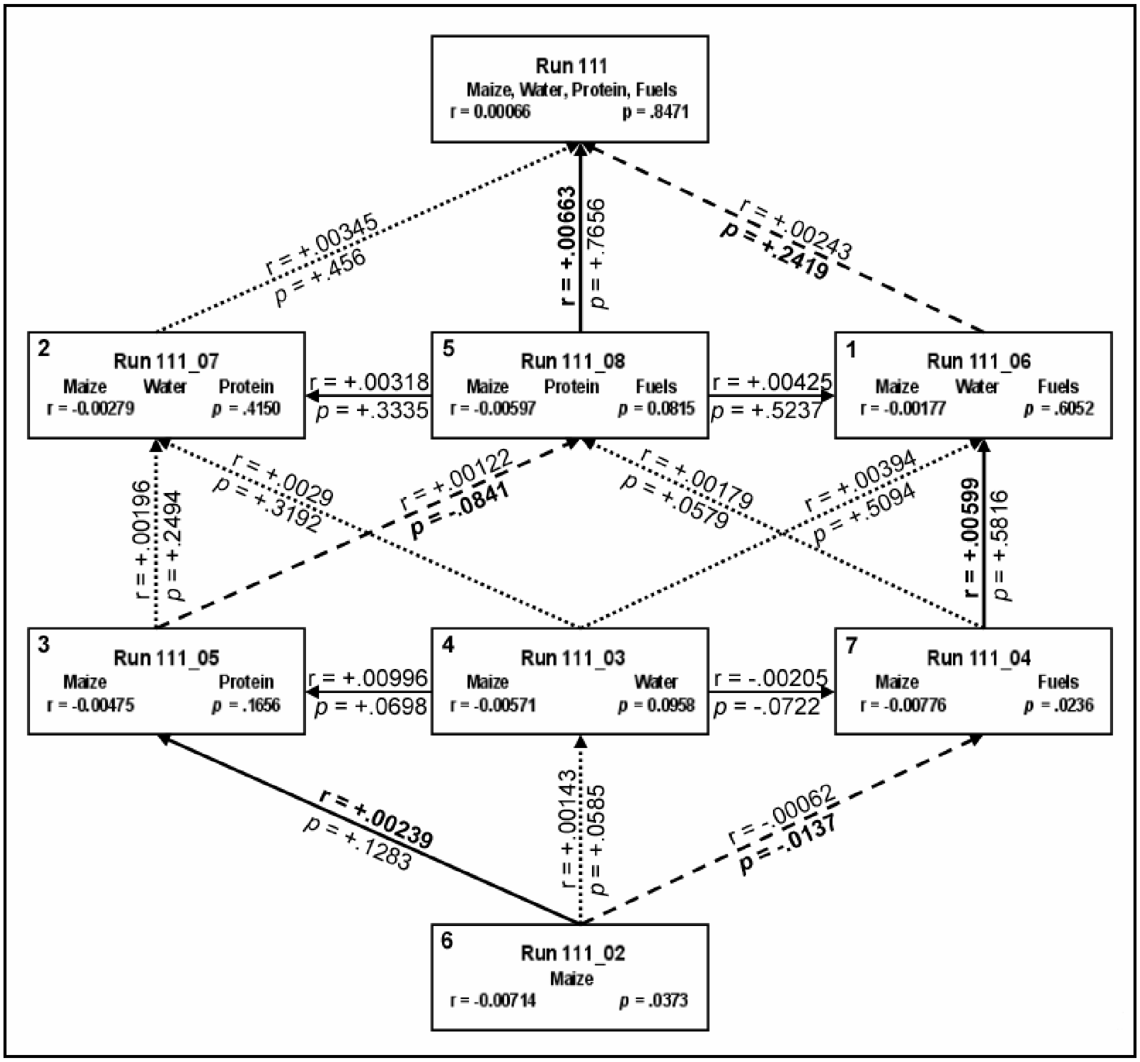

Figure 9.2. Difference in Pearson product-moment correlation between the best-fitting run 111 and the seven incremental runs using the same parameter values. Results are based on the unsmoothed correlation values produced by the entire 700-year simulation in all eight cases. Values between levels are differences in corresponding values in boxes. Bold values indicate the greatest improvement, solid arrows correspond to best improvements in *r* values, dashed arrows indicate best improvements in *p* values. Numbers in upper left corner of each box indicate the ranking of correlation as listed in Table 9.3.

The horizontal lines and associated values show the differences in correlation between runs with the same numbers of resources.

Starting from the bottom and moving up, I begin this discussion with model run 111_02 that requires model agents to only consider the agricultural potential of the model landscape in determining where to relocate when necessary. In this respect it and run 111_03 are most similar to the original Village Project implementation as reported by Kohler et al. (2000). Run 111_02 has a Pearson's *r* value of .00714 and a *p* value of .0373. Improvement in each of these values is achieved by different runs as shown in the boxes above, those that require model agents to consider one additional resource in their settlement decisions.

The second row from the bottom includes incremental model runs 111_03 (in the center), 111_05 on the left, and 111_04 on the right. Note that these runs add water, protein, and fuels to the base resource (maize) respectively. The greatest improvement in correlation in terms of Pearson's *r* is achieved by model run 111_05, with an increase of .00239. This indicates that the addition of protein improves the correlation by decreasing the negative value to *r* = .00475. This, of course, is a rather small improvement at best, and is accompanied by an increase in the associated *p* value.

Differences in the values of Pearson's *r* among the seven incremental runs are invariably small. The bold lines ascending between model run boxes in Figure 9.2 indicate the greatest improvement, or, the best increase, in *r* values from lower to upper levels. Moving up from the single variable run 111_02, we see that the two-variable run 111_05, which adds protien to maize productivity, achieves a slight increase in *r* over that of run 111_02. This suggests that the addition of protien to the required maize resource may well improve the goodness-of-fit, since the protein requirement is set so low in these runs.

The addition of a single natural resource to the agricultural base then shows some improvement of either Pearson's *r* or the associated probability, but not both concurrently by adding the same resource. Note that adding water as a consideration increases both the *r* and *p* values, which is actually more satisfactory than adding fuels, and less so than adding protein since the increase in *r* is not as great as that achieved by adding protein, and the increase in *p* gives us less confidence that the *r* value is significant in producing an increase in positive correlation. Note also the differences between these model runs that include two resources. Run 111_05, including protein, provides the lowest negative value of Pearson's *r*, and has the highest associated *p* value. On the other side of this level of models, run 111_04, adding fuels, has the highest negative Pearson's *r*, and a substantially lower value for *p*. Based on the comparison of one versus two resources, it appears that consideration of protein resources provides the best improvement overall.

Moving to the next level of complexity of the simulation also provides mixed results. Adding water to the combination of maize and fuels provides a welcome increase in the value of Pearson's *r*, and produces the most substantial decline in confidence in the form of the greatest increase in *p*. This combination then shows the weakest negative correlation, with a strong probability that it results from chance alone. On the other hand, adding protein to the combination of maize and fuels in model run 111_08 lowers (in terms of approaching a positive correlation) the value of Pearson's *r* by a mere .00122, it also decreases the *p* value substantially. So it appears that adding both fuel and protein to maize, without water, produces the strongest negative correlation.

While the combination of maize, protein, and fuels included in run 111_08 returns a negative correlation of $r = -.00597$, this value is .00425 higher (in absolute terms) than that returned by run 111_06. At the same time, the difference in the *p* values between these two runs is .5237, indicating a much lower probability that the correlation found in run 111_06, slightly negative though it may be, is significant. At the other side of this row, the combination of protein with maize and water in run 111_07 also provides a weaker negative correlation than the combination of maize, protein, and fuels in run 111_08, and the negative correlation of run 111_07 is also less significant.

Returning to the ranking shown in Table 9.3, we see that adding water and fuels (run 111_06) produces the overall next best fit to the observed data (compared with all resources included in run 111). I suggest that this is expected, since households are required to harvest a more realistic per capita quantity of fuels than protein. Note also that run 111_07, adding water and protein to the required maize resource achieves the 2 best fit of the incremental runs, despite the very low protein requirement. Furthermore, adding only protein to maize (run 111_05) achieves the third best fit of the incremental runs. This suggests that increasing the protein requirement to levels approaching those used by other researchers (e.g., Nelson and Schollmeyer 2003) should improve the goodness-of-fit substantially.

On numerous occasions both run 111 and some of the incremental runs achieved positive correlations within particular modeling periods. Individual MP correlations will be analyzed based on the best fitting of the full 128 simulations. Analyses of all of those results are, however, beyond the scope of this work. Considering only the incremental runs described above, runs 111_03, 111_04, and 111_05 all show positive correlations with the unsmoothed observations in MP 11. As is most commonly the case, the *r* values in these instances are very low, and the *p* values are very high, so there is a good chance these positive correlations are based on chance alone. This supposition may be strengthened by the fact that during MP 11 the observed populations are very low, so resource availability should not be a significant problem. On the other hand, if the incremental runs maintain the same agent populations as run 111, the number of households has leveled off by MP 11, and is well above the levels estimated from the archaeological record (see below).

The strongest positive correlation of simulated household settlement with the observed settlement pattern is provided between incremental run 111_08 and the uniformly smoothed data and occurs in MP 8. Recall from Table 3.1 that MP 8 is the first of the shorter, 40-year modeling periods, and that the total number of observed sites is relatively low. The correlation achieved by run 111_08 is a Pearson's *r* of .02783, with a *p* value of .0183. Comparing this graphically, Figure 9.3 shows that both the observed and simulated settlement distributions are widely dispersed.

This is an interesting finding, as it is strange that a strong correlation would result from such a widely dispersed settlement pattern in both the observed and simulated systems, especially with such low numbers of households. It appears that higher densities of settled locations decrease the likelihood of positive correlation of location. Compare household densities shown in Figure 9.1 with those shown in Figure 9.3 for instance. Figure 9.1 compares the locations of observed and simulated sites for the entire 700-year model run, with run 111 achieving the only overall positive correlation with a Pearson's *r* of .00066, $p = .8471$. Figure 9.3 compares the observed and simulated settlement patterns of MP 8, in which run 111_08 achieves a Pearson's *r* of .02783, $p = .0183$. This suggests that fewer households to compare results in higher correlation.

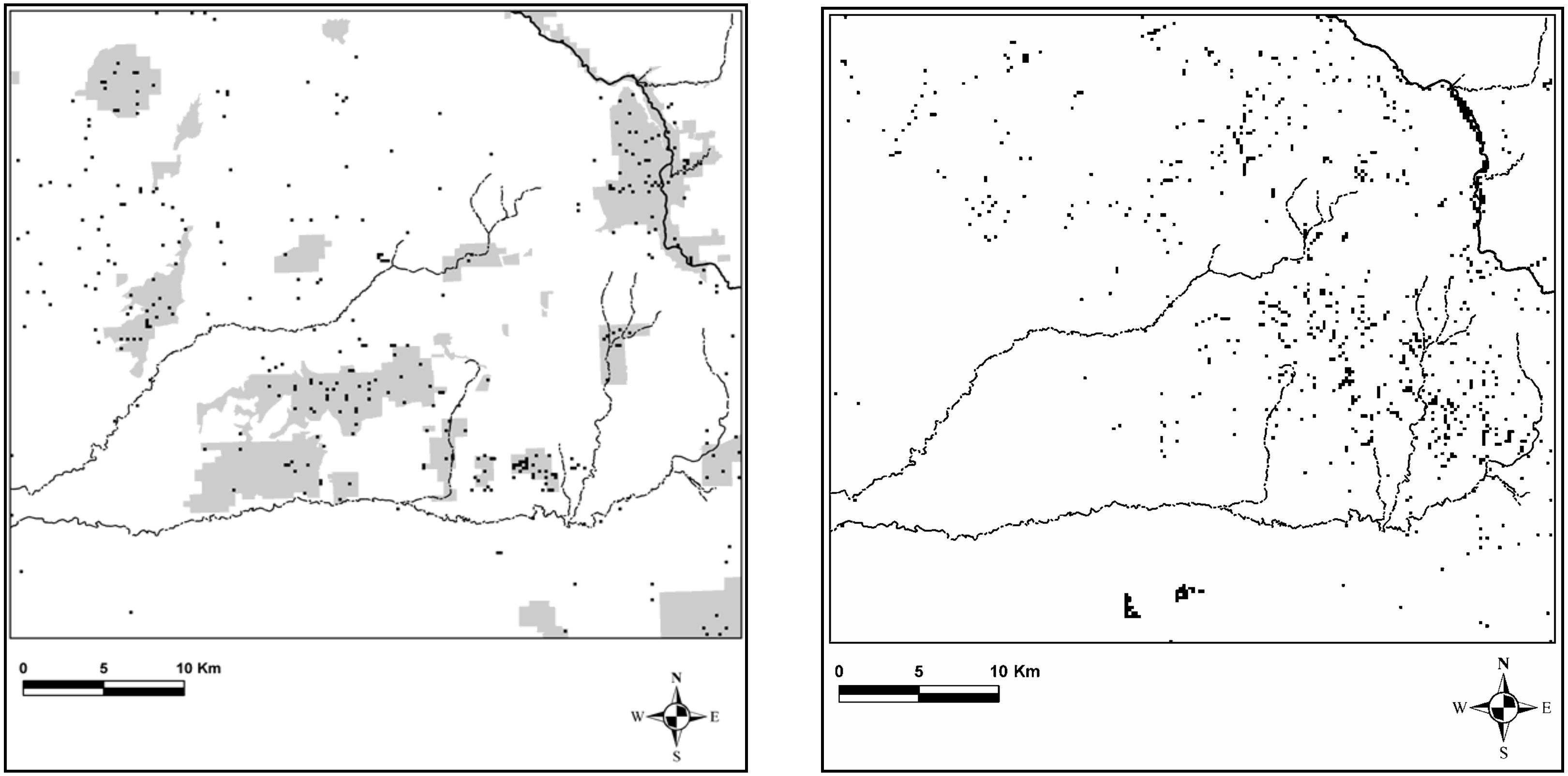

Figure 9.3. Comparison of observed site locations (left, with block-survey areas in grey) and household locations produced thoughout the 700-year simulation by model run 111_08 (right), during MP 8.

Before concluding this section, it is wise to consider the intensity of analyses employed in the current effort to correlate observed and simulated settlement patterns. Although there is no question that the analyses conducted here are valid, it may well be that we are attempting to be more rigorous than we should. Most researchers comparing spatial data from simulations with real-world data sets do so on a much less rigorous level. Many analyses test merely for the presence or absence of categorical data (Laffan 1999; Lowell 1994; Keitt 2003; Pontius 2000, 2002). In addition to the analyses presented above, I have also attempted to analyze the settlement data based on co-occurrence of location. This was done using the Map Comparison Kit (v. 3.0.1.0) developed by the Research Institute for Knowledge Systems (RIKS) branch of the Netherlands Environmental Assessment Agency and available online at http://riks.nl/mck.

Due to the widely dispersed nature of our households, however, comparison of settlement patterns at the presence/absence level is less than informative. In fact, I was unable to produce a map worthy of presentation here, even for comparative purposes. Other methods of analyses are possible, and will be investigated once the results of the revised model are available. It may be that we will return to the method of Kohler et al. (2000), though that will reduce the level of our analyses to only the spatial dimension, disregarding the number of households at each location.

Aggregation Index Results

The calculation of aggregation indices provides less favorable results than anticipated. Aside from the incongruity of the observed and simulated data described in the previous chapter, once the data were made comparable, the results are still not as expected. The normally wide dispersion of model households leads to aggregation indices that are at least an order of magnitude lower than those based on the observed data. Nevertheless, there is an interesting, though subtle, similarity in the shape of the curves as plotted in figure 9.4.

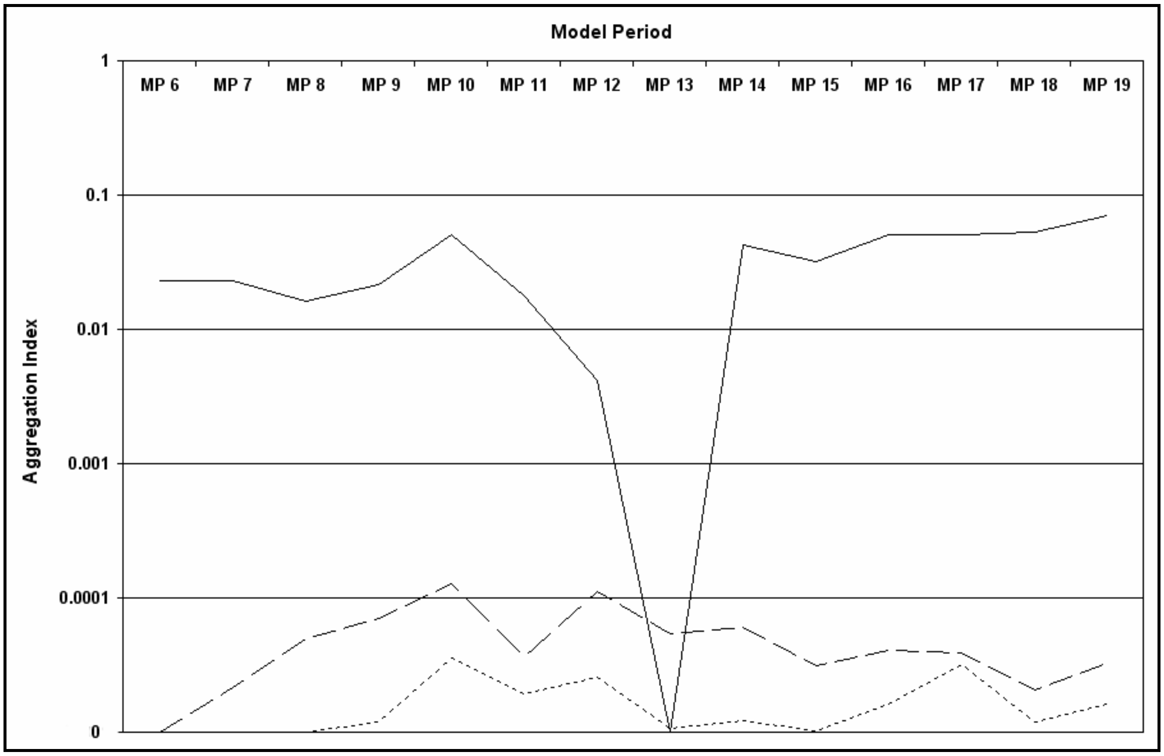

Figure 9.4. Comparison of aggregation index curves (based on raster data in these cases) showing observed data indices (solid line), average of exchange-enabled simulations (dashed line) and average of exchange-disabled runs (dotted line).

Comparing the curve of aggregation indices for the observed data as shown in Figures 3.2 and 9.4, note the difference when calculating the indices based on raster versus vector data. There is an order of magnitude reduction in the index values when based on the raster data rather than the vector, or actual data. I suspect this results from the combination of households from multiple sites, of various sizes, into the same model cells. This, of course, produces more community centers, since more households appear to be in the same location. The effect on small sites is the opposite, in that if many of these are combined into model cells, there are effectively fewer small sites. As discussed in Chapter 8, the model output data was not what I expected and thus the congruence of observed and simulated data difficult to achieve. I suspect this has led to the lack of similarity in values for aggregation indices between observed and simulated data.

As expected, however, aggregation is more common in runs allowing model agents to exchange resources than in those in which exchange is not allowed. In the current implementation, agents are allowed to exchange maize or meat, when exchange is enabled, either with relatives only (in the case of the GRN), or with any other agents within a certain distance of their home cell (when using the BRN). This should lead to some clustering of agents that rely on exchange, and so should increase the aggregation index, as is shown by the dashed line in Figure 9.4.

It appears, however, that the aggregation index, at least based on results of the current model implementation, is not very useful in examining the levels of agent cooperation as I had hoped. I will point out that in most of the 128 runs reported here, exchange was not a very important strategy for most agents in most times. Furthermore, the low protein requirements we use in these models does not deplete animal populations nearly as much as expected, so should not lead to competition for resources nor to a high necessity of relying on exchange to survive. Thus the use of the aggregation index is not as profitable as I had planned in investigating social organization. I do expect that the utility of this index will improve with future model results, as the forthcoming implementation will more realistically impact faunal populations, and thus should lead to increased competition and cooperation.

Faunal Indices Results

Results of the calculation of faunal indices based on model results are quite promising, despite the minimal protein requirements for model households. Figure 9.5 presents curves of both the artiodactyl and lagomorph indices calculated from study-area faunal assemblages as listed in Table 4.2. As reported above, dating of prehistoric sites from which these data are derived is much less precise than the annual resolution provided by model output. The limited number of sites is also nowhere near comparable in number to the volume of data produced by the simulations. Nevertheless, I feel that valid comparisons can be made for long-term trends. Therefore, I have plotted these data at the resolution of the Pecos Classification, which admittedly is less than ideal, but is arguably the most valuable to others who may want to combine and/or compare their own data sets with these.

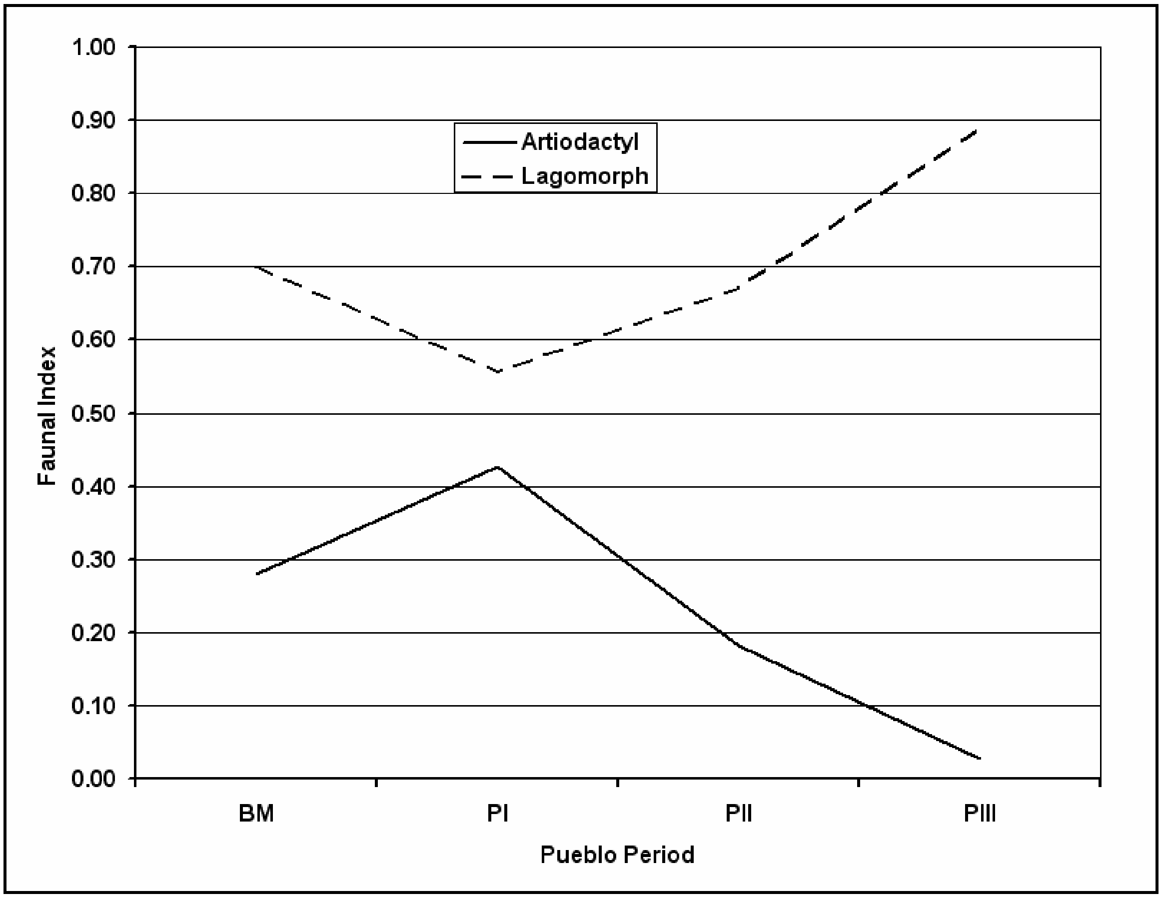

Figure 9.5. Curves of faunal indices calculated from zooarchaeological assemblages recovered from study-area sites as listed in Table 4.2.

Comparison of the faunal index curves derived from observed data with those derived from the calculation of mean numbers of animals harvested by model households in every year from all simulations (Figure 9.6) shows some congruence in values. Figure 9.6 also shows the differences between the hunting strategies used by households of all 128 model runs, and those of run 111.

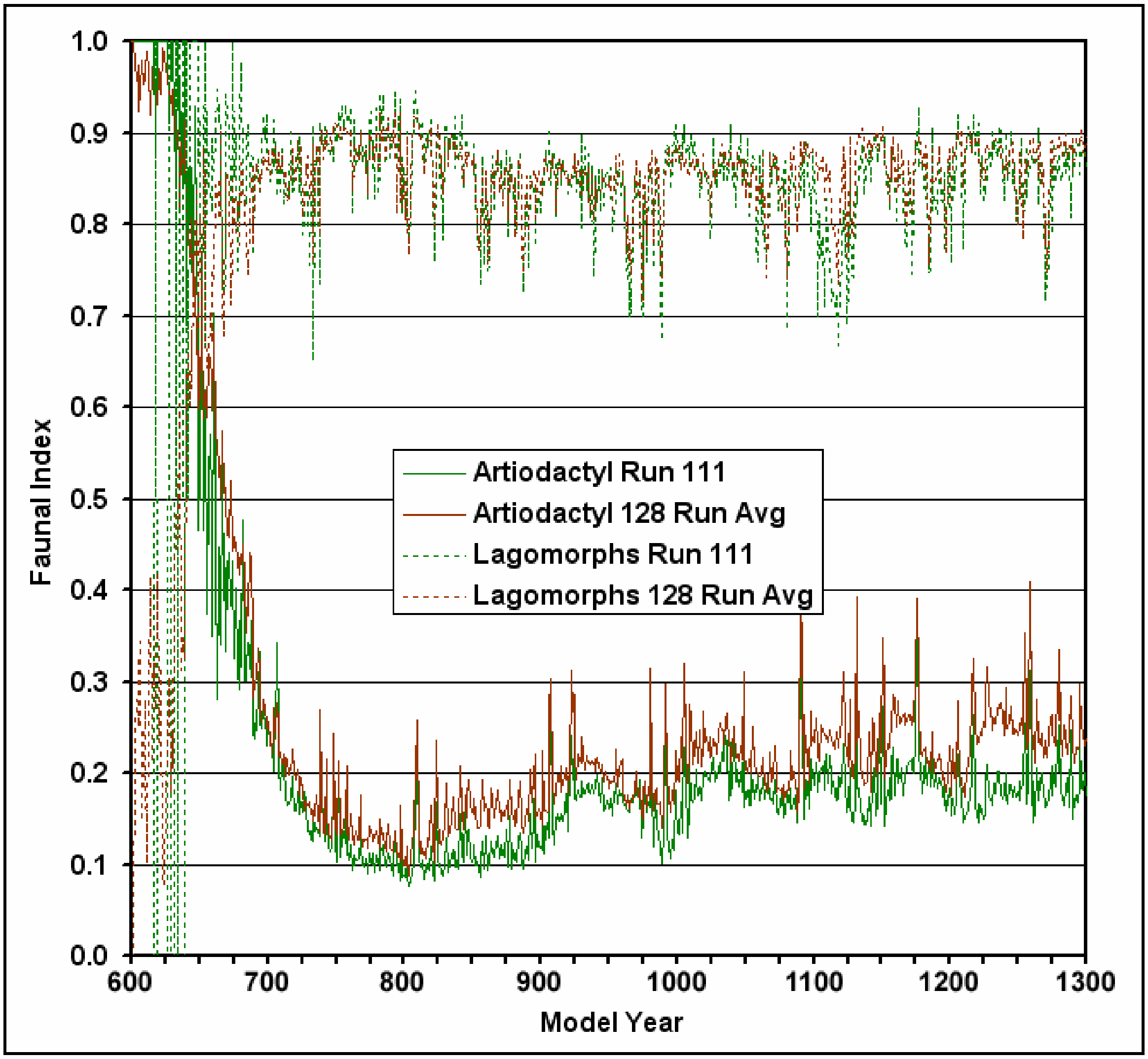

Figure 9.6. Curves of faunal indices calculated from all version 2.5 model runs (averages) and from run 111.

Note that the artiodactyl index curve for run 111 is lower than that plotted from data output by all 128 runs. On average, the artiodactyl index for run 111 is 26 percent lower than that of all 128 runs. At the same time, the lagomorph indices are nearly identical.

I suspect the lack of congruence in the shape of these observed versus simulated curves may be due, at least in part, to the very low protein requirements implemented in this version of the simulation. Future implementation of the Village model (version 2.7) is planned to account for meat weight in calculating the amounts of protein provided by each herbivore species. We will also test the effects of higher daily protein requirements, which should prompt agents to harvest higher numbers of animals. Hunting strategies should continue to select primarily for deer, as shown in the next section. This will lead to greater deer depletion, and should then decrease the artiodactyl index and increase the lagomorph index, steepening the resulting curves. This should improve the match between the shapes of faunal index curves plotted from observed and simulated data.

Mean Cost Results

Two sets of data derived from the “agent_stats” files are used to calculate the costs of procuring different resources agents are required to obtain. The first of these records the one-way distances traveled by model households to collect water and fuels. It should be expected that as households deplete preferred fuel supplies locally, they must either shift their collection of fuels to less preferred sources, or increase the distances regularly traveled to collect their fuels. Of course in the real world there are other alternatives, like constructing more thermally efficient cooking vessels and/or dwellings. But model agents don’t construct anything, so are limited to the single option of traveling farther (since they don’t distinguish among fuel types other than live versus dead wood).

Domestic water is a daily requirement of all people, and model households are required to satisfy basic water needs just as they must collect fuels. It is difficult to determine which might be more easily obtained without detailed analyses of household location. The mean distance values for water collection can shed light on how far the average household lives from a domestic water source, although it is possible that multiple sources were used. As with the other analyses of data output to the "agent_stats" files, these figures are calculated as means of means. That is, the values in the output files provide average data for each household for each year. These data are averaged for all households for each year, and the results are further averaged to smooth the final figures for all 128 runs.

Figure 9.7 plots the mean distances traveled by model households from all runs, and those from run 111, to get their supplies of both water and fuel. As expected, households settle closer to water than fuels throughout the entire 700 years of the simulation. Contrary to expectations, there seems to be only a slight initial increase in the mean distances households travel to collect fuels. On closer inspection however, in the long-term the average distances after two generations appear to fluctuate between two and three times the initial distance traveled by model households. Average distance to water varies oly slightly throughout the entire 700-year simulation.

Note that run 111 households travel greater distances for both water and fuels than the averages for households in all model runs. The differences between the mean of distances traveled by households of all 128 runs and those of households of run 111 are fairly substantial. To obtain their water supplies, run 111 households travel 20 percent farther than the average for households of the 128 simulations. To harvest their fuels, run 111 households travel 25 percent farther than the average household in the 128 model runs.

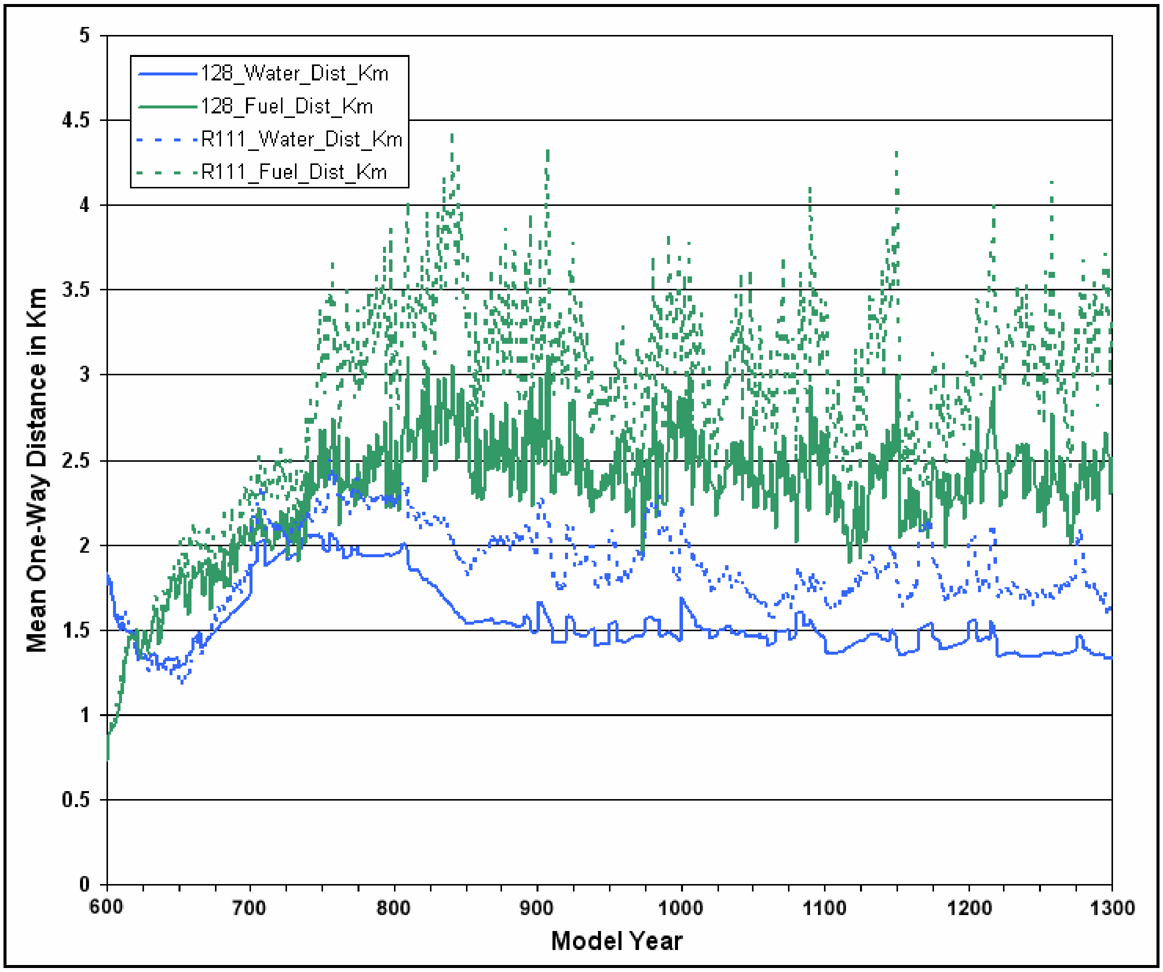

Figure 9.7. Mean distances traveled by model households based on annual output data produced by all 128 model runs, and those of run 111.

Caloric expenditures provide a second method to investigate the relative influences of resource procurement on model households. "Agent_stat" files record the average calories model households expend on resource acquisition, allowing us to track where energy obtained from growing maize is predominantly used. For present purposes, I have calculated the mean caloric expenditure for households of all 128 model runs, and those for run 111 households used to harvest both animals and fuels. Figure 9.8 plots the long-term costs of these activities.

