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**Diet optimization models and prehistoric subsistence change in
the Eastern Woodlands**

Gardner, Paul Shellie, Ph.D.

The University of North Carolina at Chapel Hill, 1992

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DIET OPTIMIZATION MODELS AND PREHISTORIC
SUBSISTENCE CHANGE IN THE EASTERN WOODLANDS

by

Paul S. Gardner

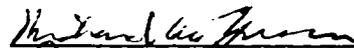
A Dissertation submitted to the faculty of the University of North Carolina at
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Philosophy in the Department of Anthropology.

Chapel Hill

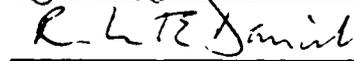
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1992

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PAUL SHELLIE GARDNER. Diet Optimization Models and Prehistoric Subsistence Change in the Eastern Woodlands (Under the direction of Bruce Winterhalder).

ABSTRACT

This dissertation hypothesizes that prehistoric Native Americans in the Eastern Woodlands selected subsistence resources to obtain sufficient energy and nutrients while minimizing the time spent in the food quest. No attempt is made to "prove" the optimization hypothesis; rather it is used to guide the construction of simple mathematical models of optimal diet. The construction, testing and comparison of the modeled optimal diets illuminates the interrelationships among subsistence system variables. The dissertation emphasizes heurism rather than hypothesis testing. In building the models, the costs and benefits of the resources are estimated from their season availability and size, population density, home range size, and nutritional content. Using linear programming, 120 seasonal optimal diet problems are solved under varying conditions of nutritional constraint, human population size, and availability of cultigens. A comparison of the model results to the subsistence remains recovered from Daugherty's Cave (44Ru14), a stratified rockshelter in southwestern Virginia, shows a limited correlation. The models correctly account for the exploitation of hickory nuts, deer and maize but predict unrealistically narrow diets. The absence of encounter-contingent foraging from the models is considered the principal cause of the poor fit.

Calcium and vitamin C are the nutrient needs most costly to fulfill, but the models indicate that at an ordinal level of measurement, the value of the resources

does not vary greatly under varying levels of nutrient constraint. Hence nutritional requirements may have had little influence on subsistence choice.

However, *Chenopodium* sp., *Iva annua*, and *Cucurbita pepo* may have been seasonally important sources of nutrients as stored foods.

Coevolution rather than population pressure is supported as an explanation of agricultural origins, since, even under conditions of low demographic stress, plants of the Eastern Agricultural Complex were selected as part of some optimal diets. In addition, maize was selected as the staple food of all models in which it was available regardless of population size; hence population pressure is not indicated as the cause of its adoption.

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The excavation of Daugherty's Cave was made possible by the landowner, Mr. Glen Breeding, an outstanding steward of our archaeological heritage. Joe Benthall graciously encouraged my work at Daugherty's Cave and shared much information concerning his earlier excavations. The UNC Research Laboratories of Anthropology provided field equipment, and Trawick Ward and Steve Davis offered much advice and encouragement. Alan Neebe of the UNC School of Business made available LPSBA,

his linear programming code for microcomputers, which greatly facilitated the mathematical modeling portion of the dissertation.

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CHAPTER I INTRODUCTION AND BACKGROUND

This dissertation is a study of subsistence change and continuity in the Eastern Woodlands of the United States, particularly the Ridge and Valley province of Virginia, from Late Archaic (ca. 3000 B.C.) to Mississippian (ca. A.D. 1500) times. The theory of economic optimization will be used to guide hypothesis formation. In particular I hypothesize that prehistoric Native Americans selected subsistence resources to obtain sufficient energy and nutrients while minimizing the time spent in the food quest. To investigate this hypothesis, I construct a set of optimal diet models using linear programming, a mathematical technique of calculating the optimal allocation of resources towards a defined goal in the face of multiple constraints. The outputs of these models will be compared to the subsistence remains recovered from the excavation of the Daugherty's Cave site (44Ru14), a small rockshelter in southwestern Virginia.

OBJECTIVES

This dissertation explores the extent to which prehistoric subsistence change and continuity in the Eastern Woodlands of the United States can be explained as the result of economically optimal strategies for achieving an adequate diet while minimizing the time spent in the food quest. I recognize that this is a simple approach to a complex cultural phenomenon. I argue, however, that simplicity can be advantageous, insofar as it allows limited aspects of a complex problem to be clearly understood free of the confounding effects of other variables. Therefore I will create a set of simple linear programming optimal diet models that can be compared to one another to investigate

the role of specific variables in shaping prehistoric subsistence choices. The variables examined in this dissertation are human nutritional requirements (for energy, protein, iron, calcium, vitamin A, B-vitamins and vitamin C), population growth, and the availability of native and Mesoamerican domesticated plants.