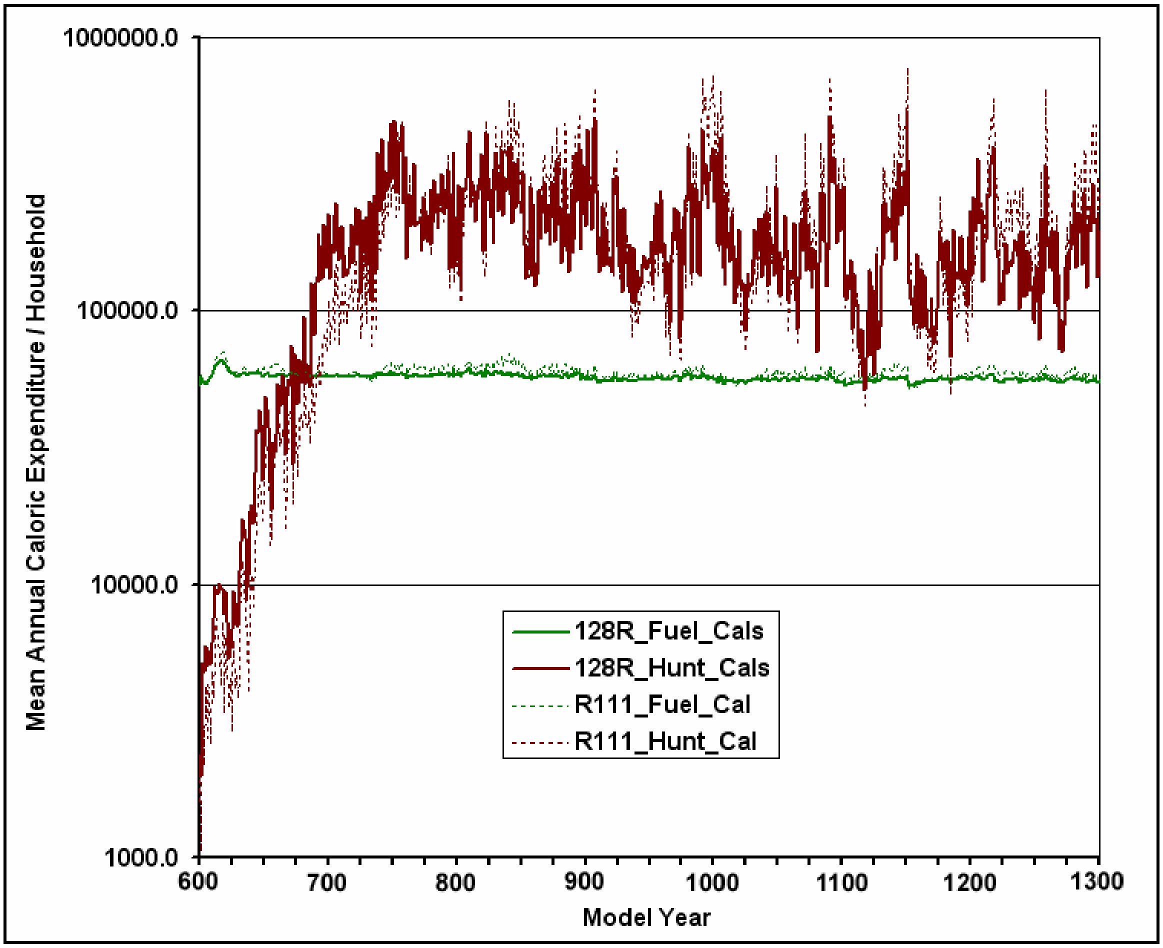

Figure 9.8. Plot of long-term caloric expenditures for model households from all 128 model runs, and those from run 111.

Here we see that although the energy spent on hunting is initially relatively low, it rises very quickly, surpassing the fairly stable costs of fuels acquisition within the first century of occupation. Run 111 households are generally spending the same amounts of energy on hunting and collecting fuels as are those from all 128 runs. Notice however, that for most of the first 150 years, run 111 households spend fewer calories on hunting, but slightly more on fuel collection.

The lower caloric hunting costs incurred by run 111 households seem to coincide with an early emphasis on hunting lagomorphs, a strategy not adopted in early centuries by households of all model runs. During these same early generations, run 111 households are traveling farther for both water and fuels. This latter tendency continues throughout the entire model run.

Interestingly, the much higher average distances traveled for fuels and water by run 111 households do not translate proportionally to caloric expenditures. Of course we can only compare those higher rates for fuels, based on the data presented here. The average 25 percent greater distances traveled for fuels by run 111 households dwarfs the four percent higher caloric expenditures for fuel acquisition. It might be that run 111 households are harvesting a much lower percentage of live woods (which have higher harvest costs) than the average household of the total 128 runs.

Conclusions

The analyses of outputs from the 128 simulations of the Village model version 2.5 have produced some interesting results, some of which are help answer the main questions this dissertation is designed to address. The three major issues are, primarily, does inclusion of the independent variables represented by critical natural resources improve the goodness-of-fit of simulated settlement to observed settlement? Secondly, is there depletion of any of these resources due to the harvesting by model agents, if so, of which resources and by how much? Lastly, how do model households respond to potential resource depletions, how does resource use correspond with that suggested by the archaeological record, and how could the fit between simulated and observed data be improved?

Answering the first question at this point appears to be fairly straightforward based on the ranking of incremental runs presented in Table 9.3. Though the statistical significance of this ranking is not currently available, of the eight incremental runs, only fuels, as a sole added resource, is ranked lower than the run in which no resources are added. In combination with water, protein and fuels improve the fit noticeably. The fact that fuel, on its own, ranks below adding no resources appears reasonable, since fuel use by model agents of run 111 had very little impact on fuel stock across the study area, as shown in Figure 9.9.

Additional analyses of household movement during run 111 may add support to the idea that fuels are a low priority in settlement decisions. It would be interesting, for instance, to run this model again, and record a full series of screen shots, similar to those presented in Johnson et al. 2005, to convert to a video for visual analyses of fuel depletion and household movement. We do not yet know whether the low value of fuels in settlement decisions is stable across parameter choices.

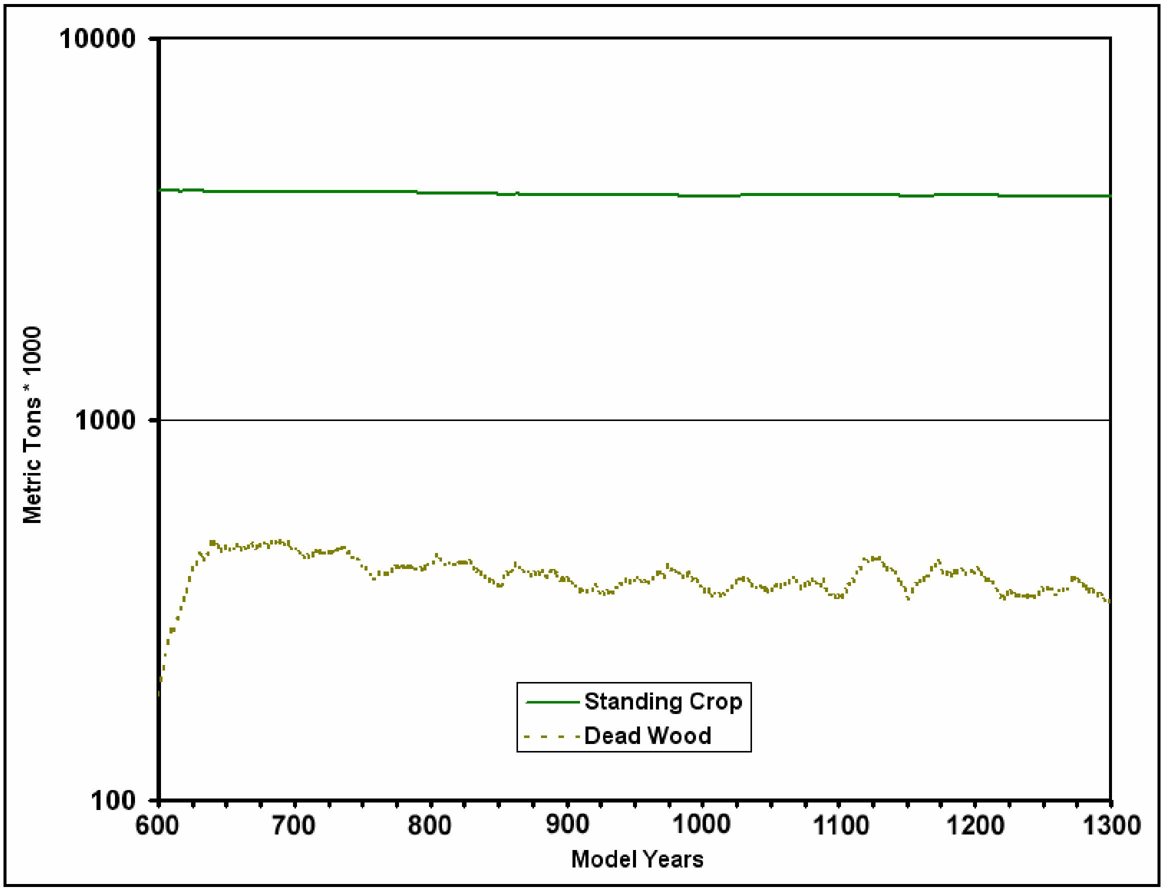

Figure 9.9. Long-term levels of fuels across the study area, as recorded by run 111 output.

Of course it is also instructive to examine population levels produced by run 111. Figure 9.10 shows long-term variation in household numbers generated by model run 111 compared with those estimated by three methods from the observed data (Varien et al. 2006). Up until model year 500 (A.D. 1100), model run 111 produces, and generally sustains, populations well above those estimated by Varien et al. (2006:Figure 4), with no apparent degradation of fuel resources.

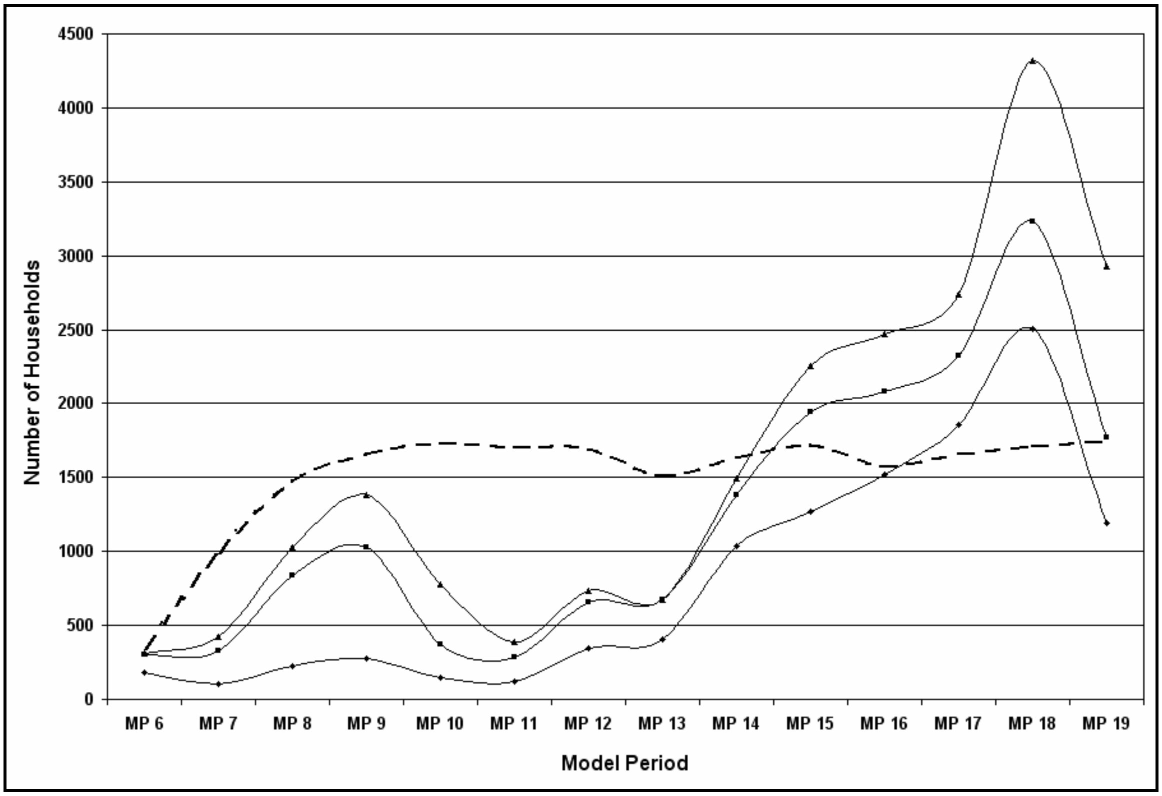

Figure 9.10. Long-term household population trajectory generated by version 2.5 run 111 (dashed line) compared to the three population estimates of Varien et al. (2006:Figure 4).

On the other hand, the energetic costs of procuring animal protein increase rapidly, about mid-way into the population increase shown here (see Figure 9.8). Does this indicate resource depletion as asked by the second question above? Figure 9.6 shows a drastic decrease in artiodactyl index, coinciding almost exactly with the population increase shown in Figure 9.10. At the same time, the lagomorph index is rising, and basically levels off for the duration of the model run. Combined with the large increase in energy expended on hunting, it appears the low growth-rate, but efficiently exploited, deer populations did not long survive being hunted by model households, despite the low protein requirement. The prolific lagomorphs, however, appear to have supported human protein needs quite well.

Finally, it appears the model households, faced with a major decrease in supply of deer, easily adjusted to exploiting lagomorphs. As suggested for further analysis of the influence of fuels on household movement, I suggest that watching the levels of lagomorphs fluctuate in conjunction with long-term household settlement shifts may be very informative in this regard. Moreover, as mentioned above, I feel confident that by increasing the protein requirement, we can produce a more clear-cut shift in faunal indices that is likely to more closely match that indicated by the archaeological record.

Further Investigations

Perhaps it should not be unexpected in a project as complicated as this that a few glitches would arise at the last minute. Of course I take responsibility for those, and am working to overcome them. The failure to implement edible meat weights in calculating animal protein supplies appears to be less problematic than I first thought, though I still believe higher protein requirements have the potential to improve matches between model results and observed data.

Despite the fact that model households have limited opportunities for social interaction, and that run 111 did not include exchange, I am optimistic that calculation and comparison of the aggregation indices of observed and future simulated households can shed light on potential factors promoting increased social interaction, and attendant organization.

There is yet much work to be done with the critical natural resources component of the Village Project. In addition to experimenting with increased requirements for daily protein intake, better estimates of woody species use should be sought and tested. Now that the natural resource productivity data are input as model landscape characteristics, additional resource use can, and should, be investigated in the future. Other plant species were certainly used in prehistoric times (Adams and Bowyer 2002), and could relatively easily be included as useful resources in future versions of the model.

Additional fuel wood collection can be, and should be, undertaken from the remaining plots in the fuel wood transects. Better control on components of native vegetation communities might be achieved through local studies of present-day vegetation, as well as additional pollen studies from within lesser disturbed portions of the study area. Future members of the Village Project team will certainly introduce additional factors into the model that are bound to be both as enlightening, and difficult to implement, as were the critical natural resources introduced by this study.

There are other potential uses of this simulation model of natural resources on this landscape, and a similar implementation is certainly possible for other areas. Wildlife ecologists and range managers, for instance, could apply the methods developed here to better manage wild and domestic herds of herbivores, as well as plan for optimal populations of wild carnivores. Foresters and wildland fire managers can also benefit from the use of this type of simulation in planning for timber extraction and fire prevention respectively. Of course the basis of the Village Project productivity might also be profitably applied to future agricultural operations as well, to more efficiently supply food for our ever-increasing human population.

In closing, I look forward to further experimentation with the resources now included as integral components of this fascinating model. It is a real privilege to be in a position to work so closely with the many others participating in this endeavor.

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Appendices

Appendix A. Data from the Soils Survey Soil Properties Tables used to Calculate Available Water Capacities for each Soil Complex.

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
1: Ackmen	0.9	0-6	6	0.15-0.17	0.16	0.96		0.864	
	0.9	6-60	54	0.16-0.18	0.17		9.18		8.262
			60						
Aquents	0.05	---		---	0				
								0.864	8.262
2: Ackmen	0.9	0-6	6	0.15-0.17	0.16	0.96		0.864	
	0.9	6-60	54	0.16-0.18	0.17		9.18		8.262
			60						
Aquents	0.5	---		---	0				
								0.864	8.262
3: Arabrab	0.8	0-4	4	0.06-0.08	0.07	0.28		0.224	
	0.8	4-13	2	0.13-0.15	0.14	0.28		0.224	
	0.8	4-13	7	0.13-0.15	0.14		0.98		0.784
	0.8	13-16	3	0.13-0.15	0.14		0.42		0.336
	0.8	16-26	10	---	0		0		0
			26					0.448	1.12
4: Arabrab	0.45	0-4	4	0.06-0.08	0.07	0.28		0.126	
	0.45	4-13	2	0.13-0.15	0.14	0.28		0.126	
	0.45	4-13	7	0.13-0.15	0.14		0.98		0.441
	0.45	13-16	3	0.13-0.15	0.14		0.42		0.189
	0.45	16-26	10	---	0		0		0
			26						
Longburn	0.4	0-1	1	0.09-0.11	0.1	0.1		0.04	
	0.4	1-4	3	0.07-0.09	0.08	0.24		0.096	
	0.4	4-17	2	0.09-0.11	0.1	0.2		0.08	
	0.4	4-17	11	0.09-0.11	0.1		1.1		0.44
	0.4	17-27	10	---	0		0		0
			27					0.468	1.07
	0.45	0-1	1	---	0	0		0	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
5: Archuleta									
	0.45	1-5	4	0.13-0.15	0.14	0.56		0.252	
	0.45	5-13	1	0.10-0.16	0.13	0.13		0.0585	
	0.45	5-13	7	0.10-0.16	0.13		0.91		0.4095
	0.45	13-17	4	---	0		0		0
			17						
Sanchez	0.3	0-5	5	0.07-0.09	0.08	0.4		0.12	
	0.3	5-11	1	0.08-0.10	0.09	0.09		0.027	
	0.3	5-11	5	0.08-0.10	0.09		0.45		0.135
	0.3	11-15	4	0.10-0.12	0.11		0.44		0.132
	0.3	15-19	4	---	0		0		0
			19					0.4575	0.6765
6: Argiustolls	0.45	0-1	1	---	0	0		0	
	0.45	1-4	3	0.04-0.07	0.055	0.165		0.07425	
	0.45	4-13	2	0.04-0.07	0.055	0.11		0.0495	
	0.45	4-13	7	0.04-0.07	0.055		0.385		0.17325
	0.45	13-20	7	0.09-0.12	0.105		0.735		0.33075
	0.45	20-50	30	0.13-0.16	0.145		4.35		1.9575
	0.45	50-60	10	0.14-0.16	0.15		1.5		0.675
			60						
Haplustalfs	0.4	0-5	5	0.07-0.10	0.85	4.25		1.7	
	0.4	5-10	1	0.09-0.11	0.1	0.1		0.04	
	0.4	5-10	4	0.09-0.11	0.1		0.4		0.16
	0.4	10-41	31	0.07-0.11	0.09		2.79		1.116
	0.4	41-60	19	0.07-0.12	0.095		1.805		0.722
			60					1.86375	5.1345
7: Argiustolls	0.3	0-1	1	---	0	0		0	
	0.3	1-4	3	0.04-0.07	0.055	0.165		0.0495	
	0.3	4-13	2	0.04-0.07	0.055	0.11		0.033	
	0.3	4-13	7	0.04-0.07	0.055		0.385		0.1155
	0.3	13-20	7	0.09-0.12	0.105		0.735		0.2205
	0.3	20-50	30	0.13-0.16	0.145		4.35		1.305
	0.3	50-60	10	0.14-0.16	0.15		1.5		0.45
			60						
Haplustalfs	0.3	0-5	5	0.07-0.10	0.085	0.425		0.1275	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.3	5-10	1	0.09-0.11	0.1	0.1		0.03	
	0.3	5-10	4	0.09-0.11	0.1		0.4		0.12
	0.3	10-41	31	0.07-0.11	0.09		2.79		0.837
	0.3	41-60	19	0.07-0.12	0.095		1.805		0.5415
			60						
Rock outcrop	0.25	0-60	0	---	0				
								0.24	3.5895
8: Barx	0.9	0-3	3	0.14-0.18	0.16	0.48		0.432	
	0.9	3-31	3	0.14-0.18	0.16	0.48		0.432	
	0.9	3-31	25	0.14-0.18	0.16		4		3.6
	0.9	31-60	29	0.14-0.18	0.16		4.64		4.176
			60					0.864	7.776
9: Barx	0.85	0-3	3	0.14-0.18	0.16	0.48		0.408	
	0.85	3-31	3	0.14-0.18	0.16	0.48		0.408	
	0.85	3-31	25	0.14-0.18	0.16		4		3.4
	0.85	31-60	29	0.14-0.18	0.16		4.64		3.944
			60					0.816	7.344
10: Barx	0.9	0--3	3	.14--.16	0.15	0.45		0.405	
	0.9	3--9	3	.11--.13	0.12	0.36		0.324	
	0.9	3--9	3	.11--.13	0.12		0.36		0.324
	0.9	9--23	14	.17--.18	0.175		2.45		2.205
	0.9	23--36	13	.17--.18	0.175		2.275		2.0475
	0.9	36--55	19	.17--.18	0.175		3.325		2.9925
	0.9	55--60	5	.17--.18	0.175		0.875		0.7875
			60					0.729	8.3565
11: Barx	0.6	0--3	3	.14--.18	0.16	0.48		0.288	
	0.6	3--31	3	.14--.18	0.16	0.48		0.288	
	0.6	3--31	25	.14--.18	0.16		4		2.4
	0.6	31--60	29	.14--.18	0.16		4.64		2.784
			60						
Gapmesa	0.3	0--2	2	.13--.15	0.14	0.28		0.084	
	0.3	2--21	4	.10--.13	0.115	0.46		0.138	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.3	2--21	15	.10--.13	0.115		1.725		0.5175
	0.3	21--28	7	.05--.07	0.06		0.42		0.126
	0.3	28--38	10	----	0		0		0
			38					0.798	5.8275
12: Battlerock	0.85	0-10	6	0.17-0.20	0.185	1.11		0.9435	
	0.85	0-10	4	0.17-0.20	0.185		0.74		0.629
	0.85	10-60	50	0.15-0.18	0.165		8.25		7.0125
			60					0.9435	7.6415
13: Beje	0.6	0-2	2	0.14-0.16	0.15	0.3		0.18	
	0.6	2-14	4	0.14-0.16	0.15	0.6		0.36	
	0.6	2-14	8	0.14-0.16	0.15		1.2		0.72
	0.6	14-24	10	---	0		0		0
			24						
Tragmon	0.2	0-5	5	0.09-0.12	0.105	0.525		0.105	
	0.2	5-11	1	0.14-0.16	0.15	0.15		0.03	
	0.2	5-11	5	0.14-0.16	0.15		0.75		0.15
	0.2	11-40	29	0.14-0.16	0.15		4.35		0.87
	0.2	40-60	20	0.12-0.14	0.13		2.6		0.52
			60					0.675	2.26
14: Burnson	0.8	0-1	1	---	0	0		0	
	0.8	1-4	3	0.16-0.18	0.17	0.51		0.408	
	0.8	4-8	2	0.17-0.20	0.185	0.37		0.296	
	0.8	4-8	2	0.17-0.20	0.185		0.37		0.296
	0.8	8-44	36	0.14-0.19	0.165		5.94		4.752
	0.8	44-54	10	---	0		0		0
			54					0.704	5.048
15: Burnson, dry	0.8	0-1	1	---	0	0		0	
	0.8	1-4	3	0.16-0.18	0.17	0.51		0.408	
	0.8	4-8	2	0.17-0.20	0.185	0.37		0.296	
	0.8	4-8	2	0.17-0.20	0.185		0.37		0.296
	0.8	8-44	36	0.14-0.19	0.165		5.94		4.752
	0.8	44-54	10	---	0		0		0
			54					0.704	5.048
16: Burnson	0.5	0-1	1	---	0	0		0	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.5	1-4	3	0.17-0.20	0.185	0.555		0.2775	
	0.5	4-8	2	0.17-0.20	0.185	0.37		0.185	
	0.5	4-8	2	0.17-0.20	0.185		0.37		0.185
	0.5	8-44	36	0.14-0.19	0.165		5.94		2.97
	0.5	44-54	10	---	0		0		0
			54						
Herm	0.3	0-6	6	0.13-0.16	0.145	0.87		0.261	
	0.3	6-13	7	0.16-0.19	0.175		1.225		0.3675
	0.3	13-45	32	0.14-0.17	0.155		4.96		1.488
	0.3	45-60	15	0.16-0.19	0.175		2.625		0.7875
			60					0.7235	5.798
17: Cahona	0.85	0-5	5	0.14-0.16	0.15	0.75		0.6375	
	0.85	5-25	1	0.18-0.21	0.195	0.195		0.16575	
	0.85	5-25	19	0.18-0.21	0.195		3.705		3.14925
	0.85	25-60	35	0.16-0.19	0.175		6.125		5.20625
			60						
Aquents	0.01	---	0	---	0				
								0.80325	8.3555
18: Cahona	0.85	0-5	5	0.14-0.16	0.15	0.75		0.6375	
	0.85	5-25	1	0.18-0.21	0.195	0.195		0.16575	
	0.85	5-25	19	0.18-0.21	0.195		3.705		3.14925
	0.85	25-60	35	0.16-0.19	0.175		6.125		5.20625
			60						
Aquents	0.02	---	0	---	0				
								0.80325	8.3555
19: Cahona	0.85	0-5	5	0.14-0.16	0.15	0.75		0.6375	
	0.85	5-25	1	0.18-0.21	0.195	0.195		0.16575	
	0.85	5-25	19	0.18-0.21	0.195		3.705		3.14925
	0.85	25-60	35	0.16-0.19	0.185		6.475		5.50375
			60						
Aquents	0.01	---	0	---	0				
								0.80325	8.653
20: Cahona	0.5	0-5	5	0.14-0.16	0.15	0.75		0.375	
	0.5	5-25	1	0.18-0.21	0.195	0.195		0.0975	
	0.5	5-25	19	0.18-0.21	0.195		3.705		1.8525

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.5	25-60	35	0.16-0.19	0.175		6.125		3.0625
			60						
Pulpit	0.35	0-10	6	0.16-0.18	0.17	1.02		0.357	
	0.35	0-10	4	0.16-0.18	0.17		0.68		0.238
	0.35	10-20	10	0.19-0.21	0.2		2		0.7
	0.35	20-36	16	0.16-0.18	0.17		2.72		0.952
	0.35	36-46	10	---	0		0		0
			46					0.8295	6.805
21: Cahona	0.35	0-5	5	0.14-0.16	0.15	0.75		0.2625	
	0.35	5-25	1	0.18-0.21	0.195	0.195		0.06825	
	0.35	5-25	19	0.18-0.21	0.195		3.705		1.29675
	0.35	25-60	35	0.16-0.19	0.175		6.125		2.14375
			60						
Sharps	0.3	0-9	6	0.13-0.16	0.145	0.87		0.261	
	0.3	0-9	3	0.13-0.16	0.145		0.435		0.1305
	0.3	9-19	10	0.15-0.17	0.16		1.6		0.48
	0.3	19-30	11	0.13-0.15	0.14		1.54		0.462
	0.3	30-40	10	---	0		0		0
			40						
Wetherill	0.2	0-3	3	0.15-0.18	0.165	0.495		0.099	
	0.2	3-7	3	0.14-0.16	0.15	0.45		0.09	
	0.2	3-7	1	0.14-0.16	0.15		0.15		0.03
	0.2	7-48	41	0.18-0.21	0.195		7.995		1.599
	0.2	48-60	12	0.11-0.15	0.13		1.56		0.312
			60						
Aquents	0.03	---	0	---	0				
								0.78075	6.454
22: Claysprings	0.8	0--3	3	.10--.12	0.11	0.33		0.264	
	0.8	3--18	3	.16--.18	0.17	0.51		0.408	
	0.8	3--18	12	.16--.18	0.17		2.04		1.632
	0.8	18--28	10	----	0		0		0
			28					0.672	1.632
23: Collide	0.9	0-10	6	0.18-0.20	0.19	1.14		1.026	
	0.9	0-10	4	0.18-0.20	0.19		0.76		0.684

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.9	10-29	19	0.16-0.19	0.175		3.325		2.9925
	0.9	29-60	31	0.10-0.16	0.13		4.03		3.627
			60						
Aquents	0.05	---	0	---	0				
								1.026	7.3035
24: Collide	0.9	0-10	6	0.18-0.20	0.19	1.14		1.026	
	0.9	0-10	4	0.18-0.20	0.19		0.76		0.684
	0.9	10-29	19	0.16-0.19	0.175		3.325		2.9925
	0.9	29-60	31	0.10-0.16	0.13		4.03		3.627
			60						
Aquents	0.03	---	0	---	0				
								1.026	7.3035
25: Collide	0.45	0-10	6	0.18-0.20	0.19	1.14		0.513	
	0.45	0-10	4	0.18-0.20	0.19		0.76		0.342
	0.45	10-29	19	0.16-0.19	0.175		3.325		1.49625
	0.45	29-60	31	0.10-0.16	0.13		4.03		1.8135
			60						
Collide, cobbly	0.4	0-2	2	0.15-0.18	0.165	0.33		0.132	
	0.4	2-8	4	0.18-0.21	0.195	0.78		0.312	
	0.4	2-8	2	0.18-0.21	0.195		0.39		0.156
	0.4	8-45	37	0.15-0.18	0.165		6.105		2.442
	0.4	45-60	15	0.04-0.06	0.05		0.75		0.3
			60					0.957	6.54975
26: Collide	0.45	0-10	6	0.18-0.20	0.19	1.14		0.513	
	0.45	0-10	4	0.18-0.20	0.19		0.76		0.342
	0.45	10-29	19	0.16-0.19	0.175		3.325		1.49625
	0.45	29-60	31	0.10-0.16	0.13		4.03		1.8135
			60						
Collide, cobbly	0.4	0-2	2	0.15-0.18	0.165	0.33		0.132	
	0.4	2-8	4	0.18-0.21	0.195	0.78		0.312	
	0.4	2-8	2	0.18-0.21	0.195		0.39		0.156
	0.4	8-45	37	0.15-0.18	0.165		6.105		2.442
	0.4	45-60	15	0.04-0.06	0.05		0.75		0.3
			60					0.957	6.54975
27: Apmay	0.35	0-4	4	0.16-0.18	0.17	0.68		0.238	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.35	4-18	2	0.19-0.21	0.2	0.4		0.14	
	0.35	4-18	12	0.19-0.21	0.2		2.4		0.84
	0.35	18-22	4	0.11-0.13	0.12		0.48		0.168
	0.35	22-60	38	0.05-0.07	0.06		2.28		0.798
			60						
Dalmatian	0.35	0-39	6	0.16-0.18	0.17	1.02		0.357	
	0.35	0-39	33	0.16-0.18	0.17		5.61		1.9635
	0.35	39-49	10	0.16-0.18	0.17		1.7		0.595
	0.35	49-60	11	0.11-0.13	0.12		1.32		0.462
			60						
Schrader	0.15	0-13	6	0.16-0.18	0.17	1.02		0.153	
	0.15	0-13	7	0.16-0.18	0.17		1.19		0.1785
	0.15	13-17	4	0.13-0.15	0.14		0.56		0.084
	0.15	17-24	7	0.14-0.16	0.15		1.05		0.1575
	0.15	24-60	36	0.13-0.15	0.14		5.04		0.756
			60					0.888	6.0025
29: Endoaquolls	0.6	0-4	4	0.14-0.17	0.155	0.62		0.372	
	0.6	4-28	2	0.10-0.13	0.115	0.23		0.138	
	0.6	4-28	22	0.10-0.13	0.115		2.53		1.518
	0.6	28-60	32	0.02-0.03	0.025		0.8		0.48
			60						
Ustifluvents	0.25	0-6	6	0.14-0.18	0.16	0.96		0.24	
	0.25	6-17	11	0.13-0.17	0.15		1.65		0.4125
	0.25	17-24	7	0.10-0.15	0.125		0.875		0.21875
	0.25	24-30	6	0.13-0.17	0.15		0.9		0.225
	0.25	30-60	30	0.01-0.03	0.02		0.6		0.15
			60					0.75	3.00425
30: Falconry	0.8	0-1	1	---	0	0		0	
	0.8	1-5	4	0.07-0.10	0.085	0.34		0.272	
	0.8	5-14	1	0.06-0.08	0.07	0.07		0.056	
	0.8	5-14	8	0.06-0.08	0.07		0.56		0.448
	0.8	14-24	10	---	0		0		0
			24					0.328	0.448
31: Farb	0.55	0--3	3	.08--.13	0.105	0.315		0.17325	
	0.55	3--16	3	.06--.13	0.095	0.285		0.15675	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.55	3--16	10	.06--.13	0.095		0.95		0.5225
	0.55	16--26	10	----	0		0		0
			26						
Rock outcrop	0.3	0--60	60	.00--.00	0		0		0
								0.33	0.5225
32: Fardraw	0.8	0-11	6	0.14-0.16	0.15	0.9		0.72	
	0.8	0-11	5	0.14-0.16	0.15		0.75		0.6
	0.8	11-15	4	0.08-0.11	0.095		0.38		0.304
	0.8	15-51	36	0.07-0.09	0.08		2.88		2.304
	0.8	51-60	9	0.07-0.09	0.08		0.72		0.576
			60					0.72	3.784
33: Fardraw	0.85	0-9	6	0.06-0.09	0.075	0.45		0.3825	
	0.85	0-9	3	0.06-0.09	0.075		0.225		0.19125
	0.85	9-13	4	0.09-0.11	0.1		0.4		0.34
	0.85	13-60	47	0.07-0.10	0.085		3.995		3.39575
			60					0.3825	3.927
34: Fardraw	0.85	0-9	6	0.06-0.09	0.075	0.45		0.3825	
	0.85	0-9	3	0.06-0.09	0.075		0.225		0.19125
	0.85	9-13	4	0.09-0.11	0.1		0.4		0.34
	0.85	13-60	47	0.07-0.10	0.085		3.995		3.39575
			60					0.3825	3.927
35: Fardraw	0.5	0-9	6	0.06-0.09	0.075	0.45		0.225	
	0.5	0-9	3	0.06-0.09	0.075		0.225		0.1125
	0.5	9-13	4	0.09-0.11	0.1		0.4		0.2
	0.5	13-60	47	0.07-0.10	0.085		3.995		1.9975
			60						
Granath	0.35	0-1	1	---	0	0		0	
	0.35	1-14	5	0.18-0.20	0.19	0.95		0.3325	
	0.35	1-14	8	0.18-0.20	0.19		1.52		0.532
	0.35	14-60	46	0.18-0.20	0.19		8.74		3.059
			60					0.5575	5.901
36: Fivepine	0.6	0-3	3	0.13-0.17	0.15	0.45		0.27	
	0.6	3-9	3	0.11-0.13	0.12	0.36		0.216	
	0.6	3-9	3	0.11-0.13	0.12		0.36		0.216