The initial optimal diet model deals with an ideal population of 25 people seeking to meet their energy needs by foraging for native Eastern Woodlands game and plants. Following the determination of the optimal energy-efficiency strategy, nutrient constraints are added sequentially to the problem formulation to assess how the need for protein, iron, calcium, thiamine, riboflavin, niacin, vitamin A, and vitamin C might modify the basic energy-efficiency strategy. The foraging models are then re-run with the specification that energy and nutrients sufficient for 250 people be acquired. Comparison of the two sets of models illuminates the impact of population increase on Eastern Woodlands foraging.

To investigate the impact of native food production on Eastern Woodlands subsistence strategies, the optimal diet models are rerun for the small and large population sizes under varying nutrient constraints but with the addition of the native domesticates, squash, maygrass, chenopod, sumpweed and sunflower.

Finally, the impact of Mesoamerican-derived cultigens on prehistoric Eastern Woodlands subsistence strategies is explored by adding maize and beans to the native cultigen models.

ORGANIZATION OF THE DISSERTATION

The remainder of this chapter reviews prior studies of subsistence change in the Eastern Woodlands. Chapter 2 addresses a set of related theoretical and methodological issues: the concept of economic optimization, and its role as a heuristic device in the present study. Next I examine the tools of the optimization approach, namely optimization models, and I address criticisms of them. Following this I

introduce linear programming, the method used in this study for modeling optimal diets. Finally, I review prior uses of linear programming in archaeology with a particular eye towards illuminating avoidable weaknesses in them.

Chapter 3 develops the linear programming models used in this study. It presents the data used to construct the models, and it provides justifications for the numerous estimations, approximations and assumptions entailed by the quantitative study of a phenomenon as complex as human diet choice.

Chapter 4 presents the outputs of the models. By "solving" the optimal diet problem under varying sets of nutritional, demographic and technological constraints, it is possible to clarify which factors seem to have been most influential in shaping diet choices.

In chapter 5 the predicted optimal diets are compared to the subsistence remains recovered from the Daugherty's Cave site. This comparison tests the extent to which the models have captured the essential dynamics of the prehistoric food procurement system.

In chapter 6 prehistoric Eastern Woodlands subsistence patterns are discussed in light of the optimal diet models. In chapter 7 directions for future research are suggested and the overall utility of optimization modeling and linear programming as tools for archaeological research is evaluated. Finally, a site report of the 1982-1983 excavations at Daugherty's Cave is included as Appendix A. Appendix B consists of a list of the common and scientific names of the plants and animals discussed in the dissertation.

PRIOR SUBSISTENCE STUDIES

Implicit Optimization Approaches

In a pair of often cited works, Caldwell (1958, 1962) posed the Eastern Woodlands as a counter-example to the state-level cultures of Mesoamerica and the Near East. Caldwell proposed that the adoption of agriculture and the development of complex societies were slowed in the Eastern Woodlands by the already established, highly effective foraging practices of the resident populations. Caldwell termed this foraging adaptation "Primary Forest Efficiency" and saw it as "a kind of balanced reliance on almost all sources of natural foods (1962:288)." It was characterized by a seasonal round that combined ambush hunting and the gathering of numerous plant resources especially mast. Caldwell saw the Archaic period as the time during which Primary Forest Efficiency was established (1958:18) and the Adena/Hopewell culture as expressing its ultimate possibilities (1958:30).

Although Caldwell accepted that cultigens were present in the Eastern Woodlands during Adena/Hopewell times, he believed that agriculture did not have notable social effects until Mississippian times (1962:305). In general Caldwell seems to have underestimated the importance of agriculture in the Eastern Woodlands. He dismissed the potential importance of native cultigens (1958:30), and his description of the Historic period coastal societies as having hunted, fished, and "raised a little maize (1962:290)" seems strongly at variance with the descriptions of the Chesapeake Bay and Carolina Sounds societies whose agricultural surpluses subsidized scores of English colonists (Barbour 1986; Quinn 1955).

Considering how little empirical evidence on Eastern Woodlands subsistence was available to Caldwell, such complaints are perhaps unfair. A seemingly more significant criticism, however, is that while the study was designed to illuminate the historical processes which gave the Eastern Woodlands its unique character (1958:v) it

rarely deals explicitly with causality. The study is more descriptive than processual. Caldwell's thesis is strongly structural-functionalist and suffers from the limitations of this approach. In particular it can more readily account for cultural stasis than cultural change (Harris 197:559-560). Caldwell argues cogently that the attainment of primary forest efficiency militated against the development of further cultural complexity, but he is never explicit about the causes underlying the development of primary forest efficiency itself. It would seem, however, from his use of the word "efficiency" and his descriptions of the innovations leading to primary forest efficiency as "primarily adaptive" (1962:304) and leading to "increasingly successful adjustment to the eastern forest environment (1958:vii)" that Caldwell had some implicit notion of optimization in mind. In this respect Caldwell foreshadowed a future major focus of processual studies of Eastern Woodlands subsistence change.