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.6	9-12	3	0.11-0.13	0.12		0.36		0.216
	0.6	12-15	3	0.08-0.10	0.09		0.27		0.162
	0.6	15-25	10	---	0		0		0
			25						
Nortez	0.25	0-3	3	0.15-0.18	0.165	0.495		0.12375	
	0.25	3-10	3	0.17-0.20	0.185	0.555		0.13875	
	0.25	3-10	4	0.17-0.20	0.185		0.74		0.185
	0.25	10-32	22	0.15-0.18	0.165		3.63		0.9075
	0.25	32-42	10	---	0		0		0
			42					0.7485	1.6865
37: Fluvaquents	0.55	0-8	6	0.06-0.18	0.12	0.72		0.396	
	0.55	0-8	2	0.06-0.18	0.12		0.24		0.132
	0.55	8-60	52	0.05-0.08	0.065		3.38		1.859
			60						
Haplustolls	0.3	0-4	4	0.10-0.12	0.11	0.44		0.132	
	0.3	4-19	2	0.10-0.15	0.125	0.25		0.075	
	0.3	4-19	13	0.10-0.15	0.125		1.625		0.4875
	0.3	19-24	5	0.06-0.10	0.08		0.4		0.12
	0.3	24-60	36	0.02-0.06	0.04		1.44		0.432
			60					0.603	3.0305
38: Fluvents	0.55	0-6	6	---	0	0		0	
	0.55	6-60	54	0.03-0.06	0.045		2.43		1.3365
			60						
Fluvaquents	0.3	0-8	6	0.06-0.18	0.12	0.72		0.216	
	0.3	0-8	2	0.06-0.18	0.12		0.24		0.072
	0.3	8-60	52	0.05-0.08	0.065		3.38		1.014
			60					0.216	2.4225
39: Fughes	0.9	0-7	6	0.16-0.18	0.17	1.02		0.918	
	0.9	0-7	1	0.16-0.18	0.17		0.17		0.153
	0.9	7-26	19	0.18-0.20	0.19		3.61		3.249
	0.9	26-44	18	0.14-0.16	0.15		2.7		2.43
	0.9	44-60	16	0.14-0.16	0.15		2.4		2.16
			60					0.918	7.992
40: Fughes	0.55	0-8	6	0.16-0.18	0.17	1.02		0.561	
	0.55	0-8	2	0.16-0.18	0.17		0.34		0.187

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.55	8-26	18	0.18-0.20	0.19		3.42		1.881
	0.55	26-44	18	0.14-0.16	0.15		2.7		1.485
	0.55	44-60	16	0.10-0.16	0.13		2.08		1.144
			60						
Herm	0.35	0-6	6	0.13-0.16	0.145	0.87		0.3045	
	0.35	6-13	7	0.16-0.19	0.175		1.225		0.42875
	0.35	13-45	32	0.14-0.17	0.155		4.96		1.736
	0.35	45-60	15	0.16-0.19	0.175		2.625		0.91875
			60					0.8655	7.7805
41: Fughes	0.5	0-7	6	0.13-0.16	0.145	0.87		0.435	
	0.5	0-7	1	0.13-0.16	0.145		0.145		0.0725
	0.5	7-26	19	0.18-0.20	0.19		3.61		1.805
	0.5	26-34	8	0.16-0.19	0.175		1.4		0.7
	0.5	34-44	10	0.14-0.16	0.15		1.5		0.75
	0.5	44-60	16	0.14-0.16	0.15		2.4		1.2
			60						
Sheek	0.35	0-2	2	0.12-0.13	0.125	0.25		0.0875	
	0.35	2-7	4	0.15-0.17	0.16	0.64		0.224	
	0.35	2-7	1	0.15-0.17	0.16		0.16		0.056
	0.35	7-20	13	0.09-0.11	0.1		1.3		0.455
	0.35	20-29	9	0.07-0.09	0.08		0.72		0.252
	0.35	29-46	17	0.14-0.16	0.15		2.55		0.8925
	0.35	46-60	14	0.07-0.09	0.08		1.12		0.392
			60					0.7465	6.575
42: Gladel	0.45	0-5	5	0.10-0.12	0.11	0.55		0.2475	
	0.45	5-10	1	0.08-0.10	0.09	0.09		0.0405	
	0.45	5-10	4	0.08-0.10	0.09		0.36		0.162
	0.45	10-15	5	0.09-0.12	0.105		0.525		0.23625
	0.45	15-25	10	---	0		0		0
			25						
Pulpit	0.35	0-10	6	0.16-0.18	0.17	1.02		0.357	
	0.35	0-10	4	0.16-0.18	0.17		0.68		0.238
	0.35	10-20	10	0.19-0.21	0.2		2		0.7
	0.35	20-36	16	0.16-0.18	0.17		2.72		0.952
	0.35	36-46	10	---	0		0		0

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
			46					0.645	2.28825
43: Goldbug	0.8	0-1	1	---	0	0		0	
	0.8	1-21	5	0.06-0.08	0.07	0.35		0.28	
	0.8	1-21	15	0.06-0.08	0.07		1.05		0.84
	0.8	21-29	8	0.10-0.13	0.115		0.92		0.736
	0.8	29-60	31	0.10-0.16	0.13		4.03		3.224
			60					0.28	4.8
44: Granath	0.9	0-1	1	---	0	0		0	
	0.9	1-14	5	0.18-0.20	0.19	0.95		0.855	
	0.9	1-14	8	0.18-0.20	0.19		1.52		1.368
	0.9	14-60	46	0.18-0.20	0.19		8.74		7.866
			60					0.855	9.234
45: Granath	0.9	0-1	1	---	0	0		0	
	0.9	1-14	5	0.18-0.20	0.19	0.95		0.855	
	0.9	1-14	8	0.18-0.20	0.19		1.52		1.368
	0.9	14-60	46	0.18-0.20	0.19		8.74		7.866
			60					0.855	9.234
46: Granath	0.5	0-10	6	0.18-0.20	0.19	1.14		0.57	
	0.5	0-10	4	0.18-0.20	0.19		0.76		0.38
	0.5	10-40	30	0.14-0.21	0.175		5.25		2.625
	0.5	40-60	20	0.14-0.21	0.175		3.5		1.75
			60						
Fughes	0.35	0-7	6	0.13-0.16	0.145	0.87		0.3045	
	0.35	0-7	1	0.13-0.16	0.145		0.145		0.05075
	0.35	7-26	19	0.18-0.20	0.19		3.61		1.2635
	0.35	26-34	8	0.16-0.19	0.175		1.4		0.49
	0.35	34-44	10	0.14-0.16	0.15		1.5		0.525
	0.35	44-60	16	0.14-0.16	0.15		2.4		0.84
			60					0.8745	7.92425
47: Granath	0.55	0-10	6	0.18-0.20	0.19	1.14		0.627	
	0.55	0-10	4	0.18-0.20	0.19		0.76		0.418
	0.55	10-40	30	0.14-0.21	0.175		5.25		2.8875
	0.55	40-60	20	0.14-0.21	0.175		3.5		1.925
			60						
Nortez	0.3	0-3	3	0.15-0.18	0.165	0.495		0.1485	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.3	3-10	3	0.17-0.20	0.185	0.555		0.1665	
	0.3	3-10	4	0.17-0.20	0.185		0.74		0.222
	0.3	10-32	22	0.15-0.18	0.165		3.63		1.089
	0.3	32-42	10	---	0		0		0
			42					0.942	6.5415
48: Granath	0.4	0-10	6	0.18-0.20	0.19	1.14		0.456	
	0.4	0-10	4	0.18-0.20	0.19		0.76		0.304
	0.4	10-40	30	0.14-0.21	0.175		5.25		2.1
	0.4	40-60	20	0.14-0.21	0.175		3.5		1.4
			60						
Ormiston	0.25	0-7	6	0.13-0.16	0.145	0.87		0.2175	
	0.25	0-7	1	0.13-0.16	0.145		0.145		0.03625
	0.25	7-32	25	0.07-0.11	0.09		2.25		0.5625
	0.25	32-44	12	0.13-0.16	0.145		1.74		0.435
	0.25	44-54	10	---	0		0		0
			54						
Fivepine	0.2	0-3	3	0.13-0.17	0.15	0.45		0.09	
	0.2	3-9	3	0.11-0.13	0.125	0.375		0.075	
	0.2	3-9	3	0.11-0.13	0.125		0.375		0.075
	0.2	9-12	3	0.11-0.13	0.125		0.375		0.075
	0.2	12-15	3	0.08-0.10	0.09		0.27		0.054
	0.2	15-25	10	---	0		0		0
			25					0.8385	5.04175
49: Herm	0.8	0-7	6	0.13-0.16	0.145	0.87		0.696	
	0.8	0-7	1	0.13-0.16	0.145		0.145		0.116
	0.8	7-34	27	0.14-0.17	0.155		4.185		3.348
	0.8	34-60	26	0.16-0.19	0.175		4.55		3.64
			60					0.696	7.104
50: Herm	0.85	0-1	1	0.07-0.09	0.08	0.08		0.068	
	0.85	1-10	5	0.10-0.13	0.115	0.575		0.48875	
	0.85	1-10	4	0.10-0.13	0.115		0.46		0.391
	0.85	10-60	50	0.17-0.21	0.185		9.25		7.8625
			60					0.55675	8.2535
51: Herm	0.5	0-6	6	0.13-0.16	0.145	0.87		0.435	
	0.5	6-13	7	0.16-0.19	0.175		1.225		0.6125

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.5	13-45	32	0.14-0.17	0.155		4.96		2.48
	0.5	45-60	15	0.16-0.19	0.175		2.625		1.3125
			60						
Pagoda	0.35	0-1	1	---	0	0		0	
	0.35	1-5	4	0.16-0.18	0.17	0.68		0.238	
	0.35	5-21	1	0.19-0.21	0.2	0.2		0.07	
	0.35	5-21	15	0.19-0.21	0.2		3		1.05
	0.35	21-60	39	0.19-0.21	0.2		7.8		2.73
			60					0.743	8.185
52: Hesperus	0.9	0-11	6	0.16-0.19	0.175	1.05		0.945	
	0.9	0-11	5	0.16-0.19	0.175		0.875		0.7875
	0.9	11-44	33	0.16-0.19	0.175		5.775		5.1975
	0.9	44-60	16	0.16-0.19	0.175		2.8		2.52
			60						
Aquents	0.02	---	0	---	0				
								0.945	8.505
53: Hesperus	0.85	0-11	6	0.16-0.19	0.175	1.05		0.8925	
	0.85	0-11	5	0.16-0.19	0.175		0.875		0.74375
	0.85	11-44	33	0.16-0.19	0.175		5.775		4.90875
	0.85	44-60	16	0.16-0.19	0.175		2.8		2.38
			60					0.8925	8.0325
54: Hesperus	0.85	0-11	6	0.16-0.19	0.175	1.05		0.8925	
	0.85	0-11	5	0.16-0.19	0.175		0.875		0.74375
	0.85	11-44	33	0.16-0.19	0.175		5.775		4.90875
	0.85	44-60	16	0.16-0.19	0.175		2.8		2.38
			60					0.8925	8.0325
55: Hesperus	0.9	0-11	6	0.12-0.14	0.13	0.78		0.702	
	0.9	0-11	5	0.12-0.14	0.13		0.65		0.585
	0.9	11-44	33	0.16-0.19	0.175		5.775		5.1975
	0.9	44-60	16	0.16-0.19	0.175		2.8		2.52
			60					0.702	8.3025
56: Ilex	0.85	0-2	2	0.16-0.18	0.17	0.34		0.289	
	0.85	2-22	4	0.19-0.21	0.2	0.8		0.68	
	0.85	2-22	16	0.19-0.21	0.2		3.2		2.72
	0.85	22-37	15	0.14-0.18	0.16		2.4		2.04

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.85	37-60	23	0.14-0.18	0.16		3.68		3.128
			60					0.969	7.888
57: Ilex	0.85	0-2	2	0.16-0.18	0.17	0.34		0.289	
	0.85	2-22	4	0.19-0.21	0.2	0.8		0.68	
	0.85	2-22	16	0.19-0.21	0.2		3.2		2.72
	0.85	22-37	15	0.14-0.18	0.16		2.4		2.04
	0.85	37-60	23	0.14-0.18	0.16		3.68		3.128
			60					0.969	7.888
58: Ilex	0.6	0-2	2	0.16-0.18	0.17	0.34		0.204	
	0.6	2-22	4	0.19-0.21	0.2	0.8		0.48	
	0.6	2-22	16	0.19-0.21	0.2		3.2		1.92
	0.6	22-37	15	0.14-0.18	0.16		2.4		1.44
	0.6	37-60	23	0.14-0.18	0.16		3.68		2.208
			60						
Granath	0.25	0-1	1	---	0	0		0	
	0.25	1-14	5	0.18-0.20	0.19	0.95		0.2375	
	0.25	1-14	8	0.18-0.20	0.19		1.52		0.38
	0.25	14-60	46	0.18-0.20	0.19		8.74		2.185
			60					0.9215	8.133
59: Ilex	0.6	0-2	2	0.16-0.18	0.17	0.34		0.204	
	0.6	2-22	4	0.19-0.21	0.2	0.8		0.48	
	0.6	2-22	16	0.19-0.21	0.2		3.2		1.92
	0.6	22-37	15	0.14-0.18	0.16		2.4		1.44
	0.6	37-60	23	0.14-0.18	0.16		3.68		2.208
			60						
Granath	0.25	0-1	1	---	0	0		0	
	0.25	1-14	5	0.18-0.20	0.19	0.95		0.2375	
	0.25	1-14	8	0.18-0.20	0.19		1.52		0.38
	0.25	14-60	46	0.18-0.20	0.19		8.74		2.185
			60					0.9215	8.133
60: Ilex	0.35	0-2	2	0.16-0.18	0.17	0.34		0.119	
	0.35	2-22	4	0.19-0.21	0.2	0.8		0.28	
	0.35	2-22	16	0.19-0.21	0.2		3.2		1.12
	0.35	22-37	15	0.14-0.18	0.16		2.4		0.84
	0.35	37-60	23	0.14-0.18	0.16		3.68		1.288

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
			60						
Pramiss	0.3	0-3	3	0.07-0.09	0.08	0.24		0.072	
	0.3	3-16	3	0.16-0.18	0.17	0.51		0.153	
	0.3	3-16	10	0.16-0.18	0.17		1.7		0.51
	0.3	16-31	15	0.16-0.18	0.17		2.55		0.765
	0.3	31-41	10	---	0		0		0
			41						
Falconry	0.2	0-1	1	---	0	0		0	
	0.2	1-5	4	0.07-0.10	0.085	0.34		0.068	
	0.2	5-14	1	0.06-0.08	0.07	0.07		0.014	
	0.2	5-14	8	0.06-0.08	0.07		0.56		0.112
	0.2	14-24	10	---	0		0		0
			24					0.706	4.635
61: Ilex	0.35	0-2	2	0.16-0.18	0.17	0.34		0.119	
	0.35	2-22	4	0.19-0.21	0.2	0.8		0.28	
	0.35	2-22	16	0.19-0.21	0.2		3.2		1.12
	0.35	22-37	15	0.14-0.18	0.16		2.4		0.84
	0.35	37-60	23	0.14-0.18	0.16		3.68		1.288
			60						
Pramiss	0.3	0-3	3	0.16-0.18	0.17	0.51		0.153	
	0.3	3-16	3	0.16-0.18	0.17	0.51		0.153	
	0.3	3-16	10	0.16-0.18	0.17		1.7		0.51
	0.3	16-31	15	0.16-0.18	0.17		2.55		0.765
	0.3	31-41	10	---	0		0		0
			41						
Granath	0.2	0-1	1	---	0	0		0	
	0.2	1-14	5	0.18-0.20	0.19	0.95		0.19	
	0.2	1-14	8	0.18-0.20	0.19		1.52		0.304
	0.2	14-60	46	0.18-0.20	0.19		8.74		1.748
			60					0.895	6.575
62: Irak	0.85	0-8	6	0.14-0.17	0.155	0.93		0.7905	
	0.85	0-8	2	0.14-0.17	0.155		0.31		0.2635
	0.85	8-60	52	0.15-0.18	0.165		8.58		7.293
			60						
Aquents	0.05	---	0	---	0				

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
								0.7905	7.5565
63: Jemco	0.4	0-7	6	0.16-0.18	0.17	1.02		0.408	
	0.4	0-7	1	0.16-0.18	0.17		0.17		0.068
	0.4	7-22	15	0.16-0.18	0.17		2.55		1.02
	0.4	22-39	17	0.17-0.19	0.17		2.89		1.156
	0.4	39-49	10	---	0		0		0
			49						
Detra	0.3	0-16	6	0.14-0.18	0.16	0.96		0.288	
	0.3	0-16	10	0.14-0.18	0.16		1.6		0.48
	0.3	16-43	27	0.14-0.20	0.17		4.59		1.377
	0.3	43-57	14	0.16-0.19	0.175		2.45		0.735
	0.3	57-67	10	---	0		0		0
			67						
Beje	0.2	0-2	2	0.14-0.16	0.15	0.3		0.06	
	0.2	2-6	4	0.14-0.16	0.15	0.6			0
	0.2	6-14	8	0.14-0.20	0.17		1.36		0.272
	0.2	14-24	10	---	0		0		0
			24					0.756	5.108
64: Lazear	0.5	0-5	5	0.06-0.08	0.07	0.35		0.175	
	0.5	5-15	1	0.08-0.15	0.115	0.115		0.0575	
	0.5	5-15	9	0.08-0.15	0.115		1.035		0.5175
	0.5	15-19	4	---	0		0		0
			19						
Rock outcrop	0.3	0-60		---	0				
								0.2325	0.5175
65: Lillings	0.9	0-2	2	0.14-0.18	0.16	0.32		0.288	
	0.9	2-60	4	0.14-0.19	0.165	0.66		0.594	
	0.9	2-60	54	0.14-0.19	0.165		8.91		8.019
			60					0.882	8.019
66: Lillings	0.9	0-2	2	0.16-0.19	0.175	0.35		0.315	
	0.9	2-60	4	0.14-0.19	0.165	0.66		0.594	
	0.9	2-60	54	0.14-0.19	0.165		8.91		8.019
			60					0.909	8.019
67: Lillings	0.9	0--2	2	.16--.19	0.175	0.35		0.315	
	0.9	2--60	4	.14--.19	0.165	0.66		0.594	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.9	2--60	54	.14--.19	0.165		8.91		8.019
			60					0.909	8.019
68: Longburn	0.65	0-1	1	0.09-0.11	0.1	0.1		0.065	
	0.65	1-4	3	0.07-0.09	0.08	0.24		0.156	
	0.65	4-17	2	0.09-0.11	0.1	0.2		0.13	
	0.65	4-17	11	0.09-0.11	0.1		1.1		0.715
	0.65	17-27	10	---	0		0		0
			27						
Rock outcrop	0.2	0-60		---	0				
								0.351	0.715
69: Longburn	0.5	0-1	1	0.09-0.11	0.1	0.1		0.05	
	0.5	1-4	3	0.07-0.09	0.08	0.24		0.12	
	0.5	4-17	2	0.09-0.11	0.1	0.2		0.1	
	0.5	4-17	11	0.09-0.11	0.1		1.1		0.55
	0.5	17-27	10	---	0		0		0
			27						
Rock outcrop	0.3	0-60		---	0				
								0.27	0.55
70: Mack	0.85	0--13	6	.13--.18	0.155	0.93		0.7905	
	0.85	0--13	7	.13--.18	0.155		1.085		0.92225
	0.85	13--33	20	.14--.18	0.16		3.2		2.72
	0.85	33--60	27	.13--.16	0.145		3.915		3.32775
			60					0.7905	6.97
71: Mikett	0.85	0-8	6	0.15-0.17	0.16	0.96		0.816	
	0.85	0-8	2	0.15-0.17	0.16		0.32		0.272
	0.85	8-60	52	0.09-0.15	0.12		6.24		5.304
			60						
Aquents	0.05	---	0	---	0				
								0.816	5.576
72: Mikett	0.85	0-8	6	0.15-0.17	0.16	0.96		0.816	
	0.85	0-8	2	0.15-0.17	0.16		0.32		0.272
	0.85	8-60	52	0.15-0.17	0.16		8.32		7.072
			60						
Aquents	0.1	---	0	---	0				

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
								0.816	7.344
73: Mikim	0.9	0--3	3	.17--.20	0.185	0.555		0.4995	
	0.9	3--15	3	.17--.20	0.185	0.555		0.4995	
	0.9	3--15	9	.17--.20	0.185		1.665		1.4985
	0.9	15--32	17	.14--.17	0.155		2.635		2.3715
	0.9	32--60	28	.17--.20	0.185		5.18		4.662
			60						
Aquents	0.05	---	0	---	0				
								0.999	8.532
74: Mikim	0.85	0-3	3	0.14-0.16	0.15	0.45		0.3825	
	0.85	3-15	3	0.14-0.16	0.15	0.45		0.3825	
	0.85	3-15	9	0.14-0.16	0.15		1.35		1.1475
	0.85	15-32	17	0.12-0.15	0.135		2.295		1.95075
	0.85	32-60	28	0.12-0.15	0.135		3.78		3.213
			60						
Aquents	0.05	---	0	---	0				
								0.765	6.31125
75: Mikim	0.9	0-3	3	0.14-0.18	0.16	0.48		0.432	
	0.9	3-15	3	0.17-0.20	0.185	0.555		0.4995	
	0.9	3-15	9	0.17-0.20	0.185		1.665		1.4985
	0.9	15-32	17	0.14-0.17	0.155		2.635		2.3715
	0.9	32-60	28	0.17-0.20	0.185		5.18		4.662
			60						
Aquents	0.05	---	0	---	0				
								0.9315	8.532
76: Morefield	0.9	0-2	2	0.15-0.17	0.16	0.32		0.288	
	0.9	2-24	4	0.17-0.20	0.185	0.74		0.666	
	0.9	2-24	18	0.17-0.20	0.185		3.33		2.997
	0.9	24-60	36	0.16-0.20	0.18		6.48		5.832
			60					0.954	8.829
77: Morefield	0.9	0-2	2	0.15-0.17	0.16	0.32		0.288	
	0.9	2-24	4	0.17-0.20	0.185	0.74		0.666	
	0.9	2-24	18	0.17-0.20	0.185		3.33		2.997
	0.9	24-60	36	0.16-0.20	0.18		6.48		5.832

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
			60					0.954	8.829
78: Nortez	0.45	0-2	2	0.15-0.18	0.165	0.33		0.1485	
	0.45	2-6	4	0.17-0.20	0.185	0.74		0.333	
	0.45	6-31	25	0.15-0.18	0.165		4.125		1.85625
	0.45	31-41	10	---	0		0		0
			41						
Granath	0.4	0-1	1	---	0	0		0	
	0.4	1-14	5	0.18-0.20	0.19	0.95		0.38	
	0.4	1-14	8	0.18-0.20	0.19		1.52		0.608
	0.4	14-60	46	0.18-0.20	0.19		8.74		3.496
			60					0.8615	5.96025
79: Northrim	0.8	0-2	2	---	0	0		0	
	0.8	2-9	4	0.10-0.13	0.115	0.46		0.368	
	0.8	2-9	3	0.10-0.13	0.115		0.345		0.276
	0.8	9-22	13	0.13-0.16	0.145		1.885		1.508
	0.8	22-60	38	0.13-0.16	0.145		5.51		4.408
			60					0.368	6.192
80: Ormiston	0.5	0-7	6	0.13-0.16	0.145	0.87		0.435	
	0.5	0-7	1	0.13-0.16	0.145		0.145		0.0725
	0.5	7-32	25	0.07-0.11	0.09		2.25		1.125
	0.5	32-44	12	0.13-0.16	0.145		1.74		0.87
	0.5	44-54	10	---	0		0		0
			54						
Beje	0.35	0-2	2	0.14-0.16	0.15	0.3		0.105	
	0.35	2-6	4	0.14-0.16	0.15	0.6		0.21	
	0.35	6-14	8	0.14-0.20	0.17		1.36		0.476
	0.35	14-24	10	---	0		0		0
			24					0.75	2.5435
81: Ormiston	0.5	0-7	6	0.13-0.16	0.145	0.87		0.435	
	0.5	0-7	1	0.13-0.16	0.145		0.145		0.0725
	0.5	7-32	25	0.07-0.11	0.09		2.25		1.125
	0.5	32-44	12	0.13-0.16	0.145		1.74		0.87
	0.5	44-54	10	---	0		0		0
			54						
Fivepine	0.35	0-3	3	0.13-0.17	0.15	0.45		0.1575	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.35	3-9	3	0.11-0.13	0.12	0.36		0.126	
	0.35	3-9	3	0.11-0.13	0.12		0.36		0.126
	0.35	9-12	3	0.11-0.13	0.12		0.36		0.126
	0.35	12-15	3	0.08-0.10	0.09		0.27		0.0945
	0.35	15-25	10	---	0		0		0
			25					0.7185	2.414
82: Ormiston	0.5	0-3	3	0.04-0.05	0.045	0.135		0.0675	
	0.5	3--7	3	0.09-0.11	0.1	0.3		0.15	
	0.5	3-7	1	0.09-0.11	0.1		0.1		0.05
	0.5	7-32	25	0.07-0.11	0.09		2.25		1.125
	0.5	32-44	12	0.13-0.16	0.145		1.74		0.87
	0.5	44-54	10	---	0		0		0
			54						
Granath	0.35	0-1	1	---	0	0		0	
	0.35	1-14	5	0.18-0.20	0.19	0.95		0.3325	
	0.35	1-14	8	0.18-0.20	0.19		1.52		0.532
	0.35	14-60	46	0.18-0.20	0.19		8.74		3.059
			60					0.55	5.636
83: Ormiston	0.45	0-3	3	0.04-0.05	0.045	0.135		0.06075	
	0.45	3-7	3	0.09-0.11	0.1	0.3		0.135	
	0.45	3-7	1	0.09-0.11	0.1		0.1		0.045
	0.45	7-32	25	0.07-0.11	0.09		2.25		1.0125
	0.45	32-44	12	0.13-0.16	0.145		1.74		0.783
	0.45	44-54	10	---	0		0		0
			54						
Nortez	0.4	0-2	2	0.15-0.18	0.165	0.33		0.132	
	0.4	2-6	4	0.17-0.20	0.185	0.74		0.296	
	0.4	6-31	25	0.15-0.18	0.165		4.125		1.65
	0.4	31-41	10	---	0		0		0
			41					0.62375	3.4905
84: Payter	0.85	0-11	6	0.11-0.13	0.12	0.72		0.612	
	0.85	0-11	5	0.11-0.13	0.12		0.6		0.51
	0.85	11-39	28	0.11-0.13	0.12		3.36		2.856
	0.85	39-60	21	0.11-0.13	0.12		2.52		2.142
			60					0.612	5.508

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
85: Pinacol	0.8	0-7	6	0.14-0.21	0.175	1.05		0.84	
	0.8	0-7	1	0.14-0.21	0.175		0.175		0.14
	0.8	7-21	14	0.12-0.18	0.15		2.1		1.68
	0.8	21-38	17	0.06-0.10	0.08		1.36		1.088
	0.8	38-60	22	0.04-0.06	0.05		1.1		0.88
			60					0.84	3.788
86: Pinacol	0.8	0-7	6	0.14-0.21	0.175	1.05		0.84	
	0.8	0-7	1	0.14-0.21	0.175		0.175		0.14
	0.8	7-21	14	0.12-0.18	0.15		2.1		1.68
	0.8	21-38	17	0.06-0.10	0.08		1.36		1.088
	0.8	38-60	22	0.04-0.06	0.05		1.1		0.88
			60					0.84	3.788
88: Pogo	0.9	0-2	2	0.15-0.18	0.165	0.33		0.297	
	0.9	2-60	4	0.10-0.20	0.15	0.6		0.54	
	0.9	2-60	54	0.10-0.20	0.15		8.1		7.29
			60					0.837	7.29
89: Pramiss	0.85	0-3	3	0.07-0.09	0.08	0.24		0.204	
	0.85	3-16	3	0.16-0.18	0.17	0.51		0.4335	
	0.85	3-16	10	0.16-0.18	0.17		1.7		1.445
	0.85	16-31	15	0.16-0.18	0.17		2.55		2.1675
	0.85	31-41	10	---	0		0		0
			41					0.6375	3.6125
90: Pramiss	0.45	0-3	3	0.13-0.16	0.145	0.435		0.19575	
	0.45	3-16	3	0.16-0.18	0.17	0.51		0.2295	
	0.45	3-16	10	0.16-0.18	0.17		1.7		0.765
	0.45	16-31	15	0.16-0.18	0.17		2.55		1.1475
	0.45	31-41	10	---	0		0		0
			41						
Granath	0.35	0-1	1	---	0	0		0	
	0.35	1-14	5	0.18-0.20	0.19	0.95		0.3325	
	0.35	1-14	8	0.18-0.20	0.19		1.52		0.532
	0.35	14-60	46	0.18-0.20	0.19		8.74		3.059
			60					0.75775	5.5035
91: Prater	0.85	0-1	1	0.10-0.13	0.115	0.115		0.09775	
	0.85	1-3	2	0.10-0.16	0.13	0.26		0.221	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.85	3-9	3	0.10-0.16	0.13	0.39		0.3315	
	0.85	3-9	3	0.10-0.16	0.13		0.39		0.3315
	0.85	9-21	12	0.10-0.16	0.13		1.56		1.326
	0.85	21-60	39	0.10-0.16	0.13		5.07		4.3095
			60					0.65025	5.967
92: Prater	0.6	0-1	1	0.13-0.16	0.145	0.145		0.087	
	0.6	1-3	2	0.10-0.16	0.13	0.26		0.156	
	0.6	3-9	3	0.10-0.16	0.13	0.39		0.234	
	0.6	3-9	3	0.10-0.16	0.13		0.39		0.234
	0.6	9-21	12	0.10-0.16	0.13		1.56		0.936
	0.6	21-60	39	0.10-0.16	0.13		5.07		3.042
			60						
Dolcan	0.15	0-2	2	0.03-0.07	0.05	0.1		0.015	
	0.15	2-11	4	0.16-0.19	0.175	0.7		0.105	
	0.15	2-11	5	0.16-0.19	0.175		0.875		0.13125
	0.15	11-21	10	---	0		0		0
			21					0.597	4.34325
93: Pulpit	0.8	0-5	5	0.16-0.18	0.17	0.85		0.68	
	0.8	5-21	1	0.17-0.19	0.18	0.18		0.144	
	0.8	5-21	15	0.17-0.19	0.18		2.7		2.16
	0.8	21-35	14	0.16-0.18	0.17		2.38		1.904
	0.8	35-39	4	---	0		0		0
			39					0.824	4.064
94: Pulpit	0.8	0-10	6	0.16-0.18	0.17	1.02		0.816	
	0.8	0-10	4	0.16-0.18	0.17		0.68		0.544
	0.8	10-20	10	0.19-0.21	0.2		2		1.6
	0.8	20-36	16	0.16-0.18	0.17		2.72		2.176
	0.8	36-46	10	---	0		0		0
			46						
Aquents	0.02	---	0	---	0				
								0.816	4.32
95: Pulpit	0.8	0-10	6	0.16-0.18	0.17	1.02		0.816	
	0.8	0-10	4	0.16-0.18	0.17		0.68		0.544
	0.8	10-20	10	0.19-0.21	0.2		2		1.6
	0.8	20-36	16	0.16-0.18	0.17		2.72		2.176

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.8	36-46	10	---	0		0		0
			46						
Aquents	0.01	---	0	---	0				
								0.816	4.32
96: Purcella	0.85	0-4	4	0.15-0.18	0.165	0.66		0.561	
	0.85	4-11	2	0.12-0.15	0.135	0.27		0.2295	
	0.85	4-11	5	0.12-0.15	0.135		0.675		0.57375
	0.85	11-41	30	0.05-0.08	0.065		1.95		1.6575
	0.85	41-60	19	0.03-0.05	0.04		0.76		0.646
			60						
Aquents	0.05	---	0	---	0				
								0.7905	2.87725
97: Ramper	0.9	0-3	3	0.17-0.20	0.185	0.555		0.4995	
	0.9	3-60	3	0.14-0.17	0.155	0.465		0.4185	
	0.9	3-60	54	0.14-0.17	0.155		8.37		7.533
			60						
Aquents	0.01	---	0	---	0				
								0.918	7.533
98: Ramper	0.9	0-3	3	0.15-0.18	0.165	0.495		0.4455	
	0.9	3-60	3	0.14-0.17	0.155	0.465		0.4185	
	0.9	3-60	54	0.14-0.17	0.155		8.37		7.533
			60						
Aquents	0.01	---	0	---	0				
								0.864	7.533
99: Ravola	0.85	0-9	6	0.05-0.08	0.065	0.39		0.3315	
	0.85	0-9	3	0.05-0.08	0.065		0.195		0.16575
	0.85	9-60	51	0.05-0.15	0.1		5.1		4.335
			60					0.3315	4.50075
100: Recapture	0.8	0-7	6	0.11-0.13	0.12	0.72		0.576	
	0.8	0-7	1	0.11-0.13	0.12		0.12		0.096
	0.8	7-26	19	0.15-0.17	0.16		3.04		2.432
	0.8	26-60	34	0.10-0.12	0.11		3.74		2.992
			60					0.576	5.52
101: Recapture	0.8	0-6	6	0.08-0.10	0.09	0.54		0.432	
	0.8	6-13	7	0.15-0.17	0.16		1.12		0.896