Economic optimization (particularly energetic efficiency) is also implicit in Cleland's "focal-diffuse model" of cultural adaptation (1966, 1976). To Cleland it was the "continuing search for economic security ...[that] ultimately tends to move adaptive patterns from less productive to more productive in terms of input-output energy ratios (1976:60)". Cleland characterized subsistence adaptations as either focal or diffuse. Focal adaptations are based on one resource, or a few similar resources (1976:61), while diffuse adaptations were based on the regularized exploitation of a variety of different resources (1976:64).

In applying his model to the Eastern Woodlands, Cleland described the Paleoindian and Early Archaic periods as the Early Focal pattern based on a presumed dependence on big game hunting (1976:68). This gave way in the Middle Archaic period as climatic change eliminated big game as a feasible resource thereby causing dietary generalization. Cleland denoted this as the Early Diffuse pattern (1976:69). This was followed by the Late Diffuse pattern that encompassed the Late Archaic through Middle Woodland periods and which was characterized by well-established

exploitation of multiple resources, regional specializations and eventually agriculture based on native cultigens. This pattern ended in the Late Woodland period when the adoption of maize agriculture produced the Late Focal pattern (1976:71).

Actually Cleland's (1976) scenario closely mirrors Caldwell's (1958). In both, early big game hunting gives way to climatically induced diet generalization, which in turn is followed by increasingly efficient generalization that was eventually replaced by maize agriculture. Furthermore, Cleland assigns no independent causal role to optimization. Rather, as in Caldwell's model, the forces compelling the shifts from one pattern to the next (e.g. climate change, diffusion of maize) are induced post hoc from the archaeological record.

Climate Change

Other researchers have attempted to formulate a priori causal mechanisms of Eastern Woodlands subsistence change and to test their applicability by archaeological test. Climate change figures prominently in this regard, but results have been mixed at best. In the early 1960's Griffin (1960, 1961) attempted to link the initial expansion and later collapse of Hopewell to climatic changes in the American Midwest that first promoted, then hindered maize agriculture. It is now apparent that Hopewellian subsistence was not based on maize (Ambrose 1987), although native cultigens were grown and might have been influenced by climate changes (Braun 1987:168). Perhaps a more pressing problem is that there is considerable ambiguity about the interpretation of the palynological data from the Midwest (Styles 1981:3). Whereas Griffin (1960) inferred cooler climates detrimental to agriculture at the onset of the Hopewell decline, other researchers have suggested that the climate may have actually ameliorated (Barreis and Bryson 1965). More recent research from Michigan suggests that cooler and drier conditions may have prevailed from ca. A.D. 250-400 to A.D. 800 and resulted in shorter growing seasons (Bernabo 1981). What effect this might have had

on societies growing native cultigens in the Hopewellian region remains unclear but should not be discounted.

The most successful attempts at explaining subsistence change as responses to climatic change in the Eastern Woodlands have come from the western edge of the area. During the mid-Holocene (ca. 6500 B.C - 2000 B.C.) there was a definite period of warmer and drier conditions (the Hypsithermal Interval) that resulted in the eastward expansion of prairie into formerly forested areas (Delcourt and Delcourt 1985). During this time period at Rodgers Shelter along the prairie-woodlands margin in the Missouri Ozarks, the exploitation of deer decreased while the use of small, grassland species increased (MacMillian and Klippel 1981). This seems clearly to be a climatically induced change. On the other hand, deer utilization actually increased during the same time period at Graham Cave in central Missouri (MacMillian and Klippel 1981). Here, however, it is thought that prairie expansion created a prairie-forest mosaic which favored deer due to its increased prevalence of forest edge (MacMillian and Klippel 1981).

Cultural responses to mid-Holocene climatic change in the Mississippi River valley region remain somewhat ambiguous. At Modoc Rockshelter along the Mississippi Valley in Western Illinois, the Hypsithermal marks no apparent change in the species recovered from the site: both the Early and Middle Archaic zones are dominated by small game (Styles et al. 1983). At Koster, also in Western Illinois, it was originally argued that the considerable topographic diversity of the bluffs flanking the Illinois River mitigated any environmental change associated with the Hypsithermal (Asch et al. 1972). More recent studies, however, indicate that the Hypsithermal climate apparently did influence Middle Archaic adaptations at Koster. In particular the first base camps were established at Koster ca. 5300 B.C., apparently in response to an abandonment of the increasingly arid uplands (Carlson 1979). Furthermore, the exploitation of aquatic resources at Koster seems to reflect

opportunistic responses to changes in the local floodplain environment induced by Hypsithermal erosion (Styles 1986). In general the attempts by Midwestern archaeologists to relate Middle Archaic subsistence change to Hypsithermal climatic change are perhaps the most successful efforts at explaining prehistoric subsistence change in the Eastern Woodlands to date.