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.8	13-17	4	0.08-0.10	0.09		0.36		0.288
	0.8	17-38	21	0.12-0.14	0.13		2.73		2.184
	0.8	38-60	22	0.07-0.09	0.08		1.76		1.408
			60					0.432	4.776
102: Ricot	0.8	0-12	6	0.16-0.18	0.17	1.02		0.816	
	0.8	0-12	6	0.16-0.18	0.17		1.02		0.816
	0.8	12-16	4	0.16-0.18	0.17		0.68		0.544
	0.8	16-34	18	0.12-0.15	0.135		2.43		1.944
	0.8	34-60	26	0.10-0.14	0.12		3.12		2.496
			60					0.816	5.8
103: Ricot	0.8	0-12	6	0.16-0.18	0.17	1.02		0.816	
	0.8	0-12	6	0.16-0.18	0.17		1.02		0.816
	0.8	12-16	4	0.16-0.18	0.17		0.68		0.544
	0.8	16-34	18	0.12-0.15	0.135		2.43		1.944
	0.8	34-60	26	0.10-0.14	0.12		3.12		2.496
			60					0.816	5.8
104: Ricot	0.8	0-12	6	0.16-0.18	0.17	1.02		0.816	
	0.8	0-12	6	0.16-0.18	0.17		1.02		0.816
	0.8	12-16	4	0.16-0.18	0.17		0.68		0.544
	0.8	16-34	18	0.12-0.15	0.135		2.43		1.944
	0.8	34-60	26	0.10-0.14	0.12		3.12		2.496
			60					0.816	5.8
105: Rizno	0.45	0--2	2	.13--.16	0.145	0.29		0.1305	
	0.45	2--9	4	.1--.13	0.115	0.46		0.207	
	0.45	2--9	3	.1--.13	0.115		0.345		0.15525
			9						
Gapmesa	0.35	0--2	2	.13--.15	0.14	0.28		0.098	
	0.35	2--21	4	.10--.13	0.115	0.46		0.161	
	0.35	2--21	15	.10--.13	0.115		1.725		0.60375
	0.35	21--28	7	.05--.07	0.06		0.42		0.147
	0.35	28--38	10	----	0		0		0
			38					0.5965	0.906
106: Rizno	0.3	0-3	3	0.10-0.13	0.115	0.345		0.1035	
	0.3	3-13	3	0.10-0.13	0.115	0.345		0.1035	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.3	3-13	7	0.10-0.13	0.115		0.805		0.2415
	0.3	13-23	10	---	0		0		0
			23						
Bodry	0.2	0-6	6	0.08-0.12	0.1	0.6		0.12	
	0.2	6-15	9	0.16-0.18	0.17		1.53		0.306
	0.2	15-36	21	0.17-0.20	0.185		3.885		0.777
	0.2	36-46	10	---	0		0		0
			46						
Littlenan	0.2	0-3	3	0.10-0.13	0.115	0.345		0.069	
	0.2	3-29	3	0.16-0.18	0.17	0.51		0.102	
	0.2	3-29	23	0.16-0.18	0.17		3.91		0.782
	0.2	29-39	10	---	0		0		0
			39					0.498	2.1065
107: Rizno	0.35	0-3	3	0.10-0.12	0.11	0.33		0.1155	
	0.35	3-13	3	0.10-0.12	0.11	0.33		0.1155	
	0.35	3-13	7	0.10-0.12	0.11		0.77		0.2695
	0.35	13-23	10	---	0		0		0
			23						
Ruinpoint	0.25	0-2	2	0.13-0.16	0.145	0.29		0.0725	
	0.25	2-13	4	0.16-0.18	0.17	0.68		0.17	
	0.25	2-13	7	0.16-0.18	0.17		1.19		0.2975
	0.25	13-23	10	0.16-0.18	0.17		1.7		0.425
	0.25	23-60	37	0.16-0.18	0.17		6.29		1.5725
			60						
Rock outcrop	0.2	0-60	0	---	0				
								0.4735	2.5645
108: Rock Outcrop	0.95	0-60	0	0	0			0	
								0	
109: Romberg	0.45	0--2	2	.06--.09	0.075	0.15		0.0675	
	0.45	2--20	4	.07--.08	0.075	0.3		0.135	
	0.45	2--20	14	.07--.08	0.075		1.05		0.4725
	0.45	20--60	40	.07--.08	0.075		3		1.35
			60						
Crosscan	0.4	0--2	2	.06--.09	0.075	0.15		0.06	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.4	2--18	4	.07--.10	0.085	0.34		0.136	
	0.4	2--18	12	.07--.10	0.085		1.02		0.408
	0.4	18--28	10	----	0		0		0
			28					0.3985	2.2305
110: Romberg	0.35	0--2	2	.06--.09	0.075	0.15		0.0525	
	0.35	2--20	4	.07--.08	0.075	0.3		0.105	
	0.35	2--20	14	.07--.08	0.075		1.05		0.3675
	0.35	20--60	40	.07--.08	0.075		3		1.05
			60						
Crosscan	0.3	0--2	2	.06--.09	0.075	0.15		0.045	
	0.3	2--18	4	.07--.10	0.085	0.34		0.102	
	0.3	2--18	12	.07--.10	0.085		1.02		0.306
	0.3	18--28	10	----	0		0		0
			28						
Rock outcrop	0.2	0--60	0	0.0--0.0	0		0		0
								0.3045	1.7235
111: Roubideau	0.8	0-6	6	0.14-0.18	0.16	0.96		0.768	
	0.8	6-36	30	0.13-0.19	0.16		4.8		3.84
	0.8	36-38	2	0.13-0.15	0.14		0.28		0.224
	0.8	38-48	10	---	0		0		0
			48					0.768	4.064
112: Sharps	0.8	0-9	6	0.13-0.16	0.145	0.87		0.696	
	0.8	0-9	3	0.13-0.16	0.145		0.435		0.348
	0.8	9-19	10	0.15-0.17	0.16		1.6		1.28
	0.8	19-30	11	0.13-0.15	0.14		1.54		1.232
	0.8	30-40	10	---	0		0		0
			40						
Aquents	0.02	---	0	---	0				
								0.696	2.86
113: Sharps	0.8	0-9	6	0.13-0.16	0.145	0.87		0.696	
	0.8	0-9	3	0.13-0.16	0.145		0.435		0.348
	0.8	9-19	10	0.15-0.17	0.16		1.6		1.28
	0.8	19-30	11	0.13-0.15	0.14		1.54		1.232

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.8	30-40	10	---	0		0		0
			40						
Aquents	0.01	---	0	---	0				
								0.696	2.86
114: Sharps, dry	0.8	0--2	2	.13--.16	0.145	0.29		0.232	
	0.8	2--12	4	.15--.17	0.16	0.64		0.512	
	0.8	2--12	6	.15--.17	0.16		0.96		0.768
	0.8	12--27	15	.13--.15	0.14		2.1		1.68
	0.8	27--32	5	.13--.15	0.14		0.7		0.56
	0.8	32--42	10	----	0		0		0
			42					0.744	3.008
115: Sharps, dry	0.45	0--2	2	.13--.16	0.145	0.29		0.1305	
	0.45	2--12	4	.15--.17	0.16	0.64		0.288	
	0.45	2--12	6	.15--.17	0.16		0.96		0.432
	0.45	12--27	15	.13--.15	0.14		2.1		0.945
	0.45	27--32	5	.13--.15	0.14		0.7		0.315
	0.45	32--42	10	----	0		0		0
			42						
Gapmesa	0.4	0--2	2	.13--.15	0.14	0.28		0.112	
	0.4	2--21	4	.10--.13	0.115	0.46		0.184	
	0.4	2--21	15	.10--.13	0.115		1.725		0.69
	0.4	21--28	7	.05--.07	0.06		0.42		0.168
	0.4	28--38	10	----	0		0		0
			38					0.7145	2.55
116: Sharps	0.45	0-9	6	0.13-0.16	0.145	0.87		0.3915	
	0.45	0-9	3	0.13-0.16	0.145		0.435		0.19575
	0.45	9-19	10	0.15-0.17	0.16		1.6		0.72
	0.45	19-30	11	0.13-0.15	0.14		1.54		0.693
	0.45	30-40	10	---	0		0		0

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
			40						
Cahona	0.4	0-5	5	0.14-0.16	0.15	0.75		0.3	
	0.4	5-25	1	0.18-0.21	0.195	0.195		0.078	
	0.4	5-25	19	0.18-0.21	0.195		3.705		1.482
	0.4	25-60	35	0.16-0.19	0.175		6.125		2.45
			60						
Aquents	0.02	---	0	---	0				
								0.7695	5.54075
117: Sharps	0.45	0-9	6	0.13-0.16	0.145	0.87		0.3915	
	0.45	0-9	3	0.13-0.16	0.145		0.435		0.19575
	0.45	9-19	10	0.15-0.17	0.16		1.6		0.72
	0.45	19-30	11	0.13-0.15	0.14		1.54		0.693
	0.45	30-40	10	---	0		0		0
			40						
Pulpit	0.4	0-10	6	0.16-0.18	0.17	1.02		0.408	
	0.4	0-10	4	0.16-0.18	0.17		0.68		0.272
	0.4	10-20	10	0.19-0.21	0.2		2		0.8
	0.4	20-36	16	0.16-0.18	0.17		2.72		1.088
	0.4	36-46	10	---	0		0		0
			46						
Aquents	0.01	---	0	---	0				
								0.7995	3.76875
118: Sharps	0.45	0-9	6	0.13-0.16	0.145	0.87		0.3915	
	0.45	0-9	3	0.13-0.16	0.145		0.435		0.19575
	0.45	9-19	10	0.15-0.17	0.16		1.6		0.72
	0.45	19-30	11	0.13-0.15	0.14		1.54		0.693
	0.45	30-40	10	---	0		0		0
			40						
Pulpit	0.4	0-10	6	0.16-0.18	0.17	1.02		0.408	
	0.4	0-10	4	0.16-0.18	0.17		0.68		0.272
	0.4	10-20	10	0.19-0.21	0.2		2		0.8
	0.4	20-36	16	0.16-0.18	0.17		2.72		1.088
	0.4	36-46	10	---	0		0		0
			46						
Aquents	0.01	---	0	---	0				

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
								0.7995	3.76875
119: Sheek	0.5	0-1	1	---	0	0		0	
	0.5	1-5	4	0.05-0.07	0.06	0.24		0.12	
	0.5	5-60	1	0.09-0.11	0.1	0.1		0.05	
	0.5	5-60	54	0.09-0.11	0.1		5.4		2.7
			60						
Archuleta	0.35	0-1	1	---	0	0		0	
	0.35	1-6	5	0.05-0.07	0.06	0.3		0.105	
	0.35	6-18	12	0.13-0.16	0.145		1.74		0.609
	0.35	18-28	10	---	0		0		0
			28					0.275	3.309
120: Sheek	0.35	0--1	1	----	0	0		0	
	0.35	1--5	4	.05--.07	0.06	0.24		0.084	
	0.35	5--60	1	.09--.11	0.1	0.1		0.035	
	0.35	5--60	54	.09--.11	0.1		5.4		1.89
			60						
Archuleta	0.3	0--1	1	----	0	0		0	
	0.3	1--6	5	.05--.07	0.06	0.3		0.09	
	0.3	6--18	12	.13--.16	0.145		1.74		0.522
	0.3	18--28	10	----	0		0		0
			28						
Rock outcrop	0.2	0--60	0	----	0		0		0
								0.209	2.412
121: Sheek	0.4	0--1	1	----	0	0		0	
	0.4	1--5	4	.05--.07	0.06	0.24		0.096	
	0.4	5--60	1	.09--.11	0.1	0.1		0.04	
	0.4	5--60	54	.09--.11	0.1		5.4		2.16
			60						
Archuleta	0.25	0--1	1	----	0	0		0	
	0.25	1--6	5	.05--.07	0.06	0.3		0.075	
	0.25	6--18	12	.13--.16	0.145		1.74		0.435
	0.25	18--28	10	----	0		0		0
			28						
Rock outcrop	0.2	0--60	0	----	0		0		0

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
								0.211	2.595
122: Sheppard	0.9	0-7	6	0.05-0.07	0.06	0.36		0.324	
	0.9	0-7	1	0.05-0.07	0.06		0.06		0.054
	0.9	7-60	53	0.06-0.08	0.07		3.71		3.339
			60					0.324	3.393
123; Sideshow	0.9	0--3	3	.18--.20	0.19	0.57		0.513	
	0.9	3--60	3	.16--.21	0.185	0.555		0.4995	
	0.9	3--60	54	.16--.21	0.185		9.99		8.991
			60						
Aquents	0.02	---	0	---	0				
								1.0125	8.991
124: Sideshow	0.9	0--3	3	.18--.20	0.19	0.57		0.513	
	0.9	3--60	3	.16--.21	0.185	0.555		0.4995	
	0.9	3--60	54	.16--.21	0.185		9.99		8.991
			60					1.0125	8.991
125: Sideshow	0.9	0-3	3	0.18-0.20	0.19	0.57		0.513	
	0.9	3-60	3	0.16-0.21	0.185	0.555		0.4995	
	0.9	3-60	54	0.16-0.21	0.185		9.99		8.991
			60					1.0125	8.991
126: Sideshow	0.45	0-3	3	0.18-0.20	0.19	0.57		0.2565	
	0.45	3-60	3	0.16-0.21	0.185	0.555		0.24975	
	0.45	3-60	54	0.16-0.21	0.185		9.99		4.4955
			60						
Zigzag	0.4	0-1	1	0.08-0.10	0.09	0.09		0.036	
	0.4	1-5	4	0.16-0.19	0.175	0.7		0.28	
	0.4	5-19	1	0.15-0.19	0.17	0.17		0.068	
	0.4	5-19	13	0.15-0.19	0.17		2.21		0.884
	0.4	19-29	10	---	0		0		0
			29					0.89025	5.3795
127: Sideslide	0.9	0-3	3	0.17-0.20	0.185	0.555		0.4995	
	0.9	3-40	3	0.17-0.21	0.185	0.555		0.4995	
	0.9	3-40	34	0.17-0.21	0.185		6.29		5.661
	0.9	40-60	20	0.14-0.21	0.175		3.5		3.15
			60						
Aquents	0.04	---	0	---	0				

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
								0.999	8.811
128: Stephouse	0.55	0-1	1	0.09-0.11	0.1	0.1		0.055	
	0.55	1-12	5	0.07-0.09	0.08	0.4		0.22	
	0.55	1-12	6	0.07-0.09	0.08		0.48		0.264
	0.55	12-22	10	---	0		0		0
			22						
Rock outcrop	0.25	0-60	0	---	0				
								0.275	0.264
129: Torriorthents	0.9	0-4	4	0.04-0.06	0.05	0.2		0.18	
	0.9	4-14	2	0.07-0.08	0.075	0.15		0.135	
	0.9	4-14	8	0.07-0.08	0.075		0.6		0.54
	0.9	14-24	10	---	0		0		0
			24					0.315	0.54
130: Torriorthents	0.5	0--4	4	.18--.20	0.19	0.76		0.38	
	0.5	4--14	2	.16--.21	0.185	0.37		0.185	
	0.5	4--14	8	.16--.21	0.185		1.48		0.74
	0.5	14--24	10	----	0		0		0
			24						
Badland	0.4	0--60	0	----	0		0		0
								0.565	0.74
131: Tragmon	0.5	0-5	5	0.09-0.12	0.105	0.525		0.2625	
	0.5	5-11	1	0.14-0.16	0.15	0.15		0.075	
	0.5	5-11	5	0.14-0.16	0.15		0.75		0.375
	0.5	11-40	29	0.14-0.16	0.15		4.35		2.175
	0.5	40-60	20	0.12-0.14	0.13		2.6		1.3
			60						
Sheek	0.35	0-4	4	0.10-0.13	0.115	0.46		0.161	
	0.35	4-16	2	0.09-0.11	0.1	0.2		0.07	
	0.35	4-16	10	0.09-0.11	0.1		1		0.35
	0.35	16-42	26	0.09-0.11	0.1		2.6		0.91
	0.35	42-60	18	0.10-0.11	0.105		1.89		0.6615
			60					0.5685	5.7715
132: Typic Argiaquolls	0.9	0-4	4	0.14-0.18	0.16	0.64		0.576	
	0.9	4-10	2	0.14-0.21	0.175	0.35		0.315	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.9	4-10	4	0.14-0.21	0.175		0.7		0.63
	0.9	10-24	14	0.17-0.21	0.19		2.66		2.394
	0.9	24-60	36	0.14-0.18	0.16		5.76		5.184
			60					0.891	8.208
133: Typic Torriorthents	0.6	0--3	3	.04--.06	0.05	0.15		0.09	
	0.6	3--16	3	.07--.09	0.08	0.24		0.144	
	0.6	3--16	10	.07--.09	0.08		0.8		0.48
	0.6	16--26	10	----	0		0		0
			26						
Rock outcrop	0.25	0--60	0	----	0		0		0
								0.234	0.48
134: Umbarg	0.35	0-2	2	0.15-0.18	0.165	0.33		0.1155	
	0.35	2-5	3	0.17-0.20	0.185	0.555		0.19425	
	0.35	5-12	1	0.17-0.20	0.185	0.185		0.06475	
	0.35	5-12	6	0.17-0.20	0.185		1.11		0.3885
	0.35	12-42	30	0.15-0.18	0.165		4.95		1.7325
	0.35	42-60	18	0.08-0.11	0.095		1.71		0.5985
			60						
Winner	0.3	0-4	4	0.18-0.20	0.19	0.76		0.228	
	0.3	4-31	2	0.18-0.20	0.19	0.38		0.114	
	0.3	4-31	25	0.18-0.20	0.19		4.75		1.425
	0.3	31-60	29	0.07-0.10	0.085		2.465		0.7395
			60						
Tesajo	0.2	0-3	3	0.08-0.11	0.095	0.285		0.057	
	0.2	3-36	3	0.04-0.06	0.05	0.15		0.03	
	0.2	3-36	30	0.04-0.06	0.05		1.5		0.3
	0.2	36-60	24	0.04-0.06	0.05		1.2		0.24
			60						
Aquents	0.05	---	0	---	0				
								0.8035	5.424
135: Ustic Torrifluvents	0.8	0-3	3	0.05-0.06	0.055	0.165		0.132	
	0.8	3-11	3	0.13-0.15	0.14	0.42		0.336	
	0.8	3-11	5	0.13-0.15	0.14		0.7		0.56

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.8	11-60	49	0.04-0.08	0.06		2.94		2.352
			60					0.468	2.912
136: Ustic Torriorthents	0.45	0--7	6	.10--.20	0.15	0.9		0.405	
	0.45	0--7	1	.10--.20	0.15		0.15		0.0675
	0.45	7--60	53	.06--.18	0.12		6.36		2.862
			60						
Gullied land	0.4	0--60	0	----	0		0		0
Aquents	0.03	---	0	---	0				
								0.405	2.9295
137: Ustorthents	0.8	0-3	3	0.07-0.09	0.08	0.24		0.192	
	0.8	3-14	3	0.07-0.09	0.08	0.24		0.192	
	0.8	3-14	8	0.07-0.09	0.08		0.64		0.512
	0.8	14-60	46	0.07-0.11	0.09		4.14		3.312
			60					0.384	3.824
138: Uzacol	0.35	0-5	5	0.17-0.21	0.185	0.925		0.32375	
	0.35	5-45	1	0.15-0.17	0.16	0.16		0.056	
	0.35	5-45	39	0.15-0.17	0.16		6.24		2.184
	0.35	45-59	14	0.15-0.19	0.17		2.38		0.833
	0.35	59-69	10	---	0		0		0
			69						
Zwicker	0.3	0-1	1	0.13-0.16	0.145	0.145		0.0435	
	0.3	1-4	3	0.16-0.20	0.18	0.54		0.162	
	0.3	4-32	2	0.14-0.19	0.165	0.33		0.099	
	0.3	4-32	26	0.14-0.19	0.165		4.29		1.287
	0.3	32-42	10	---	0		0		0
			42						
Claysprings	0.2	0-3	3	0.10-0.12	0.11	0.33		0.066	
	0.2	3-18	3	0.16-0.18	0.17	0.51		0.102	
	0.2	3-18	12	0.16-0.18	0.17		2.04		0.408
	0.2	18-28	10	---	0		0		0
			28					0.85225	4.712
140: Wauquie	0.85	0--2	2	.07--.09	0.08	0.16		0.136	
	0.85	2--20	4	.05--.09	0.07	0.28		0.238	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.85	2--20	14	.05--.09	0.07		0.98		0.833
	0.85	20--60	40	.07--.09	0.08		3.2		2.72
			60					0.374	3.553
141: Wauquie	0.45	0-2	2	0.10-0.11	0.105	0.21		0.0945	
	0.45	2-6	4	0.07-0.09	0.08	0.32		0.144	
	0.45	6-22	16	0.07-0.09	0.08		1.28		0.576
	0.45	22-60	38	0.07-0.11	0.09		3.42		1.539
			60						
Dolcan	0.4	0-2	2	0.03-0.07	0.05	0.1		0.04	
	0.4	2-11	4	0.16-0.19	0.175	0.7		0.28	
	0.4	2-11	5	0.16-0.19	0.175		0.875		0.35
	0.4	11-21	10	---	0		0		0
			21					0.5585	2.465
142: Wauquie	0.4	0-2	2	0.10-0.11	0.105	0.21		0.084	
	0.4	2-6	4	0.07-0.09	0.08	0.32		0.128	
	0.4	6-22	16	0.07-0.09	0.08		1.28		0.512
	0.4	22-60	38	0.07-0.11	0.09		3.42		1.368
			60						
Dolcan	0.3	0-2	2	0.03-0.07	0.05	0.1		0.03	
	0.3	2-11	4	0.16-0.19	0.175	0.7		0.21	
	0.3	2-11	5	0.16-0.19	0.175		0.875		0.2625
	0.3	11-21	10	---	0		0		0
			21						
Rock outcrop	0.15	0-60	0	---	0				
								0.452	2.1425
143: Wetherill	0.9	0-3	3	0.15-0.18	0.165	0.495		0.4455	
	0.9	3-7	3	0.14-0.16	0.15	0.45		0.405	
	0.9	3-7	1	0.14-0.16	0.15		0.15		0.135
	0.9	7-48	41	0.18-0.21	0.195		7.995		7.1955
	0.9	48-60	12	0.11-0.15	0.13		1.56		1.404
			60						
Aquents	0.01	---	0	---	0				
								0.8505	8.7345
144: Wetherill	0.85	0-3	3	0.15-0.18	0.165	0.495		0.42075	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.85	3-7	3	0.14-0.16	0.15	0.45		0.3825	
	0.85	3-7	1	0.14-0.16	0.15		0.15		0.1275
	0.85	7-48	41	0.18-0.21	0.195		7.995		6.79575
	0.85	48-60	12	0.11-0.15	0.13		1.56		1.326
			60						
Aquents	0.03	---	0	---	0				
								0.80325	8.24925
145: Wetherill	0.8	0-3	3	0.15-0.18	0.165	0.495		0.396	
	0.8	3-7	3	0.14-0.16	0.15	0.45		0.36	
	0.8	3-7	1	0.14-0.16	0.15		0.15		0.12
	0.8	7-48	41	0.18-0.21	0.195		7.995		6.396
	0.8	48-60	12	0.11-0.15	0.13		1.56		1.248
			60						
Aquents	0.01	---	0	---	0				
								0.756	7.764
146: Yarts	0.85	0-9	6	0.18-0.20	0.19	1.14		0.969	
	0.85	0-9	3	0.18-0.20	0.19		0.57		0.4845
	0.85	9-13	4	0.11-0.14	0.125		0.5		0.425
	0.85	13-60	47	0.11-0.12	0.115		5.405		4.59425
			60						
Aquents	0.02	---	0	---	0				
								0.969	5.50375
147: Yarts	0.85	0-9	6	0.13-0.15	0.14	0.84		0.714	
	0.85	0-9	3	0.13-0.15	0.14		0.42		0.357
	0.85	9-13	4	0.11-0.14	0.125		0.5		0.425
	0.85	13-60	47	0.11-0.12	0.115		5.405		4.59425
			60					0.714	5.37625
148: Zau	0.75	0-2	2	---	0	0		0	
	0.75	2-10	4	0.10-0.13	0.115	0.46		0.345	
	0.75	2-10	4	0.10-0.13	0.115		0.46		0.345
	0.75	10-29	19	0.15-0.17	0.16		3.04		2.28
	0.75	29-34	5	0.14-0.18	0.16		0.8		0.6
	0.75	34-44	10	---	0		0		0
			44					0.345	3.225
149: Zigzag	0.8	0-1	1	0.08-0.10	0.09	0.09		0.072	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.8	1-5	4	0.16-0.19	0.175	0.7		0.56	
	0.8	5-19	1	0.15-0.19	0.17	0.17		0.136	
	0.8	5-19	13	0.15-0.19	0.17		2.21		1.768
	0.8	19-29	10	---	0		0		0
			29					0.768	1.768
150: Zigzag	0.6	0--1	1	.08--.10	0.09	0.09		0.054	
	0.6	1--5	4	.16--.19	0.175	0.7		0.42	
	0.6	5--19	1	.15--.19	0.17	0.17		0.102	
	0.6	5--19	13	.15--.19	0.17		2.21		1.326
	0.6	19--29	10	----	0		0		0
			29						
Sideshow	0.3	0--3	3	.18--.20	0.19	0.57		0.171	
	0.3	3--60	3	.16--.21	0.185	0.555		0.1665	
	0.3	3--60	54	.16--.21	0.185		9.99		2.997
			60					0.9135	4.323
151: Zyme	0.85	0--2	2	.12--.14	0.13	0.26		0.221	
	0.85	2--12	4	.15--.17	0.16	0.64		0.544	
	0.85	2--12	6	.15--.17	0.16		0.96		0.816
	0.85	12--22	10	----	0		0		0
			22					0.765	0.816
152: Zyme	0.8	0--2	2	.08--.10	0.09	0.18		0.144	
	0.8	2--12	4	.15--.17	0.16	0.64		0.512	
	0.8	2--12	6	.15--.17	0.16		0.96		0.768
	0.8	12--22	10	----	0		0		0
			22					0.656	0.768
Ute:									
153: Decorock	0.55	0--5	5	.09--.11	0.1	0.5		0.275	
	0.55	5--10	1	.13--.16	0.145	0.145		0.07975	
	0.55	5--10	4	.13--.16	0.145		0.58		0.319
	0.55	10--15	5	.10--.12	0.11		0.55		0.3025
	0.55	15--26	11	.10--.16	0.13		1.43		0.7865

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.55	26--58	32	.04--.05	0.045		1.44		0.792
	0.55	58--68	10	----	0		0		0
			68						
Salamander	0.3	0--3	3	.14--.16	0.15	0.45		0.135	
	0.3	3--10	3	.14--.16	0.15	0.45		0.135	
	0.3	3--10	4	.14--.16	0.15		0.6		0.18
	0.3	10--27	17	.03--.06	0.045		0.765		0.2295
	0.3	27--35	8	.03--.06	0.045		0.36		0.108
	0.3	35--50	15	.05--.07	0.06		0.9		0.27
	0.3	50--80	30	.04--.06	0.05		1.5		0.45
			80					0.62475	3.4375
154: Mariano	0.75	0--11	6	.14--.17	0.155	0.93		0.6975	
	0.75	0--11	5	.14--.17	0.155		0.775		0.58125
	0.75	11--29	18	.03--.04	0.035		0.63		0.4725
	0.75	29--51	22	.03--.04	0.035		0.77		0.5775
	0.75	51--80	29	.03--.04	0.035		1.015		0.76125
	.		80					0.6975	2.3925
155: Zyme	0.45	0--2	2	.08--.10	0.09	0.18		0.081	
	0.45	2--12	4	.15--.17	0.16	0.64		0.288	
	0.45	2--12	6	.15--.17	0.16		0.96		0.432
	0.45	12--22	10	----	0		0		0
			22						
Katzine, dry	0.35	0--2	2	.05--.08	0.065	0.13		0.0455	
	0.35	2--12	4	.05--.08	0.065	0.26		0.091	
	0.35	2--12	6	.05--.08	0.065		0.39		0.1365
	0.35	12--80	68	.03--.06	0.045		3.06		1.071

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
			80					0.5055	1.6395
156: Cahona	0.35	0--2	2	.1--.13	0.115	0.23		0.0805	
	0.35	2--36	4	.1--.16	0.13	0.52		0.182	
	0.35	2--36	30	.1--.16	0.13		3.9		1.365
	0.35	36--60	24	.1--.13	0.115		2.76		0.966
			60						
Zigzag	0.35	0--1	1	.08--.1	0.09	0.09		0.0315	
	0.35	1--5	4	.16--.19	0.175	0.7		0.245	
	0.35	5--19	1	.15--.19	0.17	0.17		0.0595	
	0.35	5--19	13	.15--.19	0.17		2.21		0.7735
	0.35	19--29	10	----	0		0		0
			29					0.5985	3.1045
157: Awitava	0.85	0--1	1	.04--.05	0.045	0.045		0.03825	
	0.85	1--4	3	.07--.13	0.1	0.3		0.255	
	0.85	4--10	2	.05--.09	0.07	0.14		0.119	
	0.85	4--10	4	.05--.09	0.07		0.28		0.238
	0.85	10--21	11	.00--.01	0.005		0.055		0.04675
	0.85	21--80	59	.03--.05	0.04		2.36		2.006
			80					0.41225	2.29075
158: Wetherill	0.6	0--9	6	.15--.20	0.175	1.05		0.63	
	0.6	0--9	3	.15--.20	0.175		0.525		0.315
	0.6	9--21	12	.15--.20	0.175		2.1		1.26
	0.6	21--43	22	.15--.18	0.165		3.63		2.178
	0.6	43--80	37	.15--.18	0.165		6.105		3.663
			80						
Kucu	0.25	0--2	2	.13--.16	0.145	0.29		0.0725	
	0.25	2--15	4	.13--.19	0.16	0.64		0.16	
	0.25	2--15	9	.13--.19	0.16		1.44		0.36
	0.25	15--38	23	.05--.09	0.07		1.61		0.4025
	0.25	38--	42	.02--.04	0.03		1.26		0.315

Musym	PropSoil	Depth 80	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
			80					0.8625	8.4935
159: Wetherill	0.45	0--9	6	.15--.20	0.175	1.05		0.4725	
	0.45	0--9	3	.15--.20	0.175		0.525		0.23625
	0.45	9--21	12	.15--.20	0.175		2.1		0.945
	0.45	21--43	22	.15--.20	0.175		3.85		1.7325
	0.45	43--80	37	.15--.20	0.175		6.475		2.91375
			80						
Wetoe	0.3	0--7	6	.08--.10	0.09	0.54		0.162	
	0.3	0--7	1	.08--.10	0.09		0.09		0.027
	0.3	7--40	33	.07--.11	0.09		2.97		0.891
	0.3	40--60	20	.05--.06	0.055		1.1		0.33
			60					0.6345	7.0755
160: Katzine	0.8	0--2	2	.05--.08	0.065	0.13		0.104	
	0.8	2--7	4	.05--.08	0.065	0.26		0.208	
	0.8	2--7	1	.05--.08	0.065		0.065		0.052
	0.8	7--80	73	.03--.06	0.045		3.285		2.628
			80					0.312	2.68
161: Wetoe	0.45	0--8	6	.05--.09	0.07	0.42		0.189	
	0.45	0--8	2	.05--.09	0.07		0.14		0.063
	0.45	8--80	72	.03--.06	0.045		3.24		1.458
			80						
Nees	0.2	0--3	3	.03--.07	0.05	0.15		0.03	
	0.2	3--11	3	.03--.05	0.04	0.12		0.024	
	0.2	3--11	5	.03--.05	0.04		0.2		0.04
	0.2	11--15	4	----	0		0		0
			15						
Rock outcrop	0.15	0--80	0	.00--.00	0		0		0
								0.243	1.561
162: Towaoc	0.45	0--6	6	.05--.09	0.07	0.42		0.189	
	0.45	6--12	6	.05--.07	0.06		0.36		0.162
	0.45	12--	68	.05--.07	0.06		4.08		1.836

Musym	PropSoil	Depth 80	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
			80						
Kwiavu	0.4	0--9	6	.10--.13	0.115	0.69		0.276	0
	0.4	0--9	3	.10--.13	0.115		0.345		0.138
	0.4	9--15	6	.10--.13	0.115		0.69		0.276
	0.4	15--60	45	.13--.16	0.145		6.525		2.61
			60					0.465	5.022
163: Towaoc	0.8	0--6	6	.05--.09	0.07	0.42		0.336	
	0.8	6--11	5	.05--.07	0.06		0.3		0.24
	0.8	11--80	69	.05--.07	0.06		4.14		3.312
			80					0.336	3.552
164: Herm	0.9	0--10	6	.14--.16	0.15	0.9		0.81	
	0.9	0--10	4	.14--.16	0.15		0.6		0.54
	0.9	10--15	5	.16--.18	0.17		0.85		0.765
	0.9	15--54	39	.14--.2	0.17		6.63		5.967
								0.81	7.272
165: Littlewater	0.35	0--1	1	----	0	0		0	
	0.35	1--7	5	.06--.09	0.075	0.375		0.13125	
	0.35	1--7	1	.06--.09	0.075		0.075		0.02625
	0.35	7--20	13	.05--.09	0.07		0.91		0.3185
	0.35	20--31	11	.05--.08	0.065		0.715		0.25025
	0.35	31--80	49	.05--.08	0.065		3.185		1.11475
			80						
Rubble land	0.3	0--60	0	.00--.00	0		0		0
Rock outcrop	0.15	0--80	0	----	0		0		0
								0.13125	1.70975
166: Pagayvay	0.9	0--1	1	.03--.04	0.035	0.035		0.0315	
	0.9	1--60	5	.01--.04	0.025	0.125		0.1125	
	0.9	1--60	54	.01--.04	0.025		1.35		1.215

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
			60					0.144	1.215
A-Dolores:									
167: Hesperus	0.85	0-3	3	0.16-0.18	0.17	0.51		0.4335	
	0.85	3-8	3	0.16-0.18	0.17	0.51		0.4335	
	0.85	3-8	2	0.16-0.18	0.17		0.34		0.289
	0.85	8-15	7	0.16-0.18	0.17		1.19		1.0115
	0.85	15-22	7	0.16-0.18	0.17		1.19		1.0115
	0.85	22-28	6	0.16-0.18	0.17		1.02		0.867
	0.85	28-40	12	0.17-0.19	0.18		2.16		1.836
	0.85	40-51	11	0.16-0.18	0.17		1.87		1.5895
	0.85	51-60	9	0.16-0.18	0.17		1.53		1.3005
			60					0.867	7.905
168: Shawa	0.8	0-7	6	0.16-0.18	0.17	1.02		0.816	
	0.8	0-7	1	0.16-0.18	0.17		0.17		0.136
	0.8	7-19	12	0.16-0.18	0.17		2.04		1.632
	0.8	19-38	19	0.16-0.19	0.175		3.325		2.66
	0.8	38-60	22	0.13-0.15	0.14		3.08		2.464
			60					0.816	6.892
169: Fughes	0.85	0-2	2	0.16-0.18	0.17	0.34		0.289	
	0.85	2-7	4	0.16-0.18	0.17	0.68		0.578	
	0.85	2-7	1	0.16-0.18	0.17		0.17		0.1445
	0.85	7-18	11	0.18-0.20	0.19		2.09		1.7765
	0.85	18-26	8	0.18-0.20	0.19		1.52		1.292
	0.85	26-34	8	0.14-0.16	0.15		1.2		1.02
	0.85	34-44	10	0.14-0.16	0.15		1.5		1.275
	0.85	44-60	16	0.14-0.16	0.15		2.4		2.04
			60					0.867	7.548
170: Umbarg	0.8	0-9	6	0.16-0.18	0.17	1.02		0.816	
	0.8	0-9	3	0.16-0.18	0.17		0.51		0.408
	0.8	9-18	9	0.16-0.18	0.17		1.53		1.224
	0.8	18-25	7	0.16-0.18	0.17		1.19		0.952
	0.8	25-34	9	0.16-0.19	0.175		1.575		1.26
	0.8	34-44	10	0.16-0.19	0.175		1.75		1.4
	0.8	44-48	4	0.16-0.19	0.175		0.7		0.56
	0.8	48-60	12	0.17-0.19	0.18		2.16		1.728

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
			60						
Fluvaquents	0.05	---	0	0	0				
								0.816	7.532
171: Payter	0.85	0-3	3	0.11-0.13	0.12	0.36		0.306	
	0.85	3-6	3	0.11-0.13	0.12	0.36		0.306	
	0.85	6-11	5	0.11-0.13	0.12		0.6		0.51
	0.85	11-17	6	0.11-0.13	0.12		0.72		0.612
	0.85	17-39	22	0.11-0.13	0.12		2.64		2.244
	0.85	39-60	21	0.11-0.13	0.12		2.52		2.142
			60					0.612	5.508
172: Fluvaquents	0.55	0-6	6	0.06-0.18	0.12	0.72		0.396	
	0.55	6-60	54	0.05-0.08	0.075		4.05		2.2275
			60						
Haplustolls	0.3	0-4	4	0.10-0.12	0.11	0.44		0.132	
	0.3	4-11	2	0.10-0.15	0.125	0.25		0.075	
	0.3	4-11	5	0.10-0.15	0.125		0.625		0.1875
	0.3	11-19	8	0.10-0.15	0.125		1		0.3
	0.3	19-24	5	0.06-0.10	0.08		0.4		0.12
	0.3	24-60	36	0.02-0.06	0.14		5.04		1.512
			60					0.603	4.347
173: Sheek	0.45	0-2	2	0.12-0.13	0.125	0.25		0.1125	
	0.45	2-7	4	0.15-0.17	0.16	0.64		0.288	
	0.45	2-7	1	0.15-0.17	0.16		0.16		0.072
	0.45	7-20	13	0.09-0.11	0.1		1.3		0.585
	0.45	20-29	9	0.07-0.09	0.08		0.72		0.324
	0.45	29-46	17	0.14-0.16	0.15		2.55		1.1475
	0.45	46-60	14	0.07-0.09	0.08		1.12		0.504
			60						
Ormiston	0.35	0-7	6	0.13-0.16	0.145	0.87		0.3045	
	0.35	0-7	1	0.13-0.16	0.145		0.145		0.05075
	0.35	7-24	17	0.07-0.11	0.09		1.53		0.5355
	0.35	24-32	8	0.07-0.11	0.09		0.72		0.252
	0.35	32-44	12	0.13-0.16	0.145		1.74		0.609
	0.35	44-54	10	0	0		0		0
			54					0.705	4.07975

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
174: Dolores	0.5	0-1	1	0	0	0		0	
	0.5	1-3	2	0.13-0.16	0.145	0.29		0.145	
	0.5	3-8	3	0.13-0.16	0.145	0.435		0.2175	
	0.5	3-8	2	0.13-0.16	0.145		0.29		0.145
	0.5	8-10	2	0.06-0.07	0.065		0.13		0.065
	0.5	10-15	5	0.06-0.07	0.065		0.325		0.1625
	0.5	15-24	9	0.06-0.07	0.065		0.585		0.2925
	0.5	24-45	21	0.05-0.06	0.055		1.155		0.5775
	0.5	45-49	4	0.05-0.06	0.055		0.22		0.11
	0.5	49-61	12	0.05-0.06	0.055		0.66		0.33
			61						
Fivepine	0.35	0-3	3	0.13-0.17	0.145	0.435		0.15225	
	0.35	3-9	3	0.11-0.13	0.12	0.36		0.126	
	0.35	3-9	3	0.11-0.13	0.12		0.36		0.126
	0.35	9-12	3	0.11-0.13	0.12		0.36		0.126
	0.35	12-15	3	0.08-0.10	0.09		0.27		0.0945
	0.35	15-19	4	0	0		0		0
			19					0.64075	2.029
175: Jemco	0.4	0-2	2	0.16-0.18	0.17	0.34		0.136	
	0.4	2-7	4	0.16-0.18	0.17	0.68		0.272	
	0.4	2-7	1	0.16-0.18	0.17		0.17		0.068
	0.4	7-14	7	0.16-0.18	0.17		1.19		0.476
	0.4	14-22	8	0.16-0.18	0.17		1.36		0.544
	0.4	22-35	13	0.17-0.19	0.18		2.34		0.936
	0.4	35-39	4	0.17-0.19	0.18		0.72		0.288
	0.4	39-49	10	0	0		0		0
			49						
Detra	0.3	0-16	6	0.14-0.18	0.16	0.96		0.288	
	0.3	0-16	10	0.14-0.18	0.16		1.6		0.48
	0.3	16-30	14	0.14-0.18	0.16		2.24		0.672
	0.3	30-43	13	0.14-0.20	0.17		2.21		0.663
	0.3	43-51	8	0.14-0.20	0.17		1.36		0.408
	0.3	51-57	6	0.16-0.19	0.175		1.05		0.315
	0.3	57-61	4	0	0		0		0
			61						

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
Beje	0.2	0-2	2	0.14-0.16	0.15	0.3		0.06	
	0.2	2-6	4	0.14-0.16	0.15	0.6		0.12	
	0.2	6-14	8	0.14-0.20	0.17		1.36		0.272
	0.2	14-24	10	0	0		0		0
			24					0.876	5.122
176: Moento	0.35	0-2	2	0.15-0.18	0.165	0.33		0.1155	
	0.35	2-6	4	0.17-0.21	0.19	0.76		0.266	
	0.35	6-12	6	0.16-0.19	0.175		1.05		0.3675
	0.35	12-21	9	0.16-0.19	0.175		1.575		0.55125
	0.35	21-30	9	0.16-0.19	0.175		1.575		0.55125
	0.35	30-36	6	0.13-0.16	0.145		0.87		0.3045
	0.35	36-40	4	0	0		0		0
			40						
Detra	0.3	0-16	6	0.14-0.18	0.16	0.96		0.288	
	0.3	0-16	10	0.14-0.18	0.16		1.6		0.48
	0.3	16-30	14	0.14-0.18	0.16		2.24		0.672
	0.3	30-43	13	0.14-0.20	0.17		2.21		0.663
	0.3	43-51	8	0.14-0.20	0.17		1.36		0.408
	0.3	51-57	6	0.16-0.19	0.175		1.05		0.315
	0.3	57-61	4	0	0		0		0
			61						
Jemco	0.2	0-7	6	0.16-0.18	0.18	1.08		0.216	
	0.2	0-7	1	0.16-0.18	0.17		0.17		0.034
	0.2	7-14	7	0.16-0.18	0.17		1.19		0.238
	0.2	14-22	8	0.16-0.18	0.17		1.36		0.272
	0.2	22-35	13	0.17-0.19	0.18		2.34		0.468
	0.2	35-39	4	0.17-0.19	0.18		0.72		0.144
	0.2	39-43	4	0	0		0		0
			43					0.8855	5.4685
177: Herm	0.5	0-6	6	0.13-0.16	0.145	0.87		0.435	
	0.5	6-13	7	0.16-0.19	0.175		1.225		0.6125
	0.5	13-17	4	0.14-0.17	0.155		0.62		0.31
	0.5	17-45	28	0.14-0.17	0.155		4.34		2.17
	0.5	45-60	15	0.16-0.19	0.175		2.625		1.3125
			60						

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
Pagoda	0.35	0-1	1	0	0	0		0	
	0.35	1-5	4	0.16-0.18	0.17	0.68		0.238	
	0.35	5-16	1	0.19-0.21	0.2	0.2		0.07	
	0.35	5-16	10	0.19-0.21	0.2		2		0.7
	0.35	16-21	5	0.19-0.21	0.2		1		0.35
	0.35	21-32	11	0.19-0.21	0.2		2.2		0.77
	0.35	32-61	29	0.19-0.21	0.2		5.8		2.03
			61					0.743	8.255
178: Burnson, dry	0.8	0-1	1	0	0	0		0	
	0.8	1-4	3	0.16-0.18	0.17	0.51		0.408	
	0.8	4-8	2	0.17-0.20	0.185	0.37		0.296	
	0.8	4-8	2	0.17-0.20	0.185		0.37		0.296
	0.8	8-18	10	0.14-0.19	0.165		1.65		1.32
	0.8	18-29	11	0.14-0.19	0.165		1.815		1.452
	0.8	29-44	15	0.14-0.19	0.165		2.475		1.98
	0.8	44-54	10	0	0		0		0
			54					0.704	5.048
179: Jemco	0.6	0-7	6	0.16-0.18	0.17	1.02		0.612	
	0.6	0-7	1	0.16-0.18	0.17		0.17		0.102
	0.6	7-14	7	0.16-0.18	0.17		1.19		0.714
	0.6	14-22	8	0.16-0.18	0.17		1.36		0.816
	0.6	22-35	13	0.17-0.19	0.18		2.34		1.404
	0.6	35-39	4	0.17-0.19	0.18		0.72		0.432
	0.6	39-43	4	0	0		0		0
			43						
Moento	0.25	0-2	2	0.15-0.18	0.165	0.33		0.0825	
	0.25	2-6	4	0.17-0.21	0.195	0.78		0.195	
	0.25	6-12	6	0.17-0.21	0.195		1.17		0.2925
	0.25	12-22	10	0.17-0.21	0.195		1.95		0.4875
	0.25	22-30	8	0.16-0.18	0.17		1.36		0.34
	0.25	30-36	6	0.13-0.16	0.145		0.87		0.2175
	0.25	36-40	4	0	0		0		0
			40					0.8895	4.8055
180: Wetherill	0.85	0-6	6	0.15-0.18	0.165	0.99		0.8415	
	0.85	6-20	14	0.14-0.16	0.15		2.1		1.785

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.85	20-47	27	0.18-0.21	0.195		5.265		4.47525
	0.85	47-60	13	0.11-0.15	0.13		1.69		1.4365
			60					0.8415	7.69675
181: Ormiston	0.5	0-7	6	0.13-0.16	0.145	0.87		0.435	
	0.5	0-7	1	0.13-0.16	0.145		0.145		0.0725
	0.5	7-24	17	0.07-0.11	0.09		1.53		0.765
	0.5	24-32	8	0.07-0.11	0.09		0.72		0.36
	0.5	32-44	12	0.13-0.16	0.145		1.74		0.87
	0.5	44-54	10	0	0		0		0
			54						
Beje	0.35	0-2	2	0.14-0.16	0.15	0.3		0.105	
	0.35	2-6	4	0.14-0.16	0.15	0.6		0.21	
	0.35	6-14	8	0.14-0.20	0.17		1.36		0.476
	0.35	14-24	10	0	0		0		0
			24					0.75	2.5435
182: Burnson	0.8	0-1	1	0	0	0		0	
	0.8	1-4	3	0.16-0.18	0.17	0.51		0.408	
	0.8	4-8	2	0.17-0.20	0.185	0.37		0.296	
	0.8	4-8	2	0.17-0.20	0.185		0.37		0.296
	0.8	8-18	10	0.14-0.19	0.165		1.65		1.32
	0.8	18-29	11	0.14-0.19	0.165		1.815		1.452
	0.8	29-44	15	0.14-0.19	0.165		2.475		1.98
	0.8	44-54	10	0	0		0		0
			54					0.704	5.048
183: Burnson	0.5	0-1	1	0	0	0		0	
	0.5	1-4	3	0.17-0.20	0.185	0.555		0.2775	
	0.5	4-8	2	0.17-0.20	0.185	0.37		0.185	
	0.5	4-8	2	0.17-0.20	0.185		0.37		0.185
	0.5	8-18	10	0.14-0.19	0.165		1.65		0.825
	0.5	18-29	11	0.14-0.19	0.165		1.815		0.9075
	0.5	29-44	15	0.14-0.19	0.165		2.475		1.2375
	0.5	44-54	10	---	0		0		0
			54						
Herm	0.3	0-6	6	0.13-0.16	0.145	0.87		0.261	
	0.3	6-13	7	0.16-0.19	0.175		1.225		0.3675

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.3	13-17	4	0.14-0.17	0.155		0.62		0.186
	0.3	17-45	28	0.14-0.17	0.155		4.34		1.302
	0.3	45-60	15	0.16-0.19	0.175		2.625		0.7875
			60					0.7235	5.798
184: Bradfield	0.9	0-7	6	0.18-0.20	0.19	1.14		1.026	
	0.9	0-7	1	0.18-0.20	0.19		0.19		0.171
	0.9	7-15	8	0.15-0.18	0.165		1.32		1.188
	0.9	15-28	13	0.15-0.18	0.165		2.145		1.9305
	0.9	28-36	8	0.15-0.18	0.165		1.32		1.188
	0.9	36-60	24	0.14-0.18	0.16		3.84		3.456
			60					1.026	7.9335
185: Fughes	0.5	0-7	6	0.13-0.16	0.145	0.87		0.435	
	0.5	0-7	1	0.13-0.16	0.145		0.145		0.0725
	0.5	7-26	19	0.18-0.20	0.19		3.61		1.805
	0.5	26-44	18	0.16-0.19	0.175		3.15		1.575
	0.5	44-60	16	0.14-0.16	0.15		2.4		1.2
			60						
Sheek	0.35	0-2	2	0.12-0.13	0.125	0.25		0.0875	
	0.35	2-7	4	0.15-0.17	0.16	0.64		0.224	
	0.35	2-7	1	0.15-0.17	0.16		0.16		0.056
	0.35	7-20	13	0.09-0.11	0.1		1.3		0.455
	0.35	20-29	9	0.07-0.09	0.08		0.72		0.252
	0.35	29-46	17	0.14-0.16	0.15		2.55		0.8925
	0.35	46-60	14	0.07-0.09	0.08		1.12		0.392
			60					0.7465	6.7
186: Argiustolls	0.3	0-1	1	0	0	0		0	
	0.3	1-4	3	0.04-0.07	0.055	0.165		0.0495	
	0.3	4-7	2	0.04-0.07	0.055	0.11		0.033	
	0.3	4-7	1	0.04-0.07	0.055		0.055		0.0165
	0.3	7-13	6	0.04-0.07	0.055		0.33		0.099
	0.3	13-20	7	0.09-0.12	0.105		0.735		0.2205
	0.3	20-37	17	0.13-0.16	0.145		2.465		0.7395
	0.3	37-50	13	0.13-0.16	0.145		1.885		0.5655
	0.3	50-61	11	0.14-0.16	0.15		1.65		0.495
			61						

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
Haplustalfs	0.3	0-2	2	0.07-0.10	0.085	0.17		0.051	
	0.3	2-5	3	0.07-0.10	0.085	0.255		0.0765	
	0.3	5-10	1	0.09-0.11	0.1	0.1		0.03	
	0.3	5-10	4	0.09-0.11	0.1		0.4		0.12
	0.3	10-24	14	0.07-0.11	0.09		1.26		0.378
	0.3	24-41	17	0.07-0.11	0.09		1.53		0.459
	0.3	41-55	14	0.07-0.12	0.095		1.33		0.399
	0.3	55-60	5	0.07-0.12	0.095		0.475		0.1425
			60						
Rock outcrop	0.25		0	0.00-0.0	0				
								0.24	3.6345
187: Wauquie	0.4	0-3	3	0.08-0.11	0.095	0.285		0.114	
	0.4	3-9	3	0.07-0.11	0.09	0.27		0.108	
	0.4	3-9	3	0.07-0.11	0.09		0.27		0.108
	0.4	9-14	5	0.07-0.11	0.09		0.45		0.18
	0.4	14-23	9	0.07-0.16	0.115		1.035		0.414
	0.4	23-32	9	0.07-0.16	0.115		1.035		0.414
	0.4	32-60	28	0.07-0.16	0.115		3.22		1.288
			60						
Dolcan	0.25	0-4	4	0.13-0.16	0.145	0.58		0.145	
	0.25	4-9	2	0.12-0.19	0.155	0.31		0.0775	
	0.25	4-9	3	0.12-0.19	0.155		0.465		0.11625
	0.25	9-16	7	0.12-0.19	0.155		1.085		0.27125
	0.25	16-26	10	---	0		0		0
			26						
Rock outcrop	0.2	0-60	0	---	0				
								0.4445	2.7915
188: Shawa	0.45	0-7	6	0.16-0.18	0.17	1.02		0.459	
	0.45	0-7	1	0.16-0.18	0.17		0.17		0.0765
	0.45	7-19	12	0.16-0.18	0.17		2.04		0.918
	0.45	19-38	19	0.16-0.19	0.175		3.325		1.49625
	0.45	38-60	22	0.13-0.15	0.14		3.08		1.386
			60						
Fughes	0.35	0-1	1	0	0	0		0	
	0.35	1-8	5	0.16-0.18	0.17	0.85		0.2975	

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.35	1-8	2	0.16-0.18	0.17		0.34		0.119
	0.35	8-27	19	0.18-0.20	0.19		3.61		1.2635
	0.35	27-45	18	0.14-0.16	0.15		2.7		0.945
	0.35	45-61	16	0.14-0.16	0.15		2.4		0.84
			61					0.7565	7.04425
189: Fughes	0.8	0-7	6	0.17-0.21	0.19	1.14		0.912	
	0.8	0-7	1	0.17-0.21	0.19		0.19		0.152
	0.8	7-26	19	0.18-0.20	0.19		3.61		2.888
	0.8	26-44	18	0.14-0.16	0.15		2.7		2.16
	0.8	44-60	16	0.14-0.16	0.15		2.4		1.92
			60					0.912	7.12
190: Granath	0.55	0-2	2	0.18-0.20	0.19	0.38		0.209	
	0.55	2-10	4	0.18-0.20	0.19	0.76		0.418	
	0.55	2-10	4	0.18-0.20	0.19		0.76		0.418
	0.55	10-15	5	0.14-0.21	0.175		0.875		0.48125
	0.55	15-20	5	0.14-0.21	0.175		0.875		0.48125
	0.55	20-28	8	0.14-0.21	0.175		1.4		0.77
	0.55	28-40	12	0.14-0.21	0.175		2.1		1.155
	0.55	40-49	9	0.14-0.21	0.175		1.575		0.86625
	0.55	49-60	11	0.14-0.21	0.175		1.925		1.05875
			60						
Nortez	0.3	0-3	3	0.15-0.18	0.165	0.495		0.1485	
	0.3	3-10	3	0.17-0.20	0.185	0.555		0.1665	
	0.3	3-10	4	0.17-0.20	0.185		0.74		0.222
	0.3	10-23	13	0.15-0.18	0.165		2.145		0.6435
	0.3	23-28	5	0.15-0.18	0.165		0.825		0.2475
	0.3	28-32	4	0.15-0.18	0.165		0.66		0.198
	0.3	32-42	10	0	0		0		0
			42					0.942	6.5415
191: Umbarg	0.35	0-2	2	0.15-0.18	0.165	0.33		0.1155	
	0.35	2-12	4	0.17-0.20	0.185	0.74		0.259	
	0.35	2-12	6	0.17-0.20	0.185		1.11		0.3885
	0.35	12-33	21	0.15-0.18	0.165		3.465		1.21275
	0.35	33-42	9	0.15-0.18	0.165		1.485		0.51975
	0.35	42-60	18	0.08-0.11	0.095		1.71		0.5985

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
			60						
Winner	0.3	0-4	4	0.18-0.20	0.19	0.76		0.228	
	0.3	4-14	2	0.18-0.20	0.19	0.38		0.114	
	0.3	4-14	8	0.18-0.20	0.19		1.52		0.456
	0.3	14-23	9	0.18-0.20	0.19		1.71		0.513
	0.3	23-31	8	0.18-0.20	0.19		1.52		0.456
	0.3	31-60	29	0.07-0.10	0.085		2.465		0.7395
			60						
Tesajo	0.2	0-3	3	0.08-0.11	0.095	0.285		0.057	
	0.2	3-36	3	0.04-0.06	0.05	0.15		0.03	
	0.2	3-36	30	0.04-0.06	0.05		1.5		0.3
	0.2	36-60	24	0.04-0.06	0.05		1.2		0.24
Fluvaquents	0.05	---	0	0	0				
Totals			60					0.8035	5.424
192: Sheek	0.35	0-1	1	0	0	0		0	
	0.35	1-5	4	0.05-0.07	0.06	0.24		0.084	
	0.35	5-43	1	0.09-0.11	0.1	0.1		0.035	
	0.35	5-43	37	0.09-0.11	0.1		3.7		1.295
	0.35	43-61	18	0.09-0.11	0.1		1.8		0.63
Totals			61						
Archuleta	0.3	0-1	1	0	0	0		0	
	0.3	1-6	5	0.05-0.07	0.06	0.3		0.09	
	0.3	6-9	3	0.07-0.10	0.085		0.255		0.0765
	0.3	9-18	9	0.13-0.16	0.145		1.305		0.3915
	0.3	18-28	10	0	0		0		0
Rock outcrop	0.2	0-60	0	0	0				
Totals			28					0.209	2.393
193: Granath	0.9	0-2	2	0.18-0.20	0.19	0.38		0.342	
	0.9	2-10	4	0.18-0.20	0.19	0.76		0.684	
	0.9	2-10	4	0.18-0.20	0.19		0.76		0.684
	0.9	10-15	5	0.14-0.21	0.175		0.875		0.7875
	0.9	15-20	5	0.14-0.21	0.175		0.875		0.7875
	0.9	20-28	8	0.14-0.21	0.175		1.4		1.26

Musym	PropSoil	Depth	in/lev	in/in	M_in/in	M*in U	M*in L	M*in U *%C	M*in L *%C
	0.9	28-40	12	0.14-0.21	0.175		2.1		1.89
	0.9	40-60	20	0.14-0.21	0.175		3.5		3.15
Totals			60					1.026	8.559

Appendix B. Productivity of Critical Natural Resources for all Soil Complexes Mapped within the Study Area.

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
1	1317.4	896.0	Muttongrass	35.3	316.2							
% Slope: 1 - 3	350.0	919.6	Western wheatgrass	23.5	210.8							
Ackmen - .9		5.8	Wyoming big sagebrush	17.6	158.1							
Loamy Bottom			Bottlebrush squirreltail	5.9	52.7	0.0	263.5	197.6	1.9	4.9	25.2	10.5
			Fourwing saltbush	5.9	52.7							
			Indian ricegrass	5.9	52.7							
			Rubber rabbitbrush	5.9	52.7							
2	84.3	896.0	Muttongrass	35.3	316.2							
% Slope: 3 - 6	23.0	1065.3	Western wheatgrass	23.5	210.8							
Ackmen - .9		6.3	Wyoming big sagebrush	17.6	158.1							
Loamy Bottom			Bottlebrush squirreltail	5.9	52.7	0.0	263.5	197.6	1.9	4.9	1.5	2.7
			Fourwing saltbush	5.9	52.7							
			Indian ricegrass	5.9	52.7							
			Rubber rabbitbrush	5.9	52.7							
7	11.9	896.0	Gambel's oak	38.9	348.4							
% Slope: 30 - 80	0.0		Muttongrass	11.1	99.6							
Argiustolls - .3			Ponderosa pine	11.1	99.6							
Haplustalfs - .3			Utah serviceberry	11.1	99.6	99.6	597.3	522.7	8.9	1.2	0.0	3.0
Ponderosa Pine			Utah snowberry	11.1	99.6							
			Elk sedge	5.6	49.8							
			Prairie junegrass	5.6	49.8							
			True mountain mahogany	5.6	49.8							
8	1223.0	784.0	Galleta	26.3	206.3							
% Slope: 3 - 6	314.0	728.5	Indian ricegrass	17.5	137.5							
Barx - .9		4.7	Muttongrass	17.5	137.5							
Semidesert Loam			Wyoming big sagebrush	17.5	137.5	0.0	165.1	123.8	1.6	3.8	2.2	2.5
			Blue grama	8.8	68.8							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			New Mexico feathergrass	8.8	68.8							
			Winterfat	3.5	27.5							
9	188.8	784.0	Galleta	26.3	206.3							
% Slope: 6 - 12	49.0	704.0	Indian ricegrass	17.5	137.5							
Barx - .85		4.5	Muttongrass	17.5	137.5							
Semidesert Loam			Wyoming big sagebrush	17.5	137.5	0.0	165.1	123.8	1.6	3.8	2.2	2.5
			Blue grama	8.8	68.8							
			New Mexico feathergrass	8.8	68.8							
			Winterfat	3.5	27.5							
10	620.8	1120.0	Wyoming big sagebrush	25.0	280.0							
% Slope: 1 - 4	150.0	1207.6	Indian ricegrass	18.8	210.0							
Barx - .9		7.0	Needleandthread	18.8	210.0							
Upland Loam (basin Big			Blue grama	6.3	70.0							
Sagebrush)			Fourwing saltbush	6.3	70.0	0.0	420.0	315.0	3.3	12.8	2.4	6.0
			Galleta	6.3	70.0							
			Muttongrass	6.3	70.0							
			Sand dropseed	6.3	70.0							
			Winterfat	6.3	70.0							
11	2338.6	784.0	Galleta	25.6	200.6							
% Slope: 2 - 6	582.0	816.2	Indian ricegrass	17.1	133.7							
Barx - .6		5.1	Wyoming big sagebrush	17.1	133.7							
Gapmesa - .3			New Mexico feathergrass	13.9	109.0							
Semidesert Loam			Muttongrass	11.7	91.6	0.0	160.5	120.3	1.6	4.0	2.2	2.5
			Blue grama	8.5	66.9							
			Winterfat	3.4	26.7							
			Western wheatgrass	2.7	21.1							
12	701.0	784.0	Alkali sacaton	31.3	245.0							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
% Slope: 0 - 6	170.0	718.9	Greasewood	18.8	147.0							
Battlerock - .85		4.2	Inland saltgrass	18.8	147.0							
Alkali Bottom			Basin big sagebrush	6.3	49.0	0.0	294.0	220.5	0.6	3.8	3.5	2.6
			Fourwing saltbush	6.3	49.0							
			Galleta	6.3	49.0							
			Saltbush	6.3	49.0							
			Western wheatgrass	6.3	49.0							
13	43.0	1680.0	Gambel's oak	20.0	336.0							
% Slope: 3 - 9	12.0	1468.0	Mountain brome	15.0	252.0							
Beje - .6		6.6	Saskatoon serviceberry	15.0	252.0							
Tragmon - .2			Muttongrass	10.0	168.0							
Brushy Loam			Snowberry	10.0	168.0	0.0	1050.0	787.5	36.4	5.2	1.3	13.1
			True mountain mahogany	10.0	168.0							
			Western wheatgrass	10.0	168.0							
			Serviceberry	5.0	84.0							
			Prairie junegrass	2.5	42.0							
			Sagebrush	2.5	42.0							
17	5.3	1120.0	Muttongrass	25.0	280.0							
% Slope: 1 - 3	1.0	1359.2	Western wheatgrass	25.0	280.0							
Cahona - .85		7.9	Big sagebrush	18.8	210.0							
Loamy Foothills			Antelope bitterbrush	6.3	70.0	0.0	350.0	262.5	3.7	6.6	2.3	4.0
			Bottlebrush squirreltail	6.3	70.0							
			Galleta	6.3	70.0							
			Needleandthread	6.3	70.0							
			Rubber rabbitbrush	6.3	70.0							
18	551.5	1120.0	Muttongrass	25.0	280.0							
% Slope: 3 - 6	133.0	1181.1	Western wheatgrass	25.0	280.0							
Cahona - .85		6.9	Big sagebrush	18.8	210.0							
Loamy Foothills			Antelope bitterbrush	6.3	70.0							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Bottlebrush squirreltail	6.3	70.0	0.0	350.0	262.5	3.7	6.6	2.3	4.0
			Galleta	6.3	70.0							
			Needleandthread	6.3	70.0							
			Rubber rabbitbrush	6.3	70.0							
19	2070.9	1120.0	Muttongrass	25.0	280.0							
% Slope: 6 - 12	538.0	1246.8	Western wheatgrass	25.0	280.0							
Cahona - .85		7.4	Big sagebrush	18.8	210.0							
Loamy Foothills			Antelope bitterbrush	6.3	70.0	0.0	350.0	262.5	3.7	6.6	2.3	4.0
			Bottlebrush squirreltail	6.3	70.0							
			Galleta	6.3	70.0							
			Needleandthread	6.3	70.0							
			Rubber rabbitbrush	6.3	70.0							
20	1954.2	1120.0	Western wheatgrass	26.8	300.0							
% Slope: 3 - 9	511.0	1150.9	Muttongrass	24.4	273.0							
Cahona - .5		6.5	Big sagebrush	15.9	177.6							
Pulpit - .35			Indian ricegrass	7.3	81.2							
Loamy Foothills			Needleandthread	6.1	68.2							
			Antelope bitterbrush	3.7	41.2	0.0	287.0	215.3	2.8	7.4	2.2	4.0
			Bottlebrush squirreltail	3.7	41.2							
			Galleta	3.7	41.2							
			Rubber rabbitbrush	3.7	41.2							
			Prairie junegrass	2.4	27.1							
			Rabbitbrush	2.4	27.1							
21	4295.5	1120.0	Western wheatgrass	31.3	351.1							
% Slope: 2 - 6	1066.0	1246.4	Muttongrass	22.5	252.2							
Cahona - .35		7.3	Big sagebrush	16.0	179.6							
Sharps - .3			Bottlebrush squirreltail	8.3	92.8							
Wetherill - .2			Indian ricegrass	5.7	64.0	0.0	261.8	196.4	2.6	7.6	2.2	4.0
Loamy Foothills			Galleta	4.8	53.5							

Soil[1]	Area[2]	Prod[3]	Common Name[4]	% VC[5]	Kg/ha[6]	Trees[7]	Shrubs[8]	Fuels[9]	Deer[10]	Hare[10]	Rabbit[10]	Protein[11]
			Needleandthread	3.9	43.4							
			Antelope bitterbrush	2.6	28.8							
			Rubber rabbitbrush	2.6	28.8							
			Black sagebrush	2.2	24.7							
22	4538.0	392.0	Galleta	22.2	87.1							
% Slope: 12 - 65	1149.0	297.4	Shadscale saltbush	22.2	87.1							
Claysprings - .8		2.3	Salina wildrye	16.7	65.3							
Saltdesert Breaks			Alkali sacaton	11.1	43.6							
			Big sagebrush	5.6	21.8	21.8	130.7	114.4	1.0	1.7	1.2	1.3
			Bottlebrush squirreltail	5.6	21.8							
			Fourwing saltbush	5.6	21.8							
			Indian ricegrass	5.6	21.8							
			Utah juniper	5.6	21.8							
27	152.8	2240.0	Elk sedge	36.5	818.3							
% Slope: 0 - 5	38.0	2115.3	Mountain brome	18.3	409.2							
Apmay - .35		10.9	Rocky Mountain iris	11.1	248.4							
Dalmatian - .35			Tufted hairgrass	11.1	248.4	0.0	0.0	0.0	0.0	26.0	2.2	9.3
Schrader - .15			Western yarrow	11.1	248.4							
River Bottom			Sedge	7.8	175.2							
			Rush	3.9	87.6							
30	231.9	728.0	Arizona fescue	22.7	165.5							
% Slope: 3 - 25	62.0	793.7	Parry's oatgrass	22.7	165.5							
Falconry - .8		4.0	Mountain muhly	11.4	82.7							
Pine Grasslands			Ponderosa pine	11.4	82.7							
			Elk sedge	5.7	41.4							
			Gambel's oak	5.7	41.4	82.7	82.7	124.1	2.9	1.5	0.1	1.4
			Needlegrass	5.7	41.4							
			Mountain brome	3.4	24.8							
			Slender wheatgrass	3.4	24.8							

Soil[1]	Area[2]	Prod[3]	Common Name[4]	% VC[5]	Kg/ha[6]	Trees[7]	Shrubs[8]	Fuels[9]	Deer[10]	Hare[10]	Rabbit[10]	Protein[11]
			True mountain mahogany	3.4	24.8							
			Muttongrass	2.3	16.5							
			Whortleleaf snowberry	2.3	16.5							
31	2602.6	448.0	New Mexico feathergrass	28.6	128.0							
% Slope: 3 - 12	653.0	501.2	Galleta	21.4	96.0							
Farb - .55		2.7	Indian ricegrass	21.4	96.0							
Shallow Desert			Fourwing saltbush	7.1	32.0	0.0	96.0	72.0	0.0	2.6	1.0	1.2
			Mormon tea	7.1	32.0							
			Needleandthread	7.1	32.0							
			Shadscale saltbush	7.1	32.0							
33	5.9	1008.0	Arizona fescue	24.4	245.9							
% Slope: 0 - 9	0.0		Parry's oatgrass	24.4	245.9							
Fardraw - .85			Mountain muhly	18.3	184.4							
Pine Grasslands			Ponderosa pine	18.3	184.4	209.0	61.5	202.8	3.1	0.0	0.0	0.9
			Bottlebrush squirreltail	6.1	61.5							
			Gambel's oak	6.1	61.5							
			Rocky Mountain juniper	2.4	24.6							
35	47.3	1008.0	Arizona fescue	25.5	257.5							
% Slope: 3 - 12	9.0	989.6	Mountain muhly	18.3	184.5							
Fardraw - .5		4.8	Parry's oatgrass	15.3	153.9							
Pine Grasslands			Gambel's oak	14.1	142.1							
Granath - .35			Ponderosa pine	7.6	77.0	92.4	176.6	201.7	6.8	1.2	0.3	2.6
Mountain Loam			Western wheatgrass	6.9	69.0							
			Bottlebrush squirreltail	3.8	38.5							
			Mountain brome	3.4	34.5							
			Snowberry	3.4	34.5							
			Rocky Mountain juniper	1.5	15.4							
36	7.6	896.0	Western wheatgrass	16.7	149.4							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
% Slope: 0 - 15	2.0	910.6	Gambel's oak	14.9	133.9							
Fivepine - .6		4.8	Ponderosa pine	10.5	94.5							
Nortez - .25			Prairie junegrass	10.5	94.5							
Ponderosa Pine			Pine dropseed	8.8	79.0							
			Arizona fescue	8.6	77.5							
			Mountain muhly	7.9	70.5	94.5	243.9	253.8	8.0	2.1	0.6	3.3
			Common snowberry	4.4	39.5							
			Nodding brome	4.4	39.5							
			Utah serviceberry	4.4	39.5							
			Parry's oatgrass	3.5	31.0							
			Antelope bitterbrush	1.7	15.5							
			Mountain big sagebrush	1.7	15.5							
			Mountain brome	1.7	15.5							
37	8.0	2240.0	Western wheatgrass	24.4	547.3							
% Slope: 0 - 5	2.0	2394.5	Willow	17.2	386.3							
Fluvaquents - .55		11.2	Alkali sacaton	10.8	241.5							
Haplustolls - .3			Inland saltgrass	7.2	161.0							
River Bottom			Needleandthread	7.2	161.0							
			Rush	7.2	161.0	80.5	386.3	350.1	6.9	13.4	6.8	8.7
			Sedge	7.2	161.0							
			Mountain brome	5.0	112.6							
			Muttongrass	5.0	112.6							
			Prairie junegrass	5.0	112.6							
			Narrowleaf cottonwood	3.6	80.5							
38	1301.6	1344.0	Western wheatgrass	35.6	477.8							
% Slope: 0 - 3	337.0	1151.3	Alkali sacaton	33.6	451.5							
Fluvents - .55		6.3	Cottonwood	9.2	124.2							
Fluvaquents - .3			Inland saltgrass	3.9	52.6							
River Bottom			Needleandthread	3.9	52.6	150.5	52.6	152.3	0.9	7.4	5.0	4.4
			Rush	3.9	52.6							