Social Approaches

On the other hand, I would argue that social approaches derived from historical materialism have done little to clarify prehistoric Eastern Woodlands subsistence change. In these approaches cultural change is not viewed as an adaptive response to exogenic stress, but rather "the locus of change revolves around tension generated within and between the spheres of sociopolitical action, symbolic representation, and technological response or constraint" (Bender 1985:27). When applied to the prehistoric Eastern Woodlands, these studies typically focus on the aspects of the archaeological record which correlate most directly with social structure, such as burial ceremonialism and long-distance trade in sumptuary goods. Subsistence change is either de-emphasized (Marquardt 1985) or overlooked (Bender 1985).

In a rare attempt to explain Eastern Woodlands subsistence change in social terms, Nassaney looked to "the contradictions in the productive relations of human social groups that promote change on the basis of their own internal dynamics" (1986:131). Nassaney viewed increasing political complexity in the Mississippi River Valley as necessitating surplus production that was generated by subsistence intensification (1986:135). Political complexity was then read from the archaeological record of the central and lower Mississippi Valley based on the presence of earthworks and long distance trade. Nassaney then determined three periods, Poverty Point, Marksville, and Coles Creek/Mississippi to display political complexity, and he found what he considered satisfactory evidence of subsistence intensification at these times.

There are several problems with Nassaney's study. First, the equation of earthworks and long-distance trade with political complexity seems facile, as it would lump together social organizations as disparate as Archaic period foraging bands and Mississippian period chiefdoms. Such a crude typology seems unlikely to illuminate prehistoric social relationships or the "tensions" they engendered. Second, it is odd that Nassaney chose as his test case the central and lower Mississippi River valley, an area with remarkably little subsistence data. The area immediately north of Nassaney's study area, the American Bottoms and lower Illinois River, has an exceedingly rich subsistence record. However, it displays a mostly gradual trend towards intensification, not one punctuated by periods of rapid intensification that correlate with political complexity. Finally, while supporters of a social approach are right to draw attention to the importance of human actions in understanding cultural change, when one of its most ardent supporters prefaces his study with the caveat that "the operating variables are neither clearly stated nor understood ..." (Nassaney 1986:134), one cannot help but question the utility of the approach for scientific analysis.

Population Growth

Population growth is another variable which has been suggested as a possible cause of subsistence change. Although Caldwell (1958) had described the Archaic period as a time in which people attained a better balance among their foods, Asch et al. (1972) pointed out that the Koster site Archaic period horizons show no observable changes in the plants foods exploited over a 3000 year period. Rather it seemed to them that the diet remained focused on mast, particularly hickory nuts (Asch et al. 1972). Asch et al. (1972) posited that a small population not stressing the carrying capacity of its environment would likely subsist on those resources most easily gathered in quantity and that were most nutritionally complete. They called these resources "first line" foods and nominated hickory nuts as a prime example (Asch et al.

1972:27). The later Woodland period expansion of the diet to include increased amounts of acorns, hazelnuts and small seeds they saw as evidence of population growth outstripping the potential of the first line foods and not as the culmination of a millennia long process of mastering the local environment.

In a later study Christensen (1980) presented much the same argument using the concept of the food niche. The food niche has two components. The first is resource diversity (or "richness"), which is the number of items in the diet. The second is niche breadth (or "evenness"), which measures the proportional contribution of each item the diet Christensen 1980:34). A population attempting to maintain the least-cost diet in the face of a growing population would first add additional resources, i.e. richness would increase, until no resources that could be feasibly exploited were available. If demographic pressure continued, then the population would be forced to intensify the exploitation of those resources that could sustain the largest yield (Christensen 1980:35).

Christensen attempted to test his model against the subsistence remains collected from the midwestern U.S. but found a rather poor fit. Even this was vitiated by the fact that he had no way of measuring the proportional contribution of the recovered plant foods to the overall diet and hence had to rely solely on his "educated estimates" (Christensen 1980:50). Nonetheless, the generally accepted reconstruction of Eastern Woodlands subsistence change is that a narrow Archaic period diet broadened through time eventually leading to the cultivation and domestication of a number of native weedy plants in the Woodland period. During the subsequent Mississippian period the diet became increasingly focused on one very high yielding plant, maize. Hence, in general terms the widely accepted pattern of subsistence change in the Eastern Woodlands is congruent with that predicted by Christensen.