Soil[1]	Area[2]	Prod[3]	Common Name[4]	% VC[5]	Kg/ha[6]	Trees[7]	Shrubs[8]	Fuels[9]	Deer[10]	Hare[10]	Rabbit[10]	Protein[11]
			Sedge	3.9	52.6							
			Willow	3.9	52.6							
			Narrowleaf cottonwood	2.0	26.3							
39	230.5	2016.0	Arizona fescue	35.3	711.5							
% Slope 1 - 12	58.0	1736.4	Mountain muhly	23.5	474.4							
Fughes - .9		9.0	Parry's oatgrass	17.6	355.8	0.0	118.6	88.9	1.4	5.1	1.3	2.5
Loamy Park			Western wheatgrass	11.8	237.2							
			Big sagebrush	5.9	118.6							
			Slender wheatgrass	5.9	118.6							
40	7.2	2240.0	Arizona fescue	18.2	406.9							
% Slope: 5 - 25	2.0	1838.4	Gambel's oak	18.2	406.9							
Fughes - .55		9.7	Mountain brome	18.2	406.9							
Herm - .35			Saskatoon serviceberry	12.3	275.1	0.0	885.4	664.1	31.5	9.5	2.4	13.4
Brushy Loam			Western wheatgrass	12.3	275.1							
			Common snowberry	9.1	203.4							
			Mountain muhly	5.9	131.8							
			Slender wheatgrass	5.9	131.8							
42	13716.0	392.0	Western wheatgrass	28.7	112.6							
% Slope: 3 - 9	3378.0	461.5	Muttongrass	11.7	45.7							
Gladel - .45		3.1	Needleandthread	10.4	40.8							
Pinyon-Juniper			Big sagebrush	9.6	37.5							
Pulpit - .35			Indian ricegrass	7.5	29.4	44.1	93.0	102.8	2.5	2.9	0.6	1.9
Loamy Foothills			True mountain mahogany	7.5	29.4							
			Twoneedle pinyon	7.5	29.4							
			Antelope bitterbrush	6.7	26.1							
			Bottlebrush squirreltail	6.7	26.1							
			Utah juniper	3.7	14.7							
44	771.9	1568.0	Arizona fescue	33.3	522.7							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
% Slope: 3 - 6	196.0	1321.4	Big sagebrush	16.7	261.3							
Granath - .9		6.8	Mountain muhly	16.7	261.3	0.0	392.0	294.0	7.8	6.6	1.7	5.1
Mountain Loam			Western wheatgrass	16.7	261.3							
			Mountain brome	8.3	130.7							
			Snowberry	8.3	130.7							
45	462.8	1568.0	Arizona fescue	33.3	522.7							
% Slope: 6 - 12	119.0	1297.8	Big sagebrush	16.7	261.3							
Granath - .9		6.6	Mountain muhly	16.7	261.3	0.0	392.0	294.0	7.8	6.6	1.7	5.1
Mountain Loam			Western wheatgrass	16.7	261.3							
			Mountain brome	8.3	130.7							
			Snowberry	8.3	130.7							
47	26.2	1680.0	Arizona fescue	33.2	557.3							
% Slope: 0 - 15	1.0	1343.1	Mountain muhly	16.6	278.6							
Granath - .55		7.3	Mountain brome	13.2	221.9							
Mountain Loam			Western wheatgrass	11.8	197.6							
Nortez - .3			Big sagebrush	8.3	139.3	81.0	196.0	207.8	3.4	6.0	1.6	3.5
Pine Grasslands			Parry's oatgrass	7.2	121.5							
			Ponderosa pine	4.8	81.0							
			Gambel's oak	2.4	40.5							
			Prairie junegrass	1.4	24.3							
			Antelope bitterbrush	1.0	16.2							
50	40.8	1456.0	Arizona fescue	23.1	336.0							
% Slope: 15 - 40	6.0	912.1	Gambel's oak	15.4	224.0							
Herm - .85		4.8	Mountain muhly	15.4	224.0							
Ponderosa Pine			Ponderosa pine	15.4	224.0	224.0	448.0	504.0	16.0	0.0	0.0	4.8
			Prairie junegrass	15.4	224.0							
			Common snowberry	7.7	112.0							
			Saskatoon serviceberry	7.7	112.0							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
51	7.9	1456.0	Arizona fescue	20.4	297.3							
% Slope: 0 - 15	2.0	1360.7	Gambel's oak	15.9	231.4							
Herm - .5		7.1	Ponderosa pine	13.6	198.2							
Pagoda - .35			Prairie junegrass	13.6	198.2							
Ponderosa Pine			Mountain muhly	11.3	165.0	198.2	429.7	470.9	15.3	1.2	0.3	5.1
			Western wheatgrass	6.9	99.7							
			Common snowberry	6.8	99.1							
			Saskatoon serviceberry	6.8	99.1							
			Pine dropseed	4.6	66.5							
52	47.5	2016.0	Arizona fescue	32.5	654.5							
% Slope: 0 - 3	7.0	1451.0	Mountain muhly	19.5	392.7							
Hesperus - .9		7.4	Parry's oatgrass	19.5	392.7							
Loamy Park			Western wheatgrass	13.0	261.8	0.0	183.3	137.5	3.4	4.1	1.0	2.7
			Big sagebrush	6.5	130.9							
			Nodding brome	6.5	130.9							
			Common snowberry	2.6	52.4							
53	175.2	2016.0	Arizona fescue	31.3	630.0							
% Slope: 3 - 5	43.0	1846.3	Mountain muhly	18.8	378.0							
Hesperus - .85		9.5	Parry's oatgrass	18.8	378.0							
Loamy Park			Western wheatgrass	12.5	252.0	0.0	252.0	189.0	6.0	3.9	1.0	3.4
			Big sagebrush	6.3	126.0							
			Common snowberry	6.3	126.0							
			Nodding brome	6.3	126.0							
54	4.4	2240.0	Elk sedge	18.2	407.3							
% Slope: 6 - 12	1.0	2333.7	Gambel's oak	18.2	407.3							
Hesperus - .85		12.1	Nodding brome	18.2	407.3	0.0	814.6	610.9	29.0	16.7	0.6	14.4
Brushy Loam			Arizona fescue	9.1	203.6							
			Common snowberry	9.1	203.6							
			Needleandthread	9.1	203.6							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Utah serviceberry	9.1	203.6							
			Western wheatgrass	9.1	203.6							
55	19.6	2016.0	Arizona fescue	31.3	630.0							
% Slope: 3 - 12	4.0	1857.0	Mountain muhly	18.8	378.0							
Hesperus - .9		9.6	Parry's oatgrass	18.8	378.0							
Loamy Park			Western wheatgrass	12.5	252.0	0.0	252.0	189.0	6.0	3.9	1.0	3.4
			Big sagebrush	6.3	126.0							
			Common snowberry	6.3	126.0							
			Nodding brome	6.3	126.0							
56	9.0	1680.0	Arizona fescue	38.5	646.2							
% Slope: 3 - 12	0.0		Western wheatgrass	23.1	387.7							
Ilex - .85			Mountain muhly	15.4	258.5	258.5	129.2	290.8	4.6	4.5	1.1	3.3
Ponderosa Pine			Ponderosa pine	15.4	258.5							
			Gambel's oak	7.7	129.2							
58	1320.0	1232.0	Western wheatgrass	31.0	381.4							
% Slope: 2 - 6	326.0	1337.5	Arizona fescue	22.1	272.9							
Ilex - .6		6.8	Black sagebrush	17.6	217.1							
Mountain Clay			Gambel's oak	11.2	137.9							
Granath - .25			Mountain muhly	4.5	55.7	0.0	438.6	328.9	7.2	7.6	1.9	5.3
Mountain Loam			Prairie junegrass	4.4	54.3							
			Big sagebrush	2.3	27.9							
			Mountain brome	2.3	27.9							
			Mountain mahogany	2.3	27.9							
			Snowberry	2.3	27.9							
59	1043.6	1232.0	Western wheatgrass	32.7	403.1							
% Slope: 6 - 12	256.0	1358.8	Arizona fescue	23.3	287.3							
Ilex - .6		6.9	Black sagebrush	14.1	173.7							
Mountain Clay			Gambel's oak	11.5	141.5							

Soil[1]	Area[2]	Prod[3]	Common Name[4]	% VC[5]	Kg/ha[6]	Trees[7]	Shrubs[8]	Fuels[9]	Deer[10]	Hare[10]	Rabbit[10]	Protein[11]
Granath - .25			Prairie junegrass	4.7	57.9	0.0	398.8	299.1	7.4	7.3	1.8	5.2
Mountain Loam			Mountain muhly	4.5	55.7							
			Big sagebrush	2.3	27.9							
			Mountain brome	2.3	27.9							
			Mountain mahogany	2.3	27.9							
			Snowberry	2.3	27.9							
60	386.4	1680.0	Arizona fescue	21.7	364.4							
% Slope: 3 - 20	86.0	1342.6	Western wheatgrass	20.9	351.2							
Ilex - .35		7.2	Mountain muhly	13.5	226.8							
Mountain Loam			Ponderosa pine	11.9	199.3							
Pramiss - .3			Gambel's oak	5.9	99.7							
Ponderosa Pine			Prairie junegrass	5.6	94.4							
Falconry - .2			Slender wheatgrass	4.8	81.3	199.3	226.8	319.6	7.1	6.2	1.5	4.7
Pine Grasslands			Mountain brome	4.1	68.2							
			Needlegrass	2.7	45.9							
			Big sagebrush	2.4	40.6							
			Common snowberry	2.4	40.6							
			True mountain mahogany	1.6	27.5							
			Muttongrass	1.1	18.4							
			Whortleleaf snowberry	1.1	18.4							
61	861.0	1232.0	Western wheatgrass	30.1	371.4							
% Slope: 2 - 9	214.0	1350.6	Arizona fescue	19.4	239.6							
Ilex - .35		7.2	Black sagebrush	15.8	195.1							
Pramiss - .3			Gambel's oak	9.8	121.3							
Mountain Clay			Needlegrass	5.6	68.5							
Granath - .2			Mountain muhly	5.5	67.4	0.0	383.2	287.4	6.2	7.3	1.8	4.9
Mountain Loam			Prairie junegrass	4.4	54.5							
			Slender wheatgrass	1.9	22.8							
			Big sagebrush	1.8	22.3							
			Mountain brome	1.8	22.3							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Mountain mahogany	1.8	22.3							
			Snowberry	1.8	22.3							
62	1056.1	2800.0	Alkali sacaton	41.2	1152.9							
% Slope: 0 - 3	261.0	1945.5	Inland saltgrass	11.8	329.4							
Irak - .85		10.8	Sedge	11.8	329.4							
Wet Meadow			Western wheatgrass	11.8	329.4	0.0	329.4	247.1	0.0	9.6	13.0	7.5
			Fourwing saltbush	5.9	164.7							
			Foxtail barley	5.9	164.7							
			Rubber rabbitbrush	5.9	164.7							
			Rush	5.9	164.7							
63	90.5	1008.0	Arizona fescue	22.4	225.3							
% Slope: 1 - 15	9.0	713.4	Ponderosa pine	16.6	167.4							
Jemco - .4		3.6	Common snowberry	10.9	109.5							
Detra - .3			Western wheatgrass	10.9	109.5							
Beje - .2			Gambel's oak	10.0	100.9							
Ponderosa Pine			Prairie junegrass	8.5	86.1	208.1	337.2	409.0	9.9	1.5	0.9	3.7
			Oregongrape	8.3	83.7							
			Mountain muhly	4.0	40.7							
			Rocky Mountain juniper	4.0	40.7							
			Saskatoon serviceberry	2.6	25.8							
			Black sagebrush	1.7	17.2							
65	1082.0	672.0	Alkali sacaton	31.3	210.0							
% Slope: 1 - 3	268.0	770.8	Greasewood	18.8	126.0							
Lillings - .9		4.9	Inland saltgrass	18.8	126.0							
Alkali Bottom			Big sagebrush	6.3	42.0	0.0	252.0	189.0	0.5	3.3	3.0	2.2
			Fourwing saltbush	6.3	42.0							
			Galleta	6.3	42.0							
			Saltbush	6.3	42.0							
			Western wheatgrass	6.3	42.0							

Soil[1]	Area[2]	Prod[3]	Common Name[4]	% VC[5]	Kg/ha[6]	Trees[7]	Shrubs[8]	Fuels[9]	Deer[10]	Hare[10]	Rabbit[10]	Protein[11]
66	622.4	784.0	Alkali sacaton	31.3	245.0							
% Slope: 1 - 3	154.0	769.7	Greasewood	18.8	147.0							
Lillings - .9		5.0	Inland saltgrass	18.8	147.0							
Alkali Bottom			Big sagebrush	6.3	49.0	0.0	294.0	220.5	0.6	3.8	3.5	2.6
			Fourwing saltbush	6.3	49.0							
			Galleta	6.3	49.0							
			Saltbush	6.3	49.0							
			Western wheatgrass	6.3	49.0							
67	32.3	784.0	Alkali sacaton	31.3	245.0							
% Slope: 3 - 6	9.0	617.7	Greasewood	18.8	147.0							
Lillings - .9		3.9	Inland saltgrass	18.8	147.0							
Alkali Bottom			Big sagebrush	6.3	49.0	0.0	294.0	220.5	0.6	3.8	3.5	2.6
			Fourwing saltbush	6.3	49.0							
			Galleta	6.3	49.0							
			Saltbush	6.3	49.0							
			Western wheatgrass	6.3	49.0							
70	1448.5	784.0	Alkali sacaton	28.6	224.0							
% Slope: 0 - 6	363.0	718.0	Galleta	21.4	168.0							
Mack - .85		4.4	Greasewood	14.3	112.0							
Alkali Flat			Indian ricegrass	14.3	112.0	0.0	224.0	168.0	0.0	4.6	3.5	2.7
			Fourwing saltbush	7.1	56.0							
			Scarlet globemallow	7.1	56.0							
			Shadscale saltbush	7.1	56.0							
71	631.1	1792.0	Alkali sacaton	47.1	843.3							
% Slope: 0 -3	163.0	1239.1	Inland saltgrass	11.8	210.8							
Mikett - .85		7.7	Sedge	11.8	210.8							
Salt Meadow			Western wheatgrass	11.8	210.8	0.0	210.8	158.1	0.0	6.2	8.4	4.8
			Baltic rush	5.9	105.4							

Soil[1]	Area[2]	Prod[3]	Common Name[4]	% VC[5]	Kg/ha[6]	Trees[7]	Shrubs[8]	Fuels[9]	Deer[10]	Hare[10]	Rabbit[10]	Protein[11]
			Greasewood	5.9	105.4							
			Rubber rabbitbrush	5.9	105.4							
72	1013.7	1792.0	Alkali sacaton	35.3	632.5							
% Slope: 0 -3	250.0	1316.4	Inland saltgrass	11.8	210.8							
Mikett - .85		7.7	Rush	11.8	210.8							
Salt Meadow			Sedge	11.8	210.8	0.0	316.2	237.2	0.0	7.4	8.7	5.3
			Western wheatgrass	11.8	210.8							
			Fourwing saltbush	5.9	105.4							
			Greasewood	5.9	105.4							
			Rabbitbrush	5.9	105.4							
73	2150.5	700.0	Alkali sacaton	45.5	318.2							
% Slope: 1 - 3	543.0	790.6	Galleta	18.2	127.3							
Mikim - .9		5.1	Big sagebrush	9.1	63.6	0.0	190.9	143.2	0.8	2.7	3.3	2.2
Alkali Flat			Fourwing saltbush	9.1	63.6							
			Shadscale saltbush	9.1	63.6							
			Western wheatgrass	9.1	63.6							
74	240.3	532.0	Alkali sacaton	41.7	221.7							
% Slope: 0 - 3	59.0	895.5	Greasewood	16.7	88.7							
Mikim - .85		5.6	Big sagebrush	8.3	44.3							
Alkali Flat			Fourwing saltbush	8.3	44.3	0.0	221.7	166.3	0.5	2.9	2.3	1.9
			Galleta	8.3	44.3							
			Shadscale saltbush	8.3	44.3							
			Western wheatgrass	8.3	44.3							
75	922.1	700.0	Alkali sacaton	45.5	318.2							
% Slope: 3 - 6	227.0	749.2	Galleta	18.2	127.3							
Mikim - .9		4.9	Big sagebrush	9.1	63.6	0.0	190.9	143.2	0.8	2.7	3.3	2.2
Alkali Flat			Fourwing saltbush	9.1	63.6							
			Shadscale saltbush	9.1	63.6							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Western wheatgrass	9.1	63.6							
78	82.2	1344.0	Arizona fescue	38.3	514.2							
% Slope: 0 - 6	16.0	1259.2	Mountain muhly	14.0	187.6							
Nortez - .45		6.7	Western wheatgrass	13.4	180.5							
Pine Grasslands			Parry's oatgrass	7.2	97.4							
Granath - .4			Ponderosa pine	7.2	97.4							
Mountain Loam			Big sagebrush	6.7	90.2	97.4	207.1	228.4	3.7	3.5	0.9	2.6
			Gambel's oak	3.6	48.7							
			Mountain big sagebrush	3.6	48.7							
			Mountain brome	2.2	29.2							
			Prairie junegrass	2.2	29.2							
			Antelope bitterbrush	1.4	19.5							
79	382.5	2240.0	Gambel's oak	27.3	610.9							
% Slope: 15 - 40	90.0	2340.0	Prairie junegrass	18.2	407.3							
Northrim - .8		11.3	Rocky Mountain juniper	18.2	407.3							
Brushy Loam			Cliff fendlerbush	9.1	203.6	610.9	1221.8	1375.0	50.8	0.0	0.0	15.2
			Snowberry	9.1	203.6							
			Twoneedle pinyon	9.1	203.6							
			Utah serviceberry	9.1	203.6							
80	18.6	1120.0	Gambel's oak	13.7	152.9							
% Slope: 5 - 30	0.0		Western wheatgrass	13.7	152.9							
Ormiston - .5			Muttongrass	10.7	120.0							
Beje - .35			Rocky Mountain juniper	10.7	120.0							
Pinyon-Juniper			Blue grama	8.3	92.9							
			Black sagebrush	7.8	87.1							
			Needlegrass	5.9	65.9	180.0	354.2	400.7	13.8	4.8	1.1	6.1
			Prairie junegrass	5.9	65.9							
			Twoneedle pinyon	5.4	60.0							
			Utah serviceberry	5.4	60.0							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			True mountain mahogany	4.8	54.2							
			Mountain muhly	2.9	32.9							
			Mountain brome	2.4	27.1							
			Needleandthread	2.4	27.1							
82	345.3	1008.0	Western wheatgrass	30.3	305.5							
% Slope: 1 - 12	81.0	994.1	Arizona fescue	26.9	271.1							
Ormiston - .5		4.9	Needlegrass	9.3	93.6							
Mountain Clay			Mountain muhly	9.0	90.4							
Granath - .35			Slender wheatgrass	6.2	62.4	0.0	152.8	114.6	2.9	5.1	1.3	3.0
Mountain Loam			Big sagebrush	5.9	59.2							
			Black sagebrush	3.1	31.2							
			Gambel's oak	3.1	31.2							
			Muttongrass	3.1	31.2							
			Utah serviceberry	3.1	31.2							
83	97.9	1008.0	Arizona fescue	23.7	238.4							
% Slope: 3 - 12	21.0	1041.5	Gambel's oak	10.8	108.6							
Ormiston - .45		5.1	Mountain muhly	10.2	103.0							
Mountain Clay			Muttongrass	7.6	76.2							
Nortez - .4			Needlegrass	7.6	76.2							
Pine Grasslands			Western wheatgrass	7.6	76.2							
			Parry's oatgrass	6.4	64.9							
			Ponderosa pine	6.4	64.9	64.9	230.2	221.3	5.8	2.3	0.6	2.7
			Black sagebrush	3.8	38.1							
			Slender wheatgrass	3.8	38.1							
			Utah serviceberry	3.8	38.1							
			Mountain big sagebrush	3.2	32.4							
			Mountain brome	1.9	19.5							
			Prairie junegrass	1.9	19.5							
			Antelope bitterbrush	1.3	13.0							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
84	0.7	1344.0	Western wheatgrass	41.7	560.0							
% Slope: 3 - 15	0.0		Big sagebrush	20.8	280.0							
Payter - .85			Blue grama	20.8	280.0	0.0	280.0	210.0	3.3	14.0	3.0	6.6
Foothill Valley			Bottlebrush squirreltail	10.4	140.0							
			Needleandthread	6.3	84.0							
88	481.7	3360.0	Broadleaf cattail	33.3	1120.0							
% Slope: 0 - 2	122.0	2370.2	Sedge	33.3	1120.0	0.0	0.0	0.0	0.0	13.1	9.9	7.6
Pogo - .9		13.5	Rush	20.0	672.0							
Wet Meadow			Inland saltgrass	13.3	448.0							
89 = Pramiss	1310.4	896.0	Western wheatgrass	30.8	275.7							
% Slope: 6 - 25	330.0	1153.7	Arizona fescue	15.4	137.8							
Pramiss - .85		5.8	Needlegrass	15.4	137.8							
Mountain Clay			Black sagebrush	7.7	68.9	0.0	137.9	103.4	2.5	4.8	1.2	2.7
			Gambel's oak	7.7	68.9							
			Mountain muhly	7.7	68.9							
			Prairie junegrass	7.7	68.9							
			Slender wheatgrass	7.7	68.9							
90	84.4	1008.0	Western wheatgrass	30.1	303.9							
% Slope: 3 - 9	23.0	1001.2	Arizona fescue	17.5	176.4							
Pramiss - .45		4.9	Gambel's oak	14.8	149.4							
Mountain Clay			Needlegrass	10.2	103.0							
Granath - .35			Mountain muhly	7.5	76.0	0.0	249.8	187.4	6.0	4.9	1.2	3.8
Mountain Loam			Black sagebrush	5.1	51.5							
			Pine dropseed	4.9	48.9							
			Antelope bitterbrush	2.4	24.5							
			Big sagebrush	2.4	24.5							
			Elk sedge	2.4	24.5							
			Muttongrass	2.4	24.5							

Soil[1]	Area[2]	Prod[3]	Common Name[4]	% VC[5]	Kg/ha[6]	Trees[7]	Shrubs[8]	Fuels[9]	Deer[10]	Hare[10]	Rabbit[10]	Protein[11]
94	483.0	896.0	Western wheatgrass	29.4	263.5							
% Slope: 3 - 6	122.0	930.4	Muttongrass	23.5	210.8							
Pulpit - .8		5.7	Indian ricegrass	17.6	158.1							
Loamy Foothills			Big sagebrush	11.8	105.4	0.0	158.1	118.6	1.3	7.0	1.8	3.3
			Needleandthread	5.9	52.7							
			Prairie junegrass	5.9	52.7							
			Small Douglas rabbitbrush	5.9	52.7							
95	272.7	896.0	Western wheatgrass	29.4	263.5							
% Slope: 6 -12	70.0	1003.0	Muttongrass	23.5	210.8							
Pulpit - .8		5.8	Indian ricegrass	17.6	158.1							
Loamy Foothills			Big sagebrush	11.8	105.4	0.0	158.1	118.6	1.3	7.0	1.8	3.3
			Needleandthread	5.9	52.7							
			Prairie junegrass	5.9	52.7							
			Small Douglas rabbitbrush	5.9	52.7							
97	501.2	1008.0	Western wheatgrass	28.6	288.0							
% Slope: 0 - 3	120.0	787.0	Big sagebrush	21.4	216.0							
Ramper - .9		5.0	Slender wheatgrass	21.4	216.0	0.0	288.0	216.0	2.6	8.4	2.5	4.4
Loamy Bottom			Bottlebrush squirreltail	14.3	144.0							
			Indian ricegrass	7.1	72.0							
			Rubber rabbitbrush	7.1	72.0							
98	1586.7	1008.0	Western wheatgrass	28.6	288.0							
% Slope: 0 - 3	395.0	682.0	Big sagebrush	21.4	216.0							
Ramper - .9		4.4	Slender wheatgrass	21.4	216.0	0.0	288.0	216.0	2.6	8.4	2.5	4.4
Loamy Bottom			Bottlebrush squirreltail	14.3	144.0							
			Indian ricegrass	7.1	72.0							
			Rubber rabbitbrush	7.1	72.0							
99	279.9	672.0	Alkali sacaton	35.7	240.0							
% Slope: 0 - 3	65.0	751.3	Greasewood	21.4	144.0							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
Ravola - .85		4.5	Inland saltgrass	14.3	96.0							
Alkali Bottom			Basin big sagebrush	7.1	48.0	0.0	240.0	180.0	0.6	3.2	3.1	2.2
			Fourwing saltbush	7.1	48.0							
			Galleta	7.1	48.0							
			Western wheatgrass	7.1	48.0							
100	235.0	728.0	Alkali sacaton	33.3	242.7							
% Slope: 0 - 6	65.0	735.8	Greasewood	26.7	194.1							
Recapture - .8		4.5	Galleta	13.3	97.1							
Alkali Flat			Fourwing saltbush	6.7	48.5	0.0	291.2	218.4	0.6	4.4	3.1	2.6
			Indian ricegrass	6.7	48.5							
			Shadscale saltbush	6.7	48.5							
			Wyoming big sagebrush	6.7	48.5							
101	240.5	588.0	Alkali sacaton	35.7	210.0							
% Slope: 0 - 6	64.0	719.2	Inland saltgrass	21.4	126.0							
Recapture - .8		4.0	Greasewood	14.3	84.0							
Alkali Flat			Basin big sagebrush	7.1	42.0	0.0	210.0	157.5	0.5	2.8	2.7	2.0
			Fourwing saltbush	7.1	42.0							
			Shadscale saltbush	7.1	42.0							
			Western wheatgrass	7.1	42.0							
102	2.7	1680.0	Arizona fescue	41.7	700.0							
% Slope: 1 - 3	1.0	1343.1	Western wheatgrass	25.0	420.0							
Ricot - .8		7.3	Common snowberry	8.3	140.0	0.0	420.0	315.0	11.6	6.0	1.5	6.0
Mountain Loam			Mountain big sagebrush	8.3	140.0							
			Needlegrass	8.3	140.0							
			Saskatoon serviceberry	8.3	140.0							
105	5300.4	560.0	Galleta	21.1	118.4							
% Slope: 3 - 9	1297.0	469.1	Indian ricegrass	18.1	101.4							
Rizno - .45		2.6	Utah juniper	12.0	67.4							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
Pinyon-Juniper			Blue grama	11.1	62.0							
Gapmesa - .35			Western wheatgrass	11.1	62.0	89.9	34.0	25.5	2.8	4.2	1.4	2.7
Semidesert Loam			Needleandthread	9.1	51.0							
			Big sagebrush	6.1	34.0							
			Bottlebrush squirreltail	6.1	34.0							
			Twoneedle pinyon	4.0	22.5							
			Winterfat	1.2	6.8							
109	13175.0	392.0	Indian ricegrass	16.7	65.3							
% Slope: 6 - 25	3302.0	339.2	Mountain mahogany	16.7	65.3							
Romberg - .45		2.5	Galleta	11.1	43.5							
Crosscan - .4			Twoneedle pinyon	11.1	43.5							
Pinyon-Juniper			Utah juniper	11.1	43.5	87.0	108.8	146.9	5.4	1.3	0.6	2.2
			Western wheatgrass	11.1	43.5							
			Common snowberry	5.6	21.8							
			Muttongrass	5.6	21.8							
			Pinyon ricegrass	5.6	21.8							
			Utah serviceberry	5.6	21.8							
110	26426.9	336.0	Indian ricegrass	16.7	55.9							
% Slope: 25 - 80	6626.0	286.7	Mountain mahogany	16.7	55.9							
Romberg - .35		2.2	Galleta	11.1	37.3							
Crosscan - .3			Twoneedle pinyon	11.1	37.3							
Pinyon-Juniper			Utah juniper	11.1	37.3	74.6	93.2	125.9	4.6	1.1	0.5	1.9
			Western wheatgrass	11.1	37.3							
			Common snowberry	5.6	18.6							
			Muttongrass	5.6	18.6							
			Pinyon ricegrass	5.6	18.6							
			Utah serviceberry	5.6	18.6							
112	878.1	1008.0	Western wheatgrass	35.3	355.8							
% Slope: 3 - 6	216.0	1132.4	Bottlebrush squirreltail	17.6	177.9							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
Sharps - .8		6.8	Muttongrass	17.6	177.9							
Loamy Foothills			Big sagebrush	11.8	118.6	0.0	177.9	133.4	1.4	6.5	2.0	3.2
			Black sagebrush	5.9	59.3							
			Galleta	5.9	59.3							
			Indian ricegrass	5.9	59.3							
113	593.1	1008.0	Western wheatgrass	35.3	355.8							
% Slope: 6 - 12	156.0	980.4	Bottlebrush squirreltail	17.6	177.9							
Sharps - .8		5.8	Muttongrass	17.6	177.9							
Loamy Foothills			Big sagebrush	11.8	118.6	0.0	177.9	133.4	1.4	6.5	2.0	3.2
			Black sagebrush	5.9	59.3							
			Galleta	5.9	59.3							
			Indian ricegrass	5.9	59.3							
114	341.6	672.0	Galleta	25.0	168.0							
% Slope: 6 - 12	87.0	435.4	New Mexico feathergrass	18.8	126.0							
Sharps, Dry - .8		3.1	Wyoming big sagebrush	18.8	126.0							
Semidesert Loam			Indian ricegrass	12.5	84.0	0.0	168.0	126.0	1.5	2.9	2.0	2.1
			Blue grama	6.3	42.0							
			Bottlebrush squirreltail	6.3	42.0							
			Rubber rabbitbrush	6.3	42.0							
			Western wheatgrass	6.3	42.0							
115	256.3	672.0	Galleta	25.0	167.8							
% Slope: 6 - 12	63.0	404.8	New Mexico feathergrass	18.7	125.9							
Sharps, Dry - .45		2.9	Indian ricegrass	12.5	83.9							
Gapmesa - .4			Wyoming big sagebrush	9.9	66.7							
Semidesert Loam			Big sagebrush	8.8	59.2	0.0	167.8	125.9	1.5	2.9	2.0	2.1
			Blue grama	6.2	42.0							
			Bottlebrush squirreltail	6.2	42.0							
			Western wheatgrass	6.2	42.0							
			Rubber rabbitbrush	3.3	22.2							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Rabbitbrush	2.9	19.7							
116	3765.1	1008.0	Western wheatgrass	27.0	272.5							
% Slope: 6 - 12	933.0	983.3	Muttongrass	21.4	215.2							
Sharps - .45		5.5	Big sagebrush	15.3	154.0							
Cahona - .4			Bottlebrush squirreltail	12.0	120.5							
Loamy Foothills			Galleta	6.1	61.2	0.0	246.8	185.1	2.4	6.2	2.0	3.4
			Indian ricegrass	5.9	59.2							
			Antelope bitterbrush	3.1	31.6							
			Needleandthread	3.1	31.6							
			Rubber rabbitbrush	3.1	31.6							
			Black sagebrush	2.9	29.6							
117	571.5	1008.0	Muttongrass	25.2	253.7							
% Slope: 2 - 6	144.0	966.0	Western wheatgrass	24.4	246.0							
Sharps - .45		5.8	Big sagebrush	16.1	162.4							
Pulpit - .4			Indian ricegrass	8.3	83.6							
Loamy Foothills			Needleandthread	6.3	63.4	0.0	261.3	196.0	2.6	6.6	2.0	3.6
			Small Douglas rabbitbrush	6.3	63.4							
			Antelope bitterbrush	3.5	35.5							
			Bottlebrush squirreltail	3.5	35.5							
			Galleta	3.5	35.5							
			Prairie junegrass	2.8	27.9							
118	426.4	1008.0	Muttongrass	25.2	253.7							
% Slope: 6 - 12	106.0	967.6	Western wheatgrass	24.4	246.0							
Sharps - .45		5.6	Big sagebrush	16.1	162.4							
Pulpit - .4			Indian ricegrass	8.3	83.6							
Loamy Foothills			Needleandthread	6.3	63.4	0.0	261.3	196.0	2.6	6.6	2.0	3.6
			Small Douglas rabbitbrush	6.3	63.4							
			Antelope bitterbrush	3.5	35.5							
			Bottlebrush squirreltail	3.5	35.5							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Galleta	3.5	35.5							
			Prairie junegrass	2.8	27.9							
119	57.1	448.0	Gambel's oak	16.7	74.6							
% Slope: 6 - 12	14.0	804.1	Arizona fescue	11.1	49.7							
Sheek - .5		4.6	Mountain muhly	11.1	49.7							
Archuleta - .35			Prairie junegrass	11.1	49.7							
Ponderosa Pine			Western wheatgrass	11.1	49.7							
			Antelope bitterbrush	5.6	24.9	49.7	174.0	167.8	6.6	0.9	0.3	2.4
			Mountain brome	5.6	24.9							
			Mountain mahogany	5.6	24.9							
			Ponderosa pine	5.6	24.9							
			Rocky Mountain juniper	5.6	24.9							
			Serviceberry	5.6	24.9							
			Snowberry	5.6	24.9							
120	1534.2	448.0	Gambel's oak	15.4	69.0							
% Slope: 25 - 80	382.0	353.2	Arizona fescue	10.3	46.0							
Sheek - .35		2.5	Douglas fir	10.3	46.0							
Archuleta - .3			Mountain muhly	10.3	46.0							
Ponderosa Pine			Ponderosa pine	10.3	46.0							
			Prairie junegrass	10.3	46.0	92.0	161.1	189.8	5.3	0.7	0.2	1.9
			Western wheatgrass	7.4	33.3							
			Antelope bitterbrush	5.1	23.0							
			Mountain brome	5.1	23.0							
			Mountain mahogany	5.1	23.0							
			Serviceberry	5.1	23.0							
			Snowberry	5.1	23.0							
121	711.3	616.0	Douglas fir	22.7	139.8							
% Slope: 25 - 80	171.0	344.6	Gambel's oak	17.0	104.9							
Sheek - .4		2.4	Arizona fescue	9.1	56.0							

Soil[1]	Area[2]	Prod[3]	Common Name[4]	% VC[5]	Kg/ha[6]	Trees[7]	Shrubs[8]	Fuels[9]	Deer[10]	Hare[10]	Rabbit[10]	Protein[11]
Archuleta - .25			Antelope bitterbrush	5.7	35.0							
Douglas Fir			Mountain brome	5.7	35.0							
			Mountain mahogany	5.7	35.0							
			Mountain muhly	5.7	35.0	174.8	230.8	304.2	7.6	0.8	0.3	2.7
			Ponderosa pine	5.7	35.0							
			Prairie junegrass	5.7	35.0							
			Serviceberry	5.7	35.0							
			Western wheatgrass	5.7	35.0							
			Snowberry	3.4	21.0							
			Parry's oatgrass	2.3	13.9							
122	184.8	616.0	Alkali sacaton	43.8	269.5							
% Slope: 1 - 6	46.0	293.3	Fourwing saltbush	18.8	115.5							
Sheppard - .9		2.1	Indian ricegrass	12.5	77.0							
Desert Sand			Galleta	6.3	38.5	0.0	115.5	86.6	0.0	3.6	2.7	2.1
			Mesa dropseed	6.3	38.5							
			Sand dropseed	6.3	38.5							
			Western wheatgrass	6.3	38.5							
123	500.1	336.0	Alkali sacaton	38.5	129.2							
% Slope: 0 - 3	129.0	394.6	Greasewood	23.1	77.5							
Sideshow - .9		2.9	Inland saltgrass	15.4	51.7							
Alkali Bottom			Basin big sagebrush	7.7	25.8	0.0	129.2	96.9	0.3	1.7	1.5	1.1
			Fourwing saltbush	7.7	25.8							
			Western wheatgrass	7.7	25.8							
124	1426.1	1008.0	Western wheatgrass	66.7	672.0							
% Slope: 3 - 6	360.0	1177.4	Big sagebrush	26.7	268.8	0.0	268.8	201.6	3.2	10.8	2.7	5.4
Sideshow - .9		7.0	Indian ricegrass	6.7	67.2							
Clayey Foothills												
125	921.5	1008.0	Western wheatgrass	66.7	672.0							

Soil[1]	Area[2]	Prod[3]	Common Name[4]	% VC[5]	Kg/ha[6]	Trees[7]	Shrubs[8]	Fuels[9]	Deer[10]	Hare[10]	Rabbit[10]	Protein[11]
% Slope: 6 - 12	230.0	1172.4	Big sagebrush	26.7	268.8	0.0	268.8	201.6	3.2	10.8	2.7	5.4
Sideshow - .9		6.9	Indian ricegrass	6.7	67.2							
Clayey Foothills												
126	487.6	1008.0	Western wheatgrass	40.2	405.4							
% Slope: 3 - 25	117.0	815.5	Big sagebrush	21.5	217.0							
Sideshow - .45		4.6	Indian ricegrass	10.9	110.4							
Clayey Foothills			Twoneedle pinyon	7.4	74.8							
Zigzag - .4			Muttongrass	4.9	49.9							
Pinyon-Juniper			Antelope bitterbrush	2.5	24.9							
			Bottlebrush squirreltail	2.5	24.9	99.7	291.8	293.7	5.7	8.3	2.0	5.1
			Needleandthread	2.5	24.9							
			Serviceberry	2.5	24.9							
			True mountain mahogany	2.5	24.9							
			Utah juniper	2.5	24.9							
127	2.5	2240.0	Alkali sacaton	47.1	1054.1							
% Slope: 3 - 9	0.0		Inland saltgrass	11.8	263.5							
Sideslide - .9			Sedge	11.8	263.5							
Salt Meadow			Western wheatgrass	11.8	263.5	0.0	263.5	197.6	0.0	9.3	10.8	6.6
			Fourwing saltbush	5.9	131.8							
			Greasewood	5.9	131.8							
			Rush	5.9	131.8							
129	121.7	336.0	Galleta	28.6	96.0							
% Slope: 12 - 65	26.0	618.6	Shadscale saltbush	28.6	96.0							
Torriorthents - .9		3.4	Alkali sacaton	14.3	48.0	0.0	96.0	72.0	0.0	1.4	1.2	0.9
Saltdesert Breaks			Salina wildrye	14.3	48.0							
			Bottlebrush squirreltail	7.1	24.0							
			Indian ricegrass	7.1	24.0							
130	308.0	336.0	Galleta	28.6	96.0							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
% Slope: 25 - 100	77.0	499.9	Shadscale saltbush	28.6	96.0							
Torriorthents - .5		2.5	Alkali sacaton	14.3	48.0	0.0	96.0	72.0	0.0	1.4	1.2	0.9
Clayey Saltdesert			Salina wildrye	14.3	48.0							
			Bottlebrush squirreltail	7.1	24.0							
			Indian ricegrass	7.1	24.0							
131	34.0	2464.0	Gambel's oak	18.5	457.0							
% Slope: 12 -25	9.0	2483.9	Serviceberry	18.5	457.0							
Tragmon - .5		12.0	Prairie junegrass	12.0	296.0							
Sheek - .35			Snowberry	9.3	228.5							
Brushy Loam			Western wheatgrass	9.3	228.5							
			Muttongrass	6.5	161.0	0.0	1438.5	1078.9	46.2	4.7	1.4	15.9
			Sagebrush	6.5	161.0							
			Arizona fescue	5.5	135.0							
			Mountain muhly	5.5	135.0							
			Antelope bitterbrush	2.7	67.5							
			Mountain brome	2.7	67.5							
			Mountain mahogany	2.7	67.5							
133	6610.8	392.0	Galleta	21.1	82.5							
% Slope: 12 - 80	1666.0	484.5	Salina wildrye	21.1	82.5							
Typic Torriorthents - .6		2.5	Shadscale saltbush	21.1	82.5							
Saltdesert Breaks			Alkali sacaton	10.5	41.3							
			Big sagebrush	5.3	20.6	20.6	123.8	108.3	1.0	1.6	1.1	1.2
			Bottlebrush squirreltail	5.3	20.6							
			Fourwing saltbush	5.3	20.6							
			Indian ricegrass	5.3	20.6							
			Utah juniper	5.3	20.6							
134	457.3	2912.0	Sedge	46.4	1351.9							
% Slope: 0 - 2	116.0	2376.0	Mountain brome	13.7	398.9							

Soil[1]	Area[2]	Prod[3]	Common Name[4]	% VC[5]	Kg/ha[6]	Trees[7]	Shrubs[8]	Fuels[9]	Deer[10]	Hare[10]	Rabbit[10]	Protein[11]
Umbarg - .35		12.3	Baltic rush	11.2	326.4							
Winner - .3			Western wheatgrass	11.2	326.4	0.0	0.0	0.0	0.0	29.4	6.1	11.7
Tesajo - .2			Foxtail barley	7.5	217.6							
Wet Meadow			Tufted hairgrass	6.8	199.4							
			Rocky Mountain iris	2.9	85.5							
135	242.0	896.0	Big sagebrush	20.0	179.2							
% Slope: 0 - 3	71.0	737.6	Galleta	20.0	179.2							
Ustic Torrifluvents - .8		4.7	Western wheatgrass	20.0	179.2							
Loamy Bottom			Alkali sacaton	13.3	119.5	0.0	298.7	224.0	2.1	5.6	3.5	3.6
			Indian ricegrass	13.3	119.5							
			Greasewood	6.7	59.7							
			Rubber rabbitbrush	6.7	59.7							
136	621.5	784.0	Alkali sacaton	41.7	326.7							
% Slope: 1 - 60	165.0	859.2	Greasewood	16.7	130.7							
Ustic Torriorthents - .45		5.5	Big sagebrush	8.3	65.3							
Alkali Bottom			Fourwing saltbush	8.3	65.3	0.0	326.7	245.0	0.8	4.3	3.4	2.8
			Galleta	8.3	65.3							
			Saltbush	8.3	65.3							
			Western wheatgrass	8.3	65.3							
138	1470.5	504.0	Shadscale saltbush	37.4	188.6							
% Slope: 3 - 12	370.0	710.4	Galleta	25.0	125.7							
Uzacol - .35		4.3	Alkali sacaton	12.5	62.9	0.0	125.7	94.3	0.0	2.6	1.8	1.4
Zwicker - .3			Salina wildrye	12.5	62.9							
Claysprings - .2			Bottlebrush squirreltail	6.2	31.4							
Clayey Saltdesert			Indian ricegrass	6.2	31.4							
140	739.7	896.0	Gambel's oak	17.6	158.1							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
% Slope: 6 - 25	163.0	834.1	Western wheatgrass	17.6	158.1							
Wauquie - .85		5.2	Muttongrass	11.8	105.4							
Pinyon-Juniper			True mountain mahogany	11.8	105.4							
			Twoneedle pinyon	11.8	105.4	210.8	368.9	276.7	14.7	2.9	0.9	5.7
			Utah juniper	11.8	105.4							
			Antelope bitterbrush	5.9	52.7							
			Big sagebrush	5.9	52.7							
			Indian ricegrass	5.9	52.7							
141	2416.4	1120.0	Twoneedle pinyon	17.8	198.8							
% Slope: 6 - 25	577.0	923.7	Western wheatgrass	11.8	132.5							
Wauquie - .45		5.0	Indian ricegrass	11.1	124.8							
Dolcan - .4			Gambel's oak	9.9	111.1							
Pinyon-Juniper			Muttongrass	9.2	103.3							
			Mountain mahogany	7.8	87.7							
			True mountain mahogany	6.6	74.1	265.1	405.4	502.9	15.3	3.3	1.3	6.1
			Utah juniper	5.9	66.3							
			Galleta	5.2	58.5							
			Antelope bitterbrush	3.3	37.0							
			Big sagebrush	3.3	37.0							
			Common snowberry	2.6	29.2							
			Pinyon ricegrass	2.6	29.2							
			Utah serviceberry	2.6	29.2							
142	1786.0	1008.0	Twoneedle pinyon	17.8	179.8							
% Slope: 25 - 80	451.0	601.1	Western wheatgrass	11.9	119.9							
Wauquie - .4		3.0	Gambel's oak	10.7	107.9							
Dolcan - .3			Indian ricegrass	10.7	107.9							
Pinyon-Juniper			Muttongrass	9.5	95.9							
			True mountain mahogany	7.1	71.9							
			Mountain mahogany	7.1	71.9	239.8	371.7	458.6	13.9	2.9	1.1	5.5
			Utah juniper	5.9	59.9							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Galleta	4.8	47.9							
			Antelope bitterbrush	3.6	36.0							
			Big sagebrush	3.6	36.0							
			Common snowberry	2.4	24.0							
			Pinyon ricegrass	2.4	24.0							
			Utah serviceberry	2.4	24.0							
143	3671.6	1344.0	Muttongrass	33.3	448.0							
% Slope: 1 - 3	927.0	1278.2	Western wheatgrass	33.3	448.0							
Wetherill - .9		7.5	Big sagebrush	16.7	224.0	0.0	224.0	168.0	2.7	9.6	2.0	4.6
Loamy Foothills			Bottlebrush squirreltail	5.6	74.7							
			Indian ricegrass	5.6	74.7							
			Needleandthread	5.6	74.7							
144	22579.8	1344.0	Muttongrass	33.3	448.0							
% Slope: 3 - 6	5643.0	1239.6	Western wheatgrass	33.3	448.0							
Wetherill - .85		7.2	Big sagebrush	16.7	224.0	0.0	224.0	168.0	2.7	9.6	2.0	4.6
Loamy Foothills			Bottlebrush squirreltail	5.6	74.7							
			Indian ricegrass	5.6	74.7							
			Needleandthread	5.6	74.7							
145	4128.8	1232.0	Muttongrass	33.3	410.7							
% Slope: 6 - 12	1038.0	1235.4	Western wheatgrass	33.3	410.7							
Wetherill - .8		7.2	Big sagebrush	16.7	205.3							
Loamy Foothills			Bottlebrush squirreltail	5.6	68.4	0.0	205.3	154.0	2.4	8.8	1.8	4.2
			Indian ricegrass	5.6	68.4							
			Needleandthread	5.6	68.4							
146	68.9	784.0	Galleta	30.8	241.2							
% Slope: 1 - 6	17.0	1078.7	Big sagebrush	23.1	180.9							
Yarts - .85		6.5	New Mexico feathergrass	23.1	180.9	0.0	180.9	135.7	2.1	3.5	2.3	2.6
Semidesert Loam			Blue grama	7.7	60.3							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Indian ricegrass	7.7	60.3							
			Western wheatgrass	7.7	60.3							
147	168.1	784.0	Galleta	30.8	241.2							
% Slope: 1 - 6	42.0	699.3	New Mexico feathergrass	23.1	180.9							
Yarts - .85		4.5	Wyoming big sagebrush	23.1	180.9							
Semidesert Loam			Blue grama	7.7	60.3	0.0	180.9	135.7	2.1	3.5	2.3	2.6
			Indian ricegrass	7.7	60.3							
			Western wheatgrass	7.7	60.3							
149	1547.7	448.0	Big sagebrush	16.7	74.7							
% Slope: 3 - 25	390.0	511.4	Indian ricegrass	16.7	74.7							
Zigzag - .8		3.3	Twoneedle pinyon	16.7	74.7							
Pinyon-Juniper			Muttongrass	11.1	49.8							
			Antelope bitterbrush	5.6	24.9							
			Bottlebrush squirreltail	5.6	24.9	99.6	149.3	186.7	4.0	2.3	0.5	2.1
			Needleandthread	5.6	24.9							
			Serviceberry	5.6	24.9							
			True mountain mahogany	5.6	24.9							
			Utah juniper	5.6	24.9							
			Western wheatgrass	5.6	24.9							
150	656.0	448.0	Western wheatgrass	25.5	114.3							
% Slope: 25 - 65	160.0	759.7	Big sagebrush	17.9	80.3							
Zigzag - .6		4.3	Indian ricegrass	12.4	55.4							
Pinyon-Juniper			Twoneedle pinyon	10.5	47.1							
Sideshow - .3			Muttongrass	7.0	31.4							
Clayey Foothills			Bottlebrush squirreltail	5.4	24.0							
			Antelope bitterbrush	3.5	15.7	62.8	135.7	148.9	2.9	3.0	0.7	2.1
			Needleandthread	3.5	15.7							
			Serviceberry	3.5	15.7							
			True mountain mahogany	3.5	15.7							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Utah juniper	3.5	15.7							
			Prairie junegrass	1.9	8.3							
			Rubber rabbitbrush	1.9	8.3							
151	274.7	336.0	Galleta	20.0	67.2							
% Slope: 3 - 12	71.0	561.6	Indian ricegrass	20.0	67.2							
Zyme - .85		3.1	Western wheatgrass	20.0	67.2							
Shale Knobs			Black sagebrush	13.3	44.8	0.0	89.6	67.2	0.3	3.1	1.0	1.4
			Big sagebrush	6.7	22.4							
			Bottlebrush squirreltail	6.7	22.4							
			Fourwing saltbush	6.7	22.4							
			Needleandthread	6.7	22.4							
152	424.1	336.0	Galleta	20.0	67.2							
% Slope 12 - 65	99.0	571.6	Indian ricegrass	20.0	67.2							
Zyme - .8		3.2	Western wheatgrass	20.0	67.2							
Shale Knobs			Black sagebrush	13.3	44.8							
			Big sagebrush	6.7	22.4	0.0	89.6	67.2	0.3	3.1	1.0	1.4
			Bottlebrush squirreltail	6.7	22.4							
			Fourwing saltbush	6.7	22.4							
			Needleandthread	6.7	22.4							
153	14.6	392.0	Galleta	27.2	106.4							
% Slope: 1 - 50	3.0	410.1	Alkali sacaton	22.2	87.2							
Decorock - .55		2.4	Shadscale saltbush	20.6	80.9							
Saltdesert Breaks			Indian ricegrass	10.3	40.5							
Salamander - .3			Bottlebrush squirreltail	7.6	29.8							
Alkali Flat			Winterfat	6.5	25.5	0.0	125.5	94.1	0.0	1.9	1.6	1.1
			Fourwing saltbush	2.7	10.6							
			Snakeweed	1.6	6.4							
			Mormon tea	0.5	2.1							
			Scarlet globemallow	0.5	2.1							

Soil[1]	Area[2]	Prod[3]	Common Name[4]	% VC[5]	Kg/ha[6]	Trees[7]	Shrubs[8]	Fuels[9]	Deer[10]	Hare[10]	Rabbit[10]	Protein[11]
154	7.5	560.0	Shadscale saltbush	26.8	150.0							
% Slope: 3 - 6	2.0	259.9	Indian ricegrass	17.9	100.0							
Mariano - .75		2.2	Sand dropseed	17.9	100.0							
Sandy Saltdesert			Bottlebrush squirreltail	8.9	50.0	0.0	230.0	172.5	0.0	5.0	1.6	2.2
			Fourwing saltbush	8.9	50.0							
			Galleta	8.9	50.0							
			Mormon tea	5.4	30.0							
			Scarlet globemallow	5.4	30.0							
155	744.1	392.0	Utah juniper	16.0	62.7							
% Slope: 15 - 75	184.0	278.1	Indian ricegrass	15.5	60.8							
Zyme - .45		2.2	Salina wildrye	12.6	49.4							
Katzine, dry - .35			Twoneedle pinyon	12.6	49.4							
Steep Shallow Clay Loam			Muttongrass	9.7	38.0							
Pinyon-Juniper			Common snowberry	6.3	24.7	112.0	82.0	145.6	4.9	1.0	0.4	1.9
			Galleta	6.3	24.7							
			Mountain mahogany	6.3	24.7							
			Utah serviceberry	6.3	24.7							
			Western wheatgrass	6.3	24.7							
			Cliffrose	2.0	8.0							
156	396.4	896.0	Muttongrass	18.1	161.9							
% Slope: 5 - 45	104.0	914.5	Twoneedle pinyon	18.1	161.9							
Cahona - .35		5.3	Indian ricegrass	12.0	108.0							
Zigzag - .35			Mountain mahogany	12.0	108.0							
Southwestern Mountain			Wyoming big sagebrush	12.0	108.0							
Pinyon-Juniper			Bottlebrush squirreltail	6.0	54.0	183.5	367.0	412.9	10.7	2.6	0.6	4.3
			Gambel's oak	6.0	54.0							
			Antelope bitterbrush	3.6	32.4							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Mountain snowberry	3.6	32.4							
			Utah serviceberry	3.6	32.4							
			Utah juniper	2.4	21.6							
			Yucca	2.4	21.6							
157	229.0	448.0	New Mexico feathergrass	24.4	109.3							
% Slope: 3 - 9	57.0	271.7	Indian ricegrass	18.3	82.0							
Awitava - .85		2.2	Alkali sacaton	12.2	54.6							
Semidesert Juniper Loam			Galleta	12.2	54.6							
			Utah juniper	12.2	54.6	54.6	65.6	90.2	2.3	1.8	1.1	1.6
			Sand dropseed	6.1	27.3							
			Shadscale saltbush	6.1	27.3							
			Wyoming big sagebrush	6.1	27.3							
			Mormon tea	2.4	10.9							
158	580.4	672.0	Muttongrass	21.9	147.4							
% Slope: 3 - 6	142.0	749.1	Utah juniper	20.0	134.3							
Wetherill - .6		5.0	Indian ricegrass	13.3	89.5							
Loamy Mesa Top			Twoneedle pinyon	13.3	89.5	223.8	121.1	258.7	8.3	2.1	0.4	3.3
Pinyon-Juniper			True mountain mahogany	11.4	76.3							
Kucu - .25			Antelope bitterbrush	6.7	44.8							
Southwestern Mountain			Bottlebrush squirreltail	6.7	44.8							
Pinyon-Juniper			Needleandthread	6.7	44.8							
159	350.1	896.0	Muttongrass	20.9	186.9							
% Slope: 3 - 12	86.0	788.7	Twoneedle pinyon	20.9	186.9							
Wetherill - .45		5.3	Utah juniper	11.0	98.6							
Wetoe - .3			Indian ricegrass	9.9	88.3							
Southwestern Mountain			Wyoming big sagebrush	9.8	88.2							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
Pinyon-Juniper			Bottlebrush squirreltail	7.0	62.3	285.5	273.0	418.9	10.3	1.7	0.6	3.8
			Gambel's oak	7.0	62.3							
			Antelope bitterbrush	5.3	47.8							
			Mountain snowberry	4.2	37.4							
			Utah serviceberry	4.2	37.4							
160	792.4	896.0	Utah juniper	22.1	197.6							
% Slope: 15 - 45	189.0	890.9	Indian ricegrass	14.7	131.8							
Katzine - .8		5.2	Muttongrass	14.7	131.8							
Southwestern Mountain			Twoneedle pinyon	14.7	131.8							
Pinyon-Juniper			Bottlebrush squirreltail	7.4	65.9	329.4	171.3	375.5	8.5	2.1	1.0	3.6
			Cliffrose	7.4	65.9							
			Galleta	7.4	65.9							
			Wyoming big sagebrush	7.4	65.9							
			Antelope bitterbrush	4.4	39.5							
161	1395.1	896.0	Muttongrass	21.2	189.9							
% Slope: 35 - 90	346.0	515.6	Twoneedle pinyon	21.2	189.9							
Wetoe - .45		2.4	Indian ricegrass	14.1	126.6							
Nees - .2			Wyoming big sagebrush	10.9	97.4							
Southwestern Mountain			Bottlebrush squirreltail	7.1	63.3							
Pinyon-Juniper			Gambel's oak	7.1	63.3	215.2	283.0	373.7	7.8	2.6	0.7	3.5
			Antelope bitterbrush	5.2	46.3							
			Mountain snowberry	4.2	38.0							
			Utah serviceberry	4.2	38.0							
			Utah juniper	2.8	25.3							
			Yucca	1.9	17.0							
162	356.2	2240.0	Gambel's oak	16.4	367.3							
% Slope: 6 - 35	91.0	2364.9	Muttongrass	13.0	292.3							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
Towaoc - .45		11.6	Slender wheatgrass	13.0	292.3							
Kwiavu - .4			Utah serviceberry	13.0	292.3							
Brushy Loam			Arizona fescue	6.5	146.1							
			Elk sedge	6.5	146.1							
			Letterman needlegrass	6.5	146.1	0.0	1010.2	757.7	29.7	7.5	1.0	11.7
			Mountain snowberry	6.5	146.1							
			Nodding brome	6.5	146.1							
			Mountain big sagebrush	3.9	87.7							
			Arrowleaf balsamroot	2.6	58.5							
			Common chokecherry	2.6	58.5							
			Woods' rose	2.6	58.5							
163	245.7	2240.0	Gambel's oak	13.2	294.7							
% Slope: 35 - 75	64.0	2263.4	Muttongrass	13.2	294.7							
Towaoc - .8		9.4	Slender wheatgrass	13.2	294.7							
Brushy Loam			Utah serviceberry	13.2	294.7							
			Arizona fescue	6.6	147.4							
			Elk sedge	6.6	147.4							
			Letterman needlegrass	6.6	147.4	0.0	943.2	707.4	27.3	7.6	1.0	11.0
			Mountain snowberry	6.6	147.4							
			Nodding brome	6.6	147.4							
			Mountain big sagebrush	3.9	88.4							
			Arrowleaf balsamroot	2.6	58.9							
			Aspen peavine	2.6	58.9							
			Common chokecherry	2.6	58.9							
			Woods' rose	2.6	58.9							
164	344.0	2240.0	Gambel's oak	24.7	553.1							
% Slope: 3 - 25	84.0	2253.9	Utah juniper	18.5	414.8							
Herm - .9		11.8	Twoneedle pinyon	12.3	276.5							
Brushy Loam			Utah serviceberry	12.3	276.5							
			Common chokecherry	6.2	138.3							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Common snowberry	6.2	138.3	691.4	1272.1	1473.0	55.2	0.0	0.0	16.5
			Letterman needlegrass	6.2	138.3							
			Muttongrass	6.2	138.3							
			Kinnikinnick	3.7	83.0							
			Rocky Mountain maple	3.7	83.0							
165	1423.0	952.0	Gambel's oak	24.6	234.1							
% Slope: 25 - 90	352.0	518.0	Douglas fir	16.4	156.1							
Littlewater - .35		2.4	Utah serviceberry	16.4	156.1							
			Common chokecherry	8.2	78.0							
			Common snowberry	8.2	78.0	156.1	639.7	596.8	20.0	0.9	0.2	6.4
			Letterman needlegrass	8.2	78.0							
			Mountain brome	8.2	78.0							
			Rocky Mountain maple	4.9	46.8							
			Kinnikinnick	4.9	46.6							
166	68.7	896.0	Muttongrass	18.2	162.9							
% Slope: 1 - 6	15.0	440.2	Utah juniper	18.2	162.9							
Pagayvay - .9		2.5	Wyoming big sagebrush	18.2	162.9							
Southwestern Mountain			Cliffrose	9.1	81.5							
Pinyon-Juniper			Galleta	9.1	81.5	162.9	244.4	305.5	7.7	4.1	1.0	4.0
			Indian ricegrass	9.1	81.5							
			Needleandthread	9.1	81.5							
			Bottlebrush squirreltail	5.5	48.9							
			Skyrocket gilia	3.6	32.6							
167	30.8	3360.0	Tufted hairgrass	42.1	1414.7							
% Slope: 0 - 3	5.0	2831.5	Sedge	26.3	884.2							
Hesperus - .85		14.7	Arizona fescue	5.3	176.8							
Mountain Meadow			Bluegrass	5.3	176.8	0.0	176.8	132.6	0.0	10.4	2.6	4.3
			Cinquefoil	5.3	176.8							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Mountain muhly	5.3	176.8							
			Rocky Mountain iris	5.3	176.8							
			Shrubby cinquefoil	5.3	176.8							
168	29.0	1456.0	Arizona fescue	27.8	404.4							
% Slope: 0 - 5	6.0	1287.4	Western wheatgrass	16.7	242.7							
Shawa - .8		6.8	Indian ricegrass	11.1	161.8							
Loamy Park			Mountain brome	11.1	161.8							
			Needleandthread	11.1	161.8	0.0	242.7	182.0	6.7	11.0	1.8	6.3
			Basin big sagebrush	5.6	80.9							
			Common snowberry	5.6	80.9							
			Gambel's oak	5.6	80.9							
			Muttongrass	5.6	80.9							
169	31.2	2016.0	Arizona fescue	23.5	474.4							
% Slope: 1 - 12	9.0	1880.2	Mountain muhly	23.5	474.4							
Fughes - .85		9.7	Parry's oatgrass	11.8	237.2							
Loamy Park			Tufted hairgrass	11.8	237.2							
			Western wheatgrass	11.8	237.2	0.0	0.0	0.0	0.0	5.6	1.4	2.3
			Needlegrass	5.9	118.6							
			Sedge	5.9	118.6							
			Slender wheatgrass	5.9	118.6							
170	19.0	1680.0	Western wheatgrass	31.3	525.0							
% Slope: 0 - 5	6.0	1279.5	Basin big sagebrush	18.8	315.0							
Umbarg - .8		6.8	Needleandthread	18.8	315.0	0.0	315.0	236.3	3.7	18.4	2.8	8.1
Deep Loam			Indian ricegrass	12.5	210.0							
			Muttongrass	12.5	210.0							
			Prairie junegrass	6.3	105.0							
171	45.5	1344.0	Western wheatgrass	22.2	298.7							
% Slope: 3 - 15	11.0	1174.4	Basin big sagebrush	11.1	149.3							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
Payter - .85		6.3	Blue grama	11.1	149.3							
Foothill Valley			Skunkbush sumac	11.1	149.3							
			Blue grama	5.6	74.7							
			Bottlebrush squirreltail	5.6	74.7	149.3	448.0	448.0	9.8	9.0	1.8	6.5
			Gambel's oak	5.6	74.7							
			Needleandthread	5.6	74.7							
			Prairie junegrass	5.6	74.7							
			Twoneedle pinyon	5.6	74.7							
			Utah juniper	5.6	74.7							
			Utah serviceberry	5.6	74.7							
172	135.0	2240.0	Western wheatgrass	23.8	532.3							
% Slope: 0 - 5	35.0	2138.9	Willow	16.6	371.3							
Fluvaquents - .55		10.6	Alkali sacaton	10.8	241.5							
Haplustolls - .3			Inland saltgrass	7.2	161.0							
River Bottom			Needleandthread	7.2	161.0							
			Rush	7.2	161.0	80.5	371.3	338.9	6.6	13.7	6.9	8.8
			Sedge	7.2	161.0							
			Mountain brome	4.7	105.1							
			Muttongrass	4.7	105.1							
			Prairie junegrass	4.7	105.1							
			Narrowleaf cottonwood	3.6	80.5							
			Indian ricegrass	2.3	52.6							
173	35.0	1064.0	Gambel's oak	15.0	159.4							
% Slope: 3 - 30	9.0	1014.4	Twoneedle pinyon	12.8	136.2							
Sheek - .45		5.0	Prairie junegrass	12.2	129.5							
Ormiston - .35			Muttongrass	10.0	106.3							
Pinyon-Juniper			True mountain mahogany	8.4	89.7							
			Utah juniper	7.8	83.0							
			Western wheatgrass	6.6	69.7	219.2	385.3	453.4	13.7	2.6	0.7	5.2
			Black sagebrush	5.0	53.1							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Indian ricegrass	5.0	53.1							
			Utah serviceberry	5.0	53.1							
			Blue grama	4.4	46.5							
			Bottlebrush squirreltail	2.8	29.9							
			Squaw apple	2.8	29.9							
			Mountain muhly	2.2	23.2							
174	8.4	1344.0	Gambel's oak	18.0	242.5							
% Slope: 0 - 15	2.0	1182.3	Western wheatgrass	12.1	162.7							
Dolores - .5		5.3	Mountain muhly	10.0	135.1							
Fivepine - .35			Ponderosa pine	10.0	135.1							
			Prairie junegrass	10.0	135.1							
			Arizona fescue	8.9	119.7							
			Bluegrass	5.0	67.5							
			Common snowberry	5.0	67.5	135.1	393.5	396.5	13.4	2.7	0.6	5.1
			Utah serviceberry	5.0	67.5							
			Bottlebrush squirreltail	4.1	55.2							
			Pine dropseed	4.1	55.2							
			Mountain brome	3.0	39.9							
			Nodding brome	2.1	27.6							
			Elk sedge	1.2	16.0							
			Woods' rose	1.2	16.0							
175	1596.3	1008.0	Gambel's oak	17.0	171.1							
% Slope: 1 - 15	394.0	853.1	Arizona fescue	13.9	140.2							
Jemco - .4		4.1	Ponderosa pine	10.6	106.6							
Detra - .3			Common snowberry	9.5	95.4							
Beje - .2			Western wheatgrass	9.5	95.4							
			Mountain brome	8.6	86.9							
			Oregongrape	5.3	53.3							
			Prairie junegrass	5.3	53.3	173.8	350.8	393.4	11.0	3.0	0.9	4.6
			Quaking aspen	4.4	44.8							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Kentucky bluegrass	3.1	30.9							
			Needleandthread	3.1	30.9							
			Bottlebrush squirreltail	2.2	22.4							
			Mountain muhly	2.2	22.4							
			Rocky Mountain juniper	2.2	22.4							
			Saskatoon serviceberry	2.0	19.7							
			Black sagebrush	1.1	11.2							
176	292.9	1680.0	Arizona fescue	19.8	332.6							
% Slope: 0 -15	75.0	1231.9	Gambel's oak	11.7	197.3							
Moento - .35		6.5	Western wheatgrass	11.1	186.4							
Detra - .3			Common snowberry	10.6	178.7							
Loamy Park			Mountain brome	10.3	172.5							
Jemco - .2			Needleandthread	8.2	137.7							
Brushy Loam			Prairie junegrass	8.2	137.7							
			Bottlebrush squirreltail	3.5	58.8	0.0	434.7	326.0	14.2	7.8	1.2	7.2
			Kentucky bluegrass	3.3	55.8							
			Mule-ears	3.3	55.8							
			Mountain muhly	3.3	54.9							
			Sedge	2.2	36.3							
			Shrubby cinquefoil	2.2	36.3							
			Saskatoon serviceberry	1.3	22.4							
			Thurber's fescue	0.8	13.5							
177	4.2	1456.0	Arizona fescue	15.3	222.6							
% Slope: 0 - 15	0.0		Gambel's oak	15.3	222.6							
Herm - .5			Western wheatgrass	12.3	179.0							
Pagoda - .35			Prairie junegrass	10.2	148.4							
			Mountain muhly	8.1	117.9							
			Ponderosa pine	6.0	87.4							
			Common snowberry	5.1	74.2							
			Saskatoon serviceberry	5.1	74.2	87.4	414.7	376.6	14.8	3.6	0.7	5.8