In another study Christensen (1986) again examined Eastern Woodlands subsistence change using the assumptions of population growth and least-cost decision

making. In this study Christensen (1986) focused attention on the economic concept of marginal cost, which is the cost of the input needed to produce an additional unit of output. It is expected that due to diminishing returns, the marginal cost of exploiting a resource rises with increased exploitation. The relative desirability of resources to a consumer can be ranked by their initial marginal costs. A population attempting to maintain a least cost diet in the face of increasing demographic pressure would be expected to intensify the exploitation of the resource with the lowest initial marginal cost until its marginal cost becomes equivalent to that of the second resource. At this point the second resource should enter the diet. If further food is needed, the exploitation of the two resources should proceed at a level which maintains equivalent marginal costs for the two resources until their marginal costs become equivalent to that of the third resource which then enters the diet. It is in this manner that the optimizing consumer decides to intensify existing strategies or adopt new ones (see Earle 1980 for further elaboration of marginal cost decision making.)

Christensen (1986) attempted to estimate marginal costs for various subsistence resources in the midwestern U.S. and thereby predict the sequence in which they should appear in the archaeological record. In testing his predictions against the archaeological record of 16 sites, Christensen again obtained a rather poor fit. In particular small game with very high cost was utilized in the Early Archaic, while acorns and fish, predicted to be low cost resources, were always under-utilized. The model did correctly account for the utilization of deer and hickory and for an increased utilization of seeds in the Late Archaic (Christensen 1986). Theoretically the model is very attractive, but its operationalization seems very daunting. Not only must the initial cost of the resource be estimated but also the rate of change of the marginal cost as utilization increases. Neither of these variables is easily measured for prehistoric strategies.

THE LIMITATIONS OF INDUCTION

Modeling plays a seminal role in this dissertation. This is not meant, however, to exalt the modeling approach over traditional archaeological empiricism. Certainly the greatest contribution archaeologists can make to the study of prehistoric subsistence adaptations is through the investigation of the archaeological record to discern what subsistence activities actually took place in the past. However, the potential of the ecological approach in archaeology remains to a large extent unrealized (Butzer 1975; Smith 1976). Too frequently zooarchaeological and paleoethnobotanical studies produce little beyond descriptive summaries of the genera identified. Interpretive generalizations, when offered at all, are typically inductive and based on plausible, but untested, arguments (e.g. Streuver and Vickery 1973; Cleland 1976; Ford 1977). This approach has resulted in a continuing revision of Eastern Woodlands prehistory (cf. Yarnell 1974; Chomko and Crawford 1978; Yarnell 1986) and an increased awareness of the complexities of prehistoric subsistence adaptations (Smith 1975, 1987b; Waselkov 1978; Fritz 1990), but it is limited in some important ways.

Rarely, for example, are paleoethnobotanical and zooarchaeological studies combined to create a unified study of subsistence change. By drawing empirical generalizations from analyses of the archaeobotanical record, paleoethnobotanists have made great progress in clarifying the origins of agriculture in the Eastern Woodlands (cf. Yarnell 1977; Watson 1989). Zooarchaeologists, likewise, have emphasized empirical description, but have generated fewer diachronic studies (see Waselkov 1978 for a rare exception). Rather zooarchaeologists have preferred to infer animal procurement practices during particular time periods by relating zooarchaeological assemblages to characteristics of the local environments (Smith 1975; Styles 1984; Reitz and Quitmyer 1988). Optimization models can provide a common framework for studying both animal and plant resources.

In addition, explanation of subsistence change has lagged far behind the description of subsistence remains recovered. When offered at all, explanations for why particular resources were selected for exploitation have generally taken the form of post hoc, plausibility statements. An example is the suggestion (Gardner 1985) that walnuts and butternuts enter the diet despite their high processing costs since they can be cheaply gathered along with the more desirable hickory nuts. While not necessarily wrong, such "just-so stories" have failed to yield a systematic understanding of the causes of prehistoric subsistence change. In particular, the traditional approach has paid insufficient attention to identifying the environmental properties which influenced particular subsistence patterns or to specifying how changes in selective pressures might have generated changes in subsistence strategies.

I hope to overcome the limitations of the inductive approach by using formal optimization models as a means to generate and test specific hypotheses about the relationships of environmental conditions, selective pressures and observed behaviors (Foley 1985). I posit that the most important environmental variables structuring the prehistoric food quest was the relative costs and benefits of the available resources. I will investigate these by creating a set of simple diet models that relates the estimated costs of obtaining Eastern Woodlands resources to the nutritional benefits of consuming them. The models provide a test of the hypothesis that nutrient constraints influenced prehistoric diet choice.