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Pine dropseed	4.2	61.1							
			Mule-ears	3.1	44.5							
			Elk sedge	3.0	43.7							
			Mountain brome	3.0	43.7							
			True mountain mahogany	3.0	43.7							
			Bluegrass	2.1	30.5							
			Bottlebrush squirreltail	2.1	30.5							
			Nodding brome	2.1	30.5							
178	55.2	1008.0	Gambel's oak	20.0	201.6							
% Slope: 1 - 15	11.0	821.6	Arizona fescue	15.0	151.2							
Burnson, dry - .8		3.9	Mountain brome	15.0	151.2							
			Common snowberry	10.0	100.8							
			Antelope bitterbrush	5.0	50.4							
			Big sagebrush	5.0	50.4	151.2	403.2	415.8	14.1	2.8	0.8	5.4
			Bluegrass	5.0	50.4							
			Needlegrass	5.0	50.4							
			Ponderosa pine	5.0	50.4							
			Rocky Mountain juniper	5.0	50.4							
			Twoneedle pinyon	5.0	50.4							
			Western wheatgrass	5.0	50.4							
179	18.4	1008.0	Common snowberry	19.5	196.4							
% Slope: 0 - 15	4.0	821.6	Gambel's oak	16.4	165.2							
Jemco - .6		3.9	Arizona fescue	15.8	159.0							
Moento - .25			Mountain brome	9.0	90.4							
			Western wheatgrass	6.8	68.6							
			Ponderosa pine	5.3	53.0							
			Quaking aspen	5.3	53.0							
			Bottlebrush squirreltail	3.7	37.4	106.0	430.2	402.2	13.4	2.6	0.7	5.1
			Mountain muhly	3.7	37.4							
			Oregongrape	3.7	37.4							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Prairie junegrass	3.1	31.2							
			Elk sedge	1.5	15.6							
			Kentucky bluegrass	1.5	15.6							
			Needleandthread	1.5	15.6							
			Saskatoon serviceberry	1.5	15.6							
			Woods' rose	1.5	15.6							
180	137.3	1344.0	Muttongrass	33.3	448.0							
% Slope: 3 - 6	36.0	1275.3	Western wheatgrass	33.3	448.0							
Wetherill - .85		7.3	Big sagebrush	16.7	224.0	0.0	224.0	168.0	2.7	9.6	2.0	4.6
Loamy Foothills			Bottlebrush squirreltail	5.6	74.7							
			Indian ricegrass	5.6	74.7							
			Needleandthread	5.6	74.7							
181	855.6	1120.0	Gambel's oak	12.9	144.8							
% Slope: 5 - 30	211.0	1044.2	Western wheatgrass	12.9	144.8							
Ormiston - .5		5.2	Blue grama	12.0	134.9							
Beje - .35			Muttongrass	10.0	111.9							
Pinyon-Juniper			Twoneedle pinyon	7.9	88.9							
			Black sagebrush	7.1	79.0							
			Needlegrass	5.9	65.9							
			Prairie junegrass	5.9	65.9	144.8	325.8	352.9	10.8	5.0	1.1	5.3
			Rocky Mountain juniper	5.0	55.9							
			Utah serviceberry	5.0	55.9							
			Kentucky bluegrass	4.1	46.0							
			True mountain mahogany	4.1	46.0							
			Mountain muhly	2.9	32.9							
			Mountain brome	2.1	23.0							
			Needleandthread	2.1	23.0							
182	312.2	1008.0	Gambel's oak	20.0	201.6							
% Slope: 1 - 15	78.0	838.5	Arizona fescue	15.0	151.2							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
Burnson - .8		4.0	Mountain brome	15.0	151.2							
			Common snowberry	10.0	100.8							
			Ponderosa pine	10.0	100.8							
			Antelope bitterbrush	5.0	50.4	151.2	403.2	415.8	14.1	2.8	0.8	5.4
			Big sagebrush	5.0	50.4							
			Bluegrass	5.0	50.4							
			Needlegrass	5.0	50.4							
			Rocky Mountain juniper	5.0	50.4							
			Western wheatgrass	5.0	50.4							
183	142.8	1008.0	Gambel's oak	16.9	170.5							
% Slope: 15 - 30	32.0	852.4	Arizona fescue	16.0	161.2							
Burnson - .5		4.3	Mountain brome	11.6	116.7							
Herm - .3			Ponderosa pine	10.7	107.5							
			Common snowberry	8.5	85.2							
			Bluegrass	5.3	53.7							
			Mountain muhly	4.4	44.5							
			Prairie junegrass	4.4	44.5	139.0	340.9	359.9	12.0	2.5	0.6	4.6
			Antelope bitterbrush	3.1	31.5							
			Big sagebrush	3.1	31.5							
			Needlegrass	3.1	31.5							
			Rocky Mountain juniper	3.1	31.5							
			Western wheatgrass	3.1	31.5							
			Bottlebrush squirreltail	2.2	22.2							
			Elk sedge	2.2	22.2							
			Saskatoon serviceberry	2.2	22.2							
184	12.9	1232.0	Western wheatgrass	23.5	289.9							
% Slope: 0 - 5	4.0	1175.8	Arizona fescue	17.6	217.4							
Bradfield - .9		5.9	Mountain big sagebrush	17.6	217.4							
Mountain Clay Loam			Columbia needlegrass	11.8	144.9							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Mountain brome	11.8	144.9	0.0	217.4	163.1	2.6	6.8	1.7	3.6
			Mountain muhly	5.9	72.5							
			Muttongrass	5.9	72.5							
			Prairie junegrass	5.9	72.5							
185	189.4	1456.0	Gambel's oak	14.1	205.3							
% Slope: 15 - 30	49.0	1261.1	Prairie junegrass	12.9	188.3							
Fughes - .5		6.7	Mountain brome	12.0	175.4							
Sheek - .35			Mountain muhly	11.8	171.2							
			Western wheatgrass	11.8	171.2							
			Ponderosa pine	7.1	102.6							
			Arizona fescue	6.2	89.8							
			Utah serviceberry	5.0	72.7	102.6	363.6	349.7	11.4	4.4	1.1	5.2
			Muttongrass	4.1	59.8							
			Bluegrass	2.9	42.8							
			Common snowberry	2.9	42.8							
			Woods' rose	2.9	42.8							
			Bottlebrush squirreltail	2.1	29.9							
			Indian ricegrass	2.1	29.9							
			Letterman needlegrass	2.1	29.9							
186	1588.5	896.0	Gambel's oak	35.7	320.0							
% Slope: 30 - 80	388.0	991.5	Muttongrass	10.2	91.4							
Argiustolls - .3		4.8	Utah serviceberry	10.2	91.4							
Haplustalfs - .3			Utah snowberry	10.2	91.4							
			Antelope bitterbrush	5.1	45.7							
			Bottlebrush squirreltail	5.1	45.7							
			Elk sedge	5.1	45.7	73.1	594.3	500.6	21.0	1.1	0.1	6.7
			Prairie junegrass	5.1	45.7							
			True mountain mahogany	5.1	45.7							
			Douglas fir	2.0	18.3							
			Ponderosa pine	2.0	18.3							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Rocky Mountain juniper	2.0	18.3							
			Twoneedle pinyon	2.0	18.3							
187	1247.2	1008.0	True mountain mahogany	14.1	142.0							
% Slope: 25 - 80	319.0	953.4	Twoneedle pinyon	12.0	120.5							
Wauquie - .4		5.0	Utah juniper	12.0	120.5							
Dolcan - .25			Western wheatgrass	12.0	120.5							
Pinyon-Juniper			Gambel's oak	11.5	116.2							
			Indian ricegrass	10.2	103.3							
			Muttongrass	9.8	99.0	241.0	378.7	464.8	16.2	2.9	1.1	6.2
			Galleta	4.3	43.0							
			Antelope bitterbrush	3.8	38.7							
			Big sagebrush	3.8	38.7							
			Common snowberry	2.1	21.5							
			Pinyon ricegrass	2.1	21.5							
			Utah serviceberry	2.1	21.5							
188	140.5	2800.0	Arizona fescue	16.3	455.5							
% Slope: 30 - 60	31.0	3044.6	Common snowberry	16.3	455.5							
Shawa - .45		16.1	Mountain brome	14.0	391.1							
Fughes - .35			Gambel's oak	10.8	303.6							
Aspen Woodland			Needlegrass	10.8	303.6							
			Western wheatgrass	10.8	303.6	151.8	823.5	731.5	29.3	8.1	2.0	12.2
			Parry's oatgrass	5.4	151.8							
			Quaking aspen	5.4	151.8							
			Muttongrass	3.1	87.4							
			Bluegrass	2.3	64.4							
			Mountain muhly	2.3	64.4							
			Utah serviceberry	2.3	64.4							
189	63.8	1456.0	Gambel's oak	21.1	306.5							
% Slope: 5 - 30	14.0	1286.3	Arizona fescue	10.5	153.3							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
Fughes - .8		6.9	Big sagebrush	10.5	153.3							
			Mountain muhly	10.5	153.3							
			Ponderosa pine	10.5	153.3	153.3	459.8	459.8	12.7	5.7	1.0	6.0
			Prairie junegrass	10.5	153.3							
			Western wheatgrass	10.5	153.3							
			Bluegrass	5.3	76.6							
			Mountain brome	5.3	76.6							
			Needleandthread	5.3	76.6							
190	1000.2	1680.0	Arizona fescue	28.2	473.9							
% Slope: 0 - 15	249.0	1300.9	Needlegrass	12.9	217.4							
Granath - .55		7.0	Mountain muhly	10.0	167.8							
Mountain Loam			Parry's oatgrass	10.0	167.8							
Nortez - .3			Western wheatgrass	10.0	167.8							
Pine Grasslands			Needleandthread	5.3	88.7	29.6	197.4	170.2	3.5	5.7	1.1	3.3
			Antelope bitterbrush	5.0	83.9							
			Big sagebrush	5.0	83.9							
			Mountain brome	5.0	83.9							
			Prairie junegrass	5.0	83.9							
			Gambel's oak	1.8	29.6							
			Ponderosa pine	1.8	29.6							
191	1.3	2912.0	Sedge	25.5	742.1							
% Slope: 0 - 2	0.0		Other perennial grasses	16.1	469.3							
Umbarg -.35			Other forbs	12.5	365.2							
Winner - .3			Baltic rush	8.2	239.4							
Tesajo - .2			Western wheatgrass	8.2	239.4							
Wet Meadow			Mountain brome	6.7	194.4	0.0	40.3	30.2	0.7	23.5	4.8	9.6
			Foxtail barley	5.5	159.6							
			Kentucky bluegrass	5.5	159.6							
			Smooth brome	5.5	159.6							
			Tufted hairgrass	3.3	97.2							

Soil [1]	Area [2]	Prod [3]	Common Name [4]	% VC [5]	Kg/ha [6]	Trees [7]	Shrubs [8]	Fuels [9]	Deer [10]	Hare [10]	Rabbit [10]	Protein [11]
			Other shrubs	1.4	40.3							
			Rocky Mountain iris	1.4	40.3							
192	31.7	448.0	Gambel's oak	15.8	70.7							
% Slope: 25 - 80	5.0	256.8	Arizona fescue	10.5	47.1							
Sheek - .35		2.0	Mountain muhly	10.5	47.1							
Archuleta - .3			Ponderosa pine	10.5	47.1							
			Prairie junegrass	10.5	47.1							
			Western wheatgrass	7.7	34.4							
			Antelope bitterbrush	5.3	23.6	83.4	164.9	186.2	6.3	0.7	0.2	2.2
			Mountain brome	5.3	23.6							
			Mountain mahogany	5.3	23.6							
			Rocky Mountain juniper	5.3	23.6							
			Serviceberry	5.3	23.6							
			Snowberry	5.3	23.6							
			Douglas fir	2.8	12.7							
193	12.4	1680.0	Arizona fescue	30.0	504.0							
% Slope: 3 - 6	0.0		Needlegrass	20.0	336.0							
Granath - .9			Mountain muhly	10.0	168.0							
Mountain Loam			Parry's oatgrass	10.0	168.0							
			Western wheatgrass	10.0	168.0	0.0	168.0	126.0	2.5	3.6	1.2	2.3
			Antelope bitterbrush	5.0	84.0							
			Big sagebrush	5.0	84.0							
			Mountain brome	5.0	84.0							
			Prairie junegrass	5.0	84.0							

---

[1] Village Project soil code; slope range; component name and proportion of complex; ecological setting.
[2] Number of hectares of soil complex within the study area; number of 4-ha cells represented by soil in study area.
[3] Normal-year NPP in kg/ha as reported for the primary component in soil surveys; mean annual productivity of model; sd.
[4] Components of native vegetation communities as listed in the soil surveys.
[5] Percent species contributes to native vegetation community, weighted by proportion component contributes to soil complex.

[6] Normal-year NPP per spcies in kg/ha.
[7] Total NPP of all tree species for normal year in kg/ha for soil complex.
[8] Total NPP of all shrub species for normal year in kg/ha for soil complex.
[9] Total woody biomass produced in kg/ha for soil complex, calculated as the sum of columns 7 and 8, less 25 percent for foliage lost/not developing into wood.
[10] Kg/ha edible meat protein provided by the three herbivore species based on NPP of their preferred plant foods supported by soil complext and 65 percent of total body weight as edible meat.
[11] Total kg meat protein provided by the three herbivore species based on NPP of their preferred plant foods supported by soil complex, and the average amount of protein per unit edible meat weight.

Appendix C. MatLab Script Employed to Calculate Aggregation Indices for Observed Household Data.

```
% read the observed household/site data

mp6 = dlmread('C:\HHObs\mp6.data', ' ');
mp7 = dlmread('C:\HHObs\mp7.data', ' ');
mp8 = dlmread('C:\HHObs\mp8.data', ' ');
mp9 = dlmread('C:\HHObs\mp9.data', ' ');
mp10 = dlmread('C:\HHObs\mp10.data', ' ');
mp11 = dlmread('C:\HHObs\mp11.data', ' ');
mp12 = dlmread('C:\HHObs\mp12.data', ' ');
mp13 = dlmread('C:\HHObs\mp13.data', ' ');
mp14 = dlmread('C:\HHObs\mp14.data', ' ');
mp15 = dlmread('C:\HHObs\mp15.data', ' ');
mp16 = dlmread('C:\HHObs\mp16.data', ' ');
mp17 = dlmread('C:\HHObs\mp17.data', ' ');
mp18 = dlmread('C:\HHObs\mp18.data', ' ');
mp19 = dlmread('C:\HHObs\mp19.data', ' ');

% separate out the small site households
for i = 1:200
   for j = 1:227
      HH6(i,j) = mp6(i,j);
      if mp6(i,j)<9
         HH6(i,j) = mp6(i,j);
      else
         HH6(i,j) = 0;
      end
   end
end;

% add all values of households to get a single number
SHH6 = sum(HH6);
TSHH6 = SHH6';
THH6 = sum(TSHH6);
% multiply by the household use life of small sites for the model period
DHH6 = THH6 .* 8;

% separate out the community center households
for i = 1:200
   for j = 1:227
      % create a community center household matrix for the numerator
      NCH6(i,j) = mp6(i,j);
      % and a second to use as a denominator
      DCH6(i,j) = mp6(i,j);
      if mp6(i,j) > 8
        NCH6(i,j) = mp6(i,j);
        DCH6(i,j) = mp6(i,j);
      else
        NCH6(i,j) = 0;
        DCH6(i,j) = 0;
      end
   end
end;
```

```
% sum the values in each to get a single number
SNCH6 = sum(NCH6);
SDCH6 = sum(DCH6);
TSNCH6 = SNCH6';
TSDCH6 = SDCH6';
% divide the numerator values by 9, the minimum number of HHs in a CC
TNCH6 = ((sum(TSNCH6) ./ 9));
% convert the resulting values to integers
fix(TNCH6);
% define HH use life scalar
S6 = 28;
% and multiply by CC HH use life
FNCH6 = (TNCH6 .* S6);
% multiply denominator value by CC HH use life
TDCH6 = ((sum(TSDCH6)) .* S6);
% add hamlet and CC values for use in denominator
DHHs6 = DHH6 + TDCH6;
% calculate aggregation index for observed households
OAI6 = FNCH6/DHHs6;

% separate out the small site households
for i = 1:200
   for j = 1:227
      HH7(i,j) = mp7(i,j);
      if mp7(i,j)<9
         HH7(i,j) = mp7(i,j);
      else
         HH7(i,j) = 0;
      end
   end
end;

% add all values of households to get a single number
SHH7 = sum(HH7);
TSHH7 = SHH7';
THH7 = sum(TSHH7);
% multiply by the household use life of small sites for the model period
DHH7 = THH7 .* 13;

% separate out the community center households
for i = 1:200
   for j = 1:227
      % create a community center household matrix for the numerator
      NCH7(i,j) = mp7(i,j);
      % and a second to use as a denominator
      DCH7(i,j) = mp7(i,j);
      if mp7(i,j) > 8
        NCH7(i,j) = mp7(i,j);
        DCH7(i,j) = mp7(i,j);
      else
        NCH7(i,j) = 0;
        DCH7(i,j) = 0;
      end
   end
end;
```

```
% sum the values in each to get a single number
SNCH7 = sum(NCH7);
SDCH7 = sum(DCH7);
TSNCH7 = SNCH7';
TSDCH7 = SDCH7';
% divide the numerator values by 9, the minimum number of HHs in a CC
TNCH7 = ((sum(TSNCH7) ./ 9));
% convert the resulting values to integers
fix(TNCH7);
% define HH use life scalar
S7 = 28;
% and multiply by CC HH use life
FNCH7 = (TNCH7 .* S7);
% multiply denominator value by CC HH use life
TDCH7 = ((sum(TSDCH7)) .* S7);
% add hamlet and CC values for use in denominator
DHHs7 = DHH7 + TDCH7;
% calculate aggregation index for observed households
OAI7 = FNCH7/DHHs7;

% separate out the small site households
for i = 1:200
   for j = 1:227
      HH8(i,j) = mp8(i,j);
      if mp8(i,j)<9
         HH8(i,j) = mp8(i,j);
      else
         HH8(i,j) = 0;
      end
   end
end;

% add all values of households to get a single number
SHH8 = sum(HH8);
TSHH8 = SHH8';
THH8 = sum(TSHH8);
% multiply by the household use life of small sites for the model period
DHH8 = THH8 .* 18;

% separate out the community center households
for i = 1:200
   for j = 1:227
      % create a community center household matrix for the numerator
      NCH8(i,j) = mp8(i,j);
      % and a second to use as a denominator
      DCH8(i,j) = mp8(i,j);
      if mp8(i,j) > 8
        NCH8(i,j) = mp8(i,j);
        DCH8(i,j) = mp8(i,j);
      else
        NCH8(i,j) = 0;
        DCH8(i,j) = 0;
      end
   end
end;
```

```
% sum the values in each to get a single number
SNCH8 = sum(NCH8);
SDCH8 = sum(DCH8);
TSNCH8 = SNCH8';
TSDCH8 = SDCH8';
% divide the numerator values by 9, the minimum number of HHs in a CC
TNCH8 = ((sum(TSNCH8) ./ 9));
% convert the resulting values to integers
fix(TNCH8);
% define HH use life scalar
S8 = 28;
% and multiply by CC HH use life
FNCH8 = (TNCH8 .* S8);
% multiply denominator value by CC HH use life
TDCH8 = ((sum(TSDCH8)) .* S8);
% add hamlet and CC values for use in denominator
DHHs8 = DHH8 + TDCH8;
% calculate aggregation index for observed households
OAI8 = FNCH8/DHHs8;

% separate out the small site households
for i = 1:200
    for j = 1:227
        HH9(i,j) = mp9(i,j);
        if mp9(i,j)<9
            HH9(i,j) = mp9(i,j);
        else
            HH9(i,j) = 0;
        end
    end
end;

% add all values of households to get a single number
SHH9 = sum(HH9);
TSHH9 = SHH9';
THH9 = sum(TSHH9);
% multiply by the household use life of small sites for the model period
DHH9 = THH9 .* 18;

% separate out the community center households
for i = 1:200
    for j = 1:227
        % create a community center household matrix for the numerator
        NCH9(i,j) = mp9(i,j);
        % and a second to use as a denominator
        DCH9(i,j) = mp9(i,j);
        if mp9(i,j) > 8
           NCH9(i,j) = mp9(i,j);
           DCH9(i,j) = mp9(i,j);
        else
           NCH9(i,j) = 0;
           DCH9(i,j) = 0;
        end
    end
end;
```

```
% sum the values in each to get a single number
SNCH9 = sum(NCH9);
SDCH9 = sum(DCH9);
TSNCH9 = SNCH9';
TSDCH9 = SDCH9';
% divide the numerator values by 9, the minimum number of HHs in a CC
TNCH9 = ((sum(TSNCH9) ./ 9));
% convert the resulting values to integers
fix(TNCH9);
% define HH use life scalar
S9 = 28;
% and multiply by CC HH use life
FNCH9 = (TNCH9 .* S9);
% multiply denominator value by CC HH use life
TDCH9 = ((sum(TSDCH9)) .* S9);
% add hamlet and CC values for use in denominator
DHHs9 = DHH9 + TDCH9;
% calculate aggregation index for observed households
OAI9 = FNCH9/DHHs9;

% separate out the small site households
for i = 1:200
   for j = 1:227
      HH10(i,j) = mp10(i,j);
      if mp10(i,j)<9
         HH10(i,j) = mp10(i,j);
      else
         HH10(i,j) = 0;
      end
   end
end;

% add all values of households to get a single number
SHH10 = sum(HH10);
TSHH10 = SHH10';
THH10 = sum(TSHH10);
% multiply by the household use life of small sites for the model period
DHH10 = THH10 .* 18;

% separate out the community center households
for i = 1:200
   for j = 1:227
      % create a community center household matrix for the numerator
      NCH10(i,j) = mp10(i,j);
      % and a second to use as a denominator
      DCH10(i,j) = mp10(i,j);
      if mp10(i,j) > 8
        NCH10(i,j) = mp10(i,j);
        DCH10(i,j) = mp10(i,j);
      else
        NCH10(i,j) = 0;
        DCH10(i,j) = 0;
      end
   end
end;
```

```
% sum the values in each to get a single number
SNCH10 = sum(NCH10);
SDCH10 = sum(DCH10);
TSNCH10 = SNCH10';
TSDCH10 = SDCH10';
% divide the numerator values by 9, the minimum number of HHs in a CC
TNCH10 = ((sum(TSNCH10) ./ 9));
% convert the resulting values to integers
fix(TNCH10);
% define HH use life scalar
S10 = 28;
% and multiply by CC HH use life
FNCH10 = (TNCH10 .* S10);
% multiply denominator value by CC HH use life
TDCH10 = ((sum(TSDCH10)) .* S10);
% add hamlet and CC values for use in denominator
DHHs10 = DHH10 + TDCH10;
% calculate aggregation index for observed households
OAI10 = FNCH10/DHHs10;

% separate out the small site households
for i = 1:200
   for j = 1:227
      HH11(i,j) = mp11(i,j);
      if mp11(i,j)<9
         HH11(i,j) = mp11(i,j);
      else
         HH11(i,j) = 0;
      end
   end
end;

% add all values of households to get a single number
SHH11 = sum(HH11);
TSHH11 = SHH11';
THH11 = sum(TSHH11);
% multiply by the household use life of small sites for the model period
DHH11 = THH11 .* 18;

% separate out the community center households
for i = 1:200
   for j = 1:227
      % create a community center household matrix for the numerator
      NCH11(i,j) = mp11(i,j);
      % and a second to use as a denominator
      DCH11(i,j) = mp11(i,j);
      if mp11(i,j) > 8
        NCH11(i,j) = mp11(i,j);
        DCH11(i,j) = mp11(i,j);
      else
        NCH11(i,j) = 0;
        DCH11(i,j) = 0;
      end
   end
end;
```

```
% sum the values in each to get a single number
SNCH11 = sum(NCH11);
SDCH11 = sum(DCH11);
TSNCH11 = SNCH11';
TSDCH11 = SDCH11';
% divide the numerator values by 9, the minimum number of HHs in a CC
TNCH11 = ((sum(TSNCH11) ./ 9));
% convert the resulting values to integers
fix(TNCH11);
% define HH use life scalar
S11 = 28;
% and multiply by CC HH use life
FNCH11 = (TNCH11 .* S11);
% multiply denominator value by CC HH use life
TDCH11 = ((sum(TSDCH11)) .* S11);
% add hamlet and CC values for use in denominator
DHHs11 = DHH11 + TDCH11;
% calculate aggregation index for observed households
OAI11 = FNCH11/DHHs11;

% separate out the small site households
for i = 1:200
   for j = 1:227
      HH12(i,j) = mp12(i,j);
      if mp12(i,j)<9
         HH12(i,j) = mp12(i,j);
      else
         HH12(i,j) = 0;
      end
   end
end;

% add all values of households to get a single number
SHH12 = sum(HH12);
TSHH12 = SHH12';
THH12 = sum(TSHH12);
% multiply by the household use life of small sites for the model period
DHH12 = THH12 .* 18;

% separate out the community center households
for i = 1:200
   for j = 1:227
      % create a community center household matrix for the numerator
      NCH12(i,j) = mp12(i,j);
      % and a second to use as a denominator
      DCH12(i,j) = mp12(i,j);
      if mp12(i,j) > 8
        NCH12(i,j) = mp12(i,j);
        DCH12(i,j) = mp12(i,j);
      else
        NCH12(i,j) = 0;
        DCH12(i,j) = 0;
      end
   end
end;
```

```
% sum the values in each to get a single number
SNCH12 = sum(NCH12);
SDCH12 = sum(DCH12);
TSNCH12 = SNCH12';
TSDCH12 = SDCH12';
% divide the numerator values by 9, the minimum number of HHs in a CC
TNCH12 = ((sum(TSNCH12) ./ 9));
% convert the resulting values to integers
fix(TNCH12);
% define HH use life scalar
S12 = 28;
% and multiply by CC HH use life
FNCH12 = (TNCH12 .* S12);
% multiply denominator value by CC HH use life
TDCH12 = ((sum(TSDCH12)) .* S12);
% add hamlet and CC values for use in denominator
DHHs12 = DHH12 + TDCH12;
% calculate aggregation index for observed households
OAI12 = FNCH12/DHHs12;

% separate out the small site households
for i = 1:200
   for j = 1:227
      HH13(i,j) = mp13(i,j);
      if mp13(i,j)<9
         HH13(i,j) = mp13(i,j);
      else
         HH13(i,j) = 0;
      end
   end
end;

% add all values of households to get a single number
SHH13 = sum(HH13);
TSHH13 = SHH13';
THH13 = sum(TSHH13);
% multiply by the household use life of small sites for the model period
DHH13 = THH13 .* 21;

% separate out the community center households
for i = 1:200
   for j = 1:227
      % create a community center household matrix for the numerator
      NCH13(i,j) = mp13(i,j);
      % and a second to use as a denominator
      DCH13(i,j) = mp13(i,j);
      if mp13(i,j) > 8
         NCH13(i,j) = mp13(i,j);
         DCH13(i,j) = mp13(i,j);
      else
         NCH13(i,j) = 0;
         DCH13(i,j) = 0;
      end
   end
end;
```

```
% sum the values in each to get a single number
SNCH13 = sum(NCH13);
SDCH13 = sum(DCH13);
TSNCH13 = SNCH13';
TSDCH13 = SDCH13';
% divide the numerator values by 9, the minimum number of HHs in a CC
TNCH13 = ((sum(TSNCH13) ./ 9));
% convert the resulting values to integers
fix(TNCH13);
% define HH use life scalar
S13 = 40;
% and multiply by CC HH use life
FNCH13 = (TNCH13 .* S13);
% multiply denominator value by CC HH use life
TDCH13 = ((sum(TSDCH13)) .* S13);
% add hamlet and CC values for use in denominator
DHHs13 = DHH13 + TDCH13;
% calculate aggregation index for observed households
OAI13 = FNCH13/DHHs13;

% separate out the small site households
for i = 1:200
   for j = 1:227
      HH14(i,j) = mp14(i,j);
      if mp14(i,j)<9
         HH14(i,j) = mp14(i,j);
      else
         HH14(i,j) = 0;
      end
   end
end;

% add all values of households to get a single number
SHH14 = sum(HH14);
TSHH14 = SHH14';
THH14 = sum(TSHH14);
% multiply by the household use life of small sites for the model period
DHH14 = THH14 .* 21;

% separate out the community center households
for i = 1:200
   for j = 1:227
      % create a community center household matrix for the numerator
      NCH14(i,j) = mp14(i,j);
      % and a second to use as a denominator
      DCH14(i,j) = mp14(i,j);
      if mp14(i,j) > 8
        NCH14(i,j) = mp14(i,j);
        DCH14(i,j) = mp14(i,j);
      else
        NCH14(i,j) = 0;
        DCH14(i,j) = 0;
      end
   end
end;
```

```
% sum the values in each to get a single number
SNCH14 = sum(NCH14);
SDCH14 = sum(DCH14);
TSNCH14 = SNCH14';
TSDCH14 = SDCH14';
% divide the numerator values by 9, the minimum number of HHs in a CC
TNCH14 = ((sum(TSNCH14) ./ 9));
% convert the resulting values to integers
fix(TNCH14);
% define HH use life scalar
S14 = 40;
% and multiply by CC HH use life
FNCH14 = (TNCH14 .* S14);
% multiply denominator value by CC HH use life
TDCH14 = ((sum(TSDCH14)) .* S14);
% add hamlet and CC values for use in denominator
DHHs14 = DHH14 + TDCH14;
% calculate aggregation index for observed households
OAI14 = FNCH14/DHHs14;

% separate out the small site households
for i = 1:200
    for j = 1:227
        HH15(i,j) = mp15(i,j);
        if mp15(i,j)<9
            HH15(i,j) = mp15(i,j);
        else
            HH15(i,j) = 0;
        end
    end
end;

% add all values of households to get a single number
SHH15 = sum(HH15);
TSHH15 = SHH15';
THH15 = sum(TSHH15);
% multiply by the household use life of small sites for the model period
DHH15 = THH15 .* 40;

% separate out the community center households
for i = 1:200
    for j = 1:227
        % create a community center household matrix for the numerator
        NCH15(i,j) = mp15(i,j);
        % and a second to use as a denominator
        DCH15(i,j) = mp15(i,j);
        if mp15(i,j) > 8
           NCH15(i,j) = mp15(i,j);
           DCH15(i,j) = mp15(i,j);
        else
           NCH15(i,j) = 0;
           DCH15(i,j) = 0;
        end
    end
end;
```

```
% sum the values in each to get a single number
SNCH15 = sum(NCH15);
SDCH15 = sum(DCH15);
TSNCH15 = SNCH15';
TSDCH15 = SDCH15';
% divide the numerator values by 9, the minimum number of HHs in a CC
TNCH15 = ((sum(TSNCH15) ./ 9));
% convert the resulting values to integers
fix(TNCH15);
% define HH use life scalar
S15 = 40;
% and multiply by CC HH use life
FNCH15 = (TNCH15 .* S15);
% multiply denominator value by CC HH use life
TDCH15 = ((sum(TSDCH15)) .* S15);
% add hamlet and CC values for use in denominator
DHHs15 = DHH15 + TDCH15;
% calculate aggregation index for observed households
OAI15 = FNCH15/DHHs15;

% separate out the small site households
for i = 1:200
   for j = 1:227
      HH16(i,j) = mp16(i,j);
      if mp16(i,j)<9
         HH16(i,j) = mp16(i,j);
      else
         HH16(i,j) = 0;
      end
   end
end;

% add all values of households to get a single number
SHH16 = sum(HH16);
TSHH16 = SHH16';
THH16 = sum(TSHH16);
% multiply by the household use life of small sites for the model period
DHH16 = THH16 .* 40;

% separate out the community center households
for i = 1:200
   for j = 1:227
      % create a community center household matrix for the numerator
      NCH16(i,j) = mp16(i,j);
      % and a second to use as a denominator
      DCH16(i,j) = mp16(i,j);
      if mp16(i,j) > 8
        NCH16(i,j) = mp16(i,j);
        DCH16(i,j) = mp16(i,j);
      else
        NCH16(i,j) = 0;
        DCH16(i,j) = 0;
      end
   end
end;
```

```
% sum the values in each to get a single number
SNCH16 = sum(NCH16);
SDCH16 = sum(DCH16);
TSNCH16 = SNCH16';
TSDCH16 = SDCH16';
% divide the numerator values by 9, the minimum number of HHs in a CC
TNCH16 = ((sum(TSNCH16) ./ 9));
% convert the resulting values to integers
fix(TNCH16);
% define HH use life scalar
S16 = 40;
% and multiply by CC HH use life
FNCH16 = (TNCH16 .* S16);
% multiply denominator value by CC HH use life
TDCH16 = ((sum(TSDCH16)) .* S16);
% add hamlet and CC values for use in denominator
DHHs16 = DHH16 + TDCH16;
% calculate aggregation index for observed households
OAI16 = FNCH16/DHHs16;


% separate out the small site households
for i = 1:200
   for j = 1:227
      HH17(i,j) = mp17(i,j);
      if mp17(i,j)<9
         HH17(i,j) = mp17(i,j);
      else
         HH17(i,j) = 0;
      end
   end
end;

% add all values of households to get a single number
SHH17 = sum(HH17);
TSHH17 = SHH17';
THH17 = sum(TSHH17);
% multiply by the household use life of small sites for the model period
DHH17 = THH17 .* 45;

% separate out the community center households
for i = 1:200
   for j = 1:227
      % create a community center household matrix for the numerator
      NCH17(i,j) = mp17(i,j);
      % and a second to use as a denominator
      DCH17(i,j) = mp17(i,j);
      if mp17(i,j) > 8
        NCH17(i,j) = mp17(i,j);
        DCH17(i,j) = mp17(i,j);
      else
        NCH17(i,j) = 0;
        DCH17(i,j) = 0;
      end
   end
end;
```

```
% sum the values in each to get a single number
SNCH17 = sum(NCH17);
SDCH17 = sum(DCH17);
TSNCH17 = SNCH17';
TSDCH17 = SDCH17';
% divide the numerator values by 9, the minimum number of HHs in a CC
TNCH17 = ((sum(TSNCH17) ./ 9));
% convert the resulting values to integers
fix(TNCH17);
% define HH use life scalar
S17 = 45;
% and multiply by CC HH use life
FNCH17 = (TNCH17 .* S17);
% multiply denominator value by CC HH use life
TDCH17 = ((sum(TSDCH17)) .* S17);
% add hamlet and CC values for use in denominator
DHHs17 = DHH17 + TDCH17;
% calculate aggregation index for observed households
OAI17 = FNCH17/DHHs17;

% separate out the small site households
for i = 1:200
   for j = 1:227
      HH18(i,j) = mp18(i,j);
      if mp18(i,j)<9
         HH18(i,j) = mp18(i,j);
      else
         HH18(i,j) = 0;
      end
   end
end;

% add all values of households to get a single number
SHH18 = sum(HH18);
TSHH18 = SHH18';
THH18 = sum(TSHH18);
% multiply by the household use life of small sites for the model period
DHH18 = THH18 .* 35;

% separate out the community center households
for i = 1:200
   for j = 1:227
      % create a community center household matrix for the numerator
      NCH18(i,j) = mp18(i,j);
      % and a second to use as a denominator
      DCH18(i,j) = mp18(i,j);
      if mp18(i,j) > 8
        NCH18(i,j) = mp18(i,j);
        DCH18(i,j) = mp18(i,j);
      else
        NCH18(i,j) = 0;
        DCH18(i,j) = 0;
      end
   end
end;
```

```
% sum the values in each to get a single number
SNCH18 = sum(NCH18);
SDCH18 = sum(DCH18);
TSNCH18 = SNCH18';
TSDCH18 = SDCH18';
% divide the numerator values by 9, the minimum number of HHs in a CC
TNCH18 = ((sum(TSNCH18) ./ 9));
% convert the resulting values to integers
fix(TNCH18);
% define HH use life scalar
S18 = 35;
% and multiply by CC HH use life
FNCH18 = (TNCH18 .* S18);
% multiply denominator value by CC HH use life
TDCH18 = ((sum(TSDCH18)) .* S18);
% add hamlet and CC values for use in denominator
DHHs18 = DHH18 + TDCH18;
% calculate aggregation index for observed households
OAI18 = FNCH18/DHHs18;

% separate out the small site households
for i = 1:200
   for j = 1:227
      HH19(i,j) = mp19(i,j);
      if mp19(i,j)<9
         HH19(i,j) = mp19(i,j);
      else
         HH19(i,j) = 0;
      end
   end
end;

% add all values of households to get a single number
SHH19 = sum(HH19);
TSHH19 = SHH19';
THH19 = sum(TSHH19);
% multiply by the household use life of small sites for the model period
DHH19 = THH19 .* 20;

% separate out the community center households
for i = 1:200
   for j = 1:227
      % create a community center household matrix for the numerator
      NCH19(i,j) = mp19(i,j);
      % and a second to use as a denominator
      DCH19(i,j) = mp19(i,j);
      if mp19(i,j) > 8
        NCH19(i,j) = mp19(i,j);
        DCH19(i,j) = mp19(i,j);
      else
        NCH19(i,j) = 0;
        DCH19(i,j) = 0;
      end
   end
end;
```

```
% sum the values in each to get a single number
SNCH19 = sum(NCH19);
SDCH19 = sum(DCH19);
TSNCH19 = SNCH19';
TSDCH19 = SDCH19';
% divide the numerator values by 9, the minimum number of HHs in a CC
TNCH19 = ((sum(TSNCH19) ./ 9));
% convert the resulting values to integers
fix(TNCH19);
% define HH use life scalar
S19 = 20;
% and multiply by CC HH use life
FNCH19 = (TNCH19 .* S19);
% multiply denominator value by CC HH use life
TDCH19 = ((sum(TSDCH19)) .* S19);
% add hamlet and CC values for use in denominator
DHHs19 = DHH19 + TDCH19;
% calculate aggregation index for observed households
OAI19 = FNCH19/DHHs19;

% concatenate the 14 resulting indices into an array
OAIs = cat(14, OAI7, OAI7, OAI8, OAI9, OAI10, OAI11, OAI12, OAI13, OAI14, OAI15, OAI17,
OAI17, OAI18, OAI19);

% and write the array to a text file to plot and compare w/
% simulation results from each model run
dlmwrite('C:\HHObs\OAIs.txt', OAIs, ' ');
```