The models are then modified to investigate the consequences of population pressure and the introduction of food production. Population pressure investigated by modeling the subsistence changes necessitated by a tenfold increase in population size. This will illuminate the role of population pressure as a contributing cause of subsistence change. The introduction of food production will be investigated by creating alternative versions of the models which incorporate Eastern Woodlands native cultigens and Mesoamerican cultigens as potential foods. This will allow a test of the

hypothesis that agriculture represents a least-effort solution to the food quest.

Comparison of the models outputs to the subsistence remains from a small southwestern Virginia rockshelter, Daugherty's Cave (44Ru14), will be made in order to assess the degree to which any of the models correctly capture the essential dynamics of prehistoric Eastern Woodlands subsistence strategies.

Certainly I do not advocate that modeling should replace archaeological empiricism, rather I view it as another tool to be used for investigating the past. I do not presume that optimization modeling will provide a complete explanation of prehistoric Eastern Woodlands subsistence change. Nor do I believe that it must necessarily be more informative than post hoc generalizations from the empirical record. I do think, however, that formal optimization modeling provides a useful means of investigating prehistoric subsistence change in a systematic fashion and that a systematic approach is superior to post hoc generalization in facilitating the accumulation of knowledge about prehistoric subsistence change. In addition formal optimization modeling facilitates the accumulation of knowledge by allowing the causes of a complex phenomenon such as subsistence change to be investigated in an incremental fashion. Thus it is possible to clarify the import of the more readily operationalized technoenvironmental variables such as nutritional constraints, population growth, or the introduction of cultigens before addressing more rarified phenomena such as political dialectics.

CHAPTER II OPTIMIZATION AND LINEAR PROGRAMMING

Optimization models constructed using the technique of linear programming play a central role in this dissertation. In this chapter I discuss the concept of optimization and address criticisms of it, introduce the technique of linear programming and review prior uses of linear programming in Eastern Woodlands archaeology.

THE OPTIMIZATION ASSUMPTION

It is not the purpose of this study to "prove", or even test, the premise that prehistoric Native Americans were perfect economic optimizers. Rather, economic optimization is taken as an untestable assumption (Maynard Smith 1978). The models of diet choice constructed under its rubric function as ideal types which can be compared to each other to investigate how changes in one model component affect other components. In this fashion the effects on subsistence choices of such factors as resource characteristics, population growth or the introduction of cultigens can be investigated. If the subsistence choices predicted by the model match closely with the subsistence remains recovered from the archaeological record, this is encouraging, as it suggests that the system dynamics have been properly understood. On the other hand, each model contains so many posited interrelationships and estimated parameters and values that any discrepancy between the model and the real world must be ascribed to a failure of specific elements of the model, assuming, of course, that data are adequate for an empirical test. In no case, however, is testing a model a valid test of the economic optimization assumption (Maynard Smith 1978).

Although optimization models can be caricatured as "panglossian" (Gould and Lewontin 1984), using them does not require an assumption that people are perfect economic optimizers. It is assumed, however, that prehistoric Native Americans were rational, in the sense that their solutions to economic problems make sense given the full range of constraints (social, political, and cognitive as well as economic) that concerned them (Plattner 1989:xi). This study is meant to discover what some of those constraints might have been. As an initial approximation, it focuses on technoenvironmental variables - population size, human nutritional needs, resource characteristics and technology - as likely sources of significant constraints. This is not meant as a rejection of the importance of social and ideational factors in influencing human action. It is merely a tactical consideration necessitated by the need to construct a clearly understood, simple model (Richardson and Boyd 1987).

Although the use of optimization approaches has met with some resistance in anthropology (Smith 1987), it is widely used in other scientific disciplines. In particular, it is the foundation of much of modern theoretical biology and is the core of economics, defined as the study of the optimal allocation of resources (Smith 1987). Within anthropology resistance to optimization theory is longstanding and centers for the most part on a rejection of the assumption that humans are capable of or necessarily desire to fashion perfectly optimal institutions and behaviors (Jochim 1983; Keene 1983). A rejection of optimization theory on this grounds is misguided, as optimization theory does not posit that optimal designs or structures are created invariably or even that they can exist (Foley 1985). Rather than being a programmatic statement about the nature of the world, optimization theory is used to construct ideal models which can be used as templates against which real phenomena can be compared (Foley 1985). "This is the goal of optimization models: not an absolute statement about the perfection of behavior, but an evaluation of the relative value of alternative behaviours or morphology" (Foley 1985:230). "Thus optimization models are a

method for organizing empirical evidence, making educated guesses as to how evolution might have proceeded, and suggesting avenues for further empirical research" (Oster and Wilson 1984:273). Simply stated, optimization models provide a framework within which comparative analyses can be made.

Hence, it is not an appropriate use of optimization theory to attempt to "prove" that a certain behavior is optimal. In fact, if it is the case, as seems likely, that it is the overall survival or well-being of an organism that is selected for, then it is likely that any single component contributing to survival or well-being will be a suboptimal compromise constrained by selection on other components (Foley 1985). Since the study of the total organism cannot be operationalized, optimization theorists must deal with smaller components. They are thereby placed in a paradoxical position of comparing to ideal templates, actual behaviors which are considered unlikely to be optimal (Foley 1985). However, just as the perfect vacuum of classical physics is nonexistent but nonetheless useful for understanding inertia, the "ideal templates" of optimization models can still serve as useful tools for inquiry. This emphasizes the point that optimization theory is not the assertion of the perfection of nature, but is rather a means to generate and test specific hypotheses about the relationships of environmental conditions, selective pressures and observed behaviors (Foley 1985).

The Structure of Optimization Models

The ideal templates against which real world phenomena can be compared take the form of optimization models. Like all models, optimization models are incomplete, and simplified representations of real world complexity (Smith 1987). Simplicity is not necessarily a disadvantage however. Simple models are often sufficient to reflect how real processes actually work, and their simplicity allows the interrelationships among the system variables to be grasped clearly and completely (Richardson and Boyd 1987). If desired, clearly understood simple models can be combined to create a more nearly

complete and more complex model that more closely approximates the real world situation (Richardson and Boyd 1987).

Several recent reviews of optimization modeling are available (Maynard Smith 1978; Oster and Wilson 1984; Foley 1985; Smith 1987). While the terminology used differs among them, there is broad agreement that optimization models are composed of four components. First, optimization models require an actor that chooses among or exhibits alternative states. Second, the models require a strategy set, the range of options available to the actor. Third, the models require a currency, a cost-benefit measure which is either minimized or maximized. Fourth, there are constraints, factors which limit the strategy set and which determine the payoffs of the strategies. In the present study the actor is an idealized population of prehistoric Native Americans. The strategy set consists of the various animal and plant resources available to the population for exploitation as food. The currency is the time spent on food procurement. This is to be minimized. The constraints consist of the energy and nutritional needs of the population, the nutritional composition of the resources, the time necessary for their exploitation, and the abundance of the resources in the environment.

Criticisms of Optimization

Several criticisms have been leveled against the use of optimization models in anthropology. Some are trenchant and deserve careful consideration. Others are polemical or based on misunderstandings of the nature and purpose of optimization modeling. Six categories of criticism of optimization theory are particularly prevalent (Foley 1985; Jochim 1983; Keene 1983; Maynard Smith 1978; Smith 1987).

The Meaning of a Predicted Optimum. Foremost among the criticisms born of misunderstanding is the assertion that optimization theory is misguided because people are not universal optimizers (cf. Jochim 1983; Keene 1983). As mentioned above, this

is recognized by biologists to be true of nonhumans as well: in most situations, conflicting demands dictate a compromise solution (Maynard Smith 1978; Oster and Wilson 1984). Optimization theory does not seek to prove optimization, but rather to generate and test specific hypotheses about environmental conditions and observed behaviors (Foley 1985).

Although the "universal optimizer" is a strawman, two trenchant points are related to this criticism. First, although optimization models strive to predict the absolute optimum, nature does not progress invariably towards the "best". It merely favors the design which is better than its existing competitors. For the optimum to be approached, selection must be longstanding and unidirectional. This presupposes a degree of environmental stability which rarely can be demonstrated (Smith 1987). For the current study of food procurement strategies in the Eastern Woodlands during the last 5000 years, this is not a problem. Relative to the rates at which cultural and behavioral changes can occur, the Eastern Woodlands environment has been essentially constant (Delcourt and Delcourt 1985).

A second problem concerning the predicted optimum results from the necessity to establish the strategy set of the model a priori. As a result the optimum solution used as the ideal template is, in fact, only the best choice from a pre-established set of choices. It is not necessarily the optimum (Lewontin 1987). How closely it approaches the true optimum depends on the scope of the strategy set, which is in turn dependent on the skill, imagination and knowledge of the modeler (Foley 1985). For this reason, it is perhaps better to view the output of any optimization model not as the determination of the optimal solution to a problem, but rather as the elimination of demonstrably suboptimal choices from a predetermined set (Oster and Wilson 1984).

In the current study the scope of the strategy set is problematic. The Eastern Woodlands environment contains literally thousands of animal and plant species, most of which presumably are edible but of limited practical value (e.g. insects). It is

obviously impossible to model the cost and benefits of the entire set, so a priori choices must be made. As a matter of practicality, attention has focused on those species known to have been exploited by Native Americans. This procedure does, of course, introduce a tautology and thereby further preclude a strict test of the hypothesis that prehistoric food procurement was an optimal solution to the food quest problem. However, since I am not testing the optimization premise, but rather seeking to clarify the relationships of resource characteristics and food procurement decisions, this is an acceptable procedure.

Optimization Models as Models of Decision-Making. An-other criticism of the anthropological usage of optimization models is that they may constitute poor models of human decision-making (Jochim 1983). Optimization models are generally built using quite precise continuous interval scales of measurement (e.g. kcal/min); whereas humans may rely more on ordinal scales of discrete classes of phenomena (e.g. big, fat game versus small, lean game) (Jochim 1983). Further, optimization models consider all variables simultaneously, whereas people may often use hierarchical procedures (Jochim 1983). In addition people are forced to deal with limited knowledge, faulty conceptions and limited calculating abilities, whereas optimization models assume all of these to be perfect. Because of the divergence between optimization models and actual human decision-making, Jochim has declared that "...future research must investigate the relationship between emic decision criteria and etic adaptive factors, and how this relationship varies with the environmental context" (1985:160).

While such research would be of undeniable importance, optimization models seem a proper tool with which to begin it, as they illuminate etic adaptive factors and environmental context and can be compared to the results of emic decision-making. The use of optimization models is thus a tactical consideration reflecting the desirability of constructing clearly understood simple models of complex phenomena before

attempting to develop more complex ones. It is not meant to imply a denigration of the importance of emic analyses.

Admittedly, however, a knowledge of how a people actually categorize their environment, evaluate and rank the resources therein, calculate the utilities of each resource and make choices among them would be preferable to any simple model regardless of how clearly understood. Plainly, though, such knowledge is not forthcoming for any extinct society. Prehistoric archaeologists must forego the emic approach. Furthermore, were ethnologists to be fortunate enough to produce a body of such detailed descriptions, a time would come when they would desire to relate the individual cases to each other and seek to explain how each might be seen as a particular example of a more general phenomenon. Again, clearly understood general, albeit simple, models would be the appropriate tools for seeking such understanding. In short, while criticisms of optimization relative to more realistic and precise particular models have some merit, they do not lessen the utility of optimization models as analytical tools for investigating diet choice.

Finally even if optimization models do not replicate emic decision-making procedures, they may still nonetheless capture the evolutionarily significant environmental conditions and selective pressures which have structured food procurement strategies (Smith 1987). Thus in the terms of Mayr (1961), optimization models may be of great utility in investigating the *ultimate* causes of subsistence strategies even if they fail to mimic the *proximate* manner by which the strategies are formulated.

The Time Scale of Optimization. The choice of an appropriate time scale can also be a problem when constructing an optimization model. In nature returns can be optimized over varying degrees of time with differing results. In particular short term suboptimal behaviors might be required in order to acquire the information needed for long term optimization. In addition, territoriality can have an important influence on

the time scale of optimization. If future access to a resource is insured, then short term losses might be acceptable in order to maximize returns at a later date (Maynard Smith 1978; Jochim 1983). Foley (1985) has suggested that hominids optimize over an annual period or perhaps longer. In this study of food procurement strategies a seasonal time period will be used, as this seems the appropriate period for accessing the costs and benefits of procuring plants and animals in the temperate forest.

The Currency of Optimization. The choice of a proper currency to use in an optimization model is a thorny issue for optimization modelers in all disciplines. Economists use as a currency "utility", which is not theoretically defined but instead is determined empirically from observations of consumer choice (Foley 1985; Smith 1987). This creates a tautology: goods are chosen because they have higher utilities, and they are known to have higher utilities because they are chosen (Plattner 1989:7). Evolutionary biologists using optimization models require a currency which is a cause of differential fitness (Lewontin 1987:154). Energy is the most frequently used currency in biological and anthropological optimization models, since energetic efficiency can be linked to fitness in both human and nonhuman populations (Smith 1983). This is because, if energy is limited, increased energetic efficiency yields more energy with obvious fitness-enhancing effects. If energy is abundant, increased energetic efficiency leads to savings of time, which, theoretically at least, should be applicable to other fitness enhancing activities (Smith 1979). The acceptance of energy as a currency for humans can be questioned, however. Many environments seem energy rich, and it is difficult to know the extent to which time was a constraint in the past (Foley 1985).

In the present study, it is assumed that the prehistoric population aimed to achieve a nutritionally adequate diet while minimizing the time spent in the food quest. This seems a reasonable assumption and allows comparison with earlier subsistence

optimization studies (Reidhead 1976; Keene 1979). To investigate the roles of nutritional constraints as well as energy, linear programming will be used.

The Propriety of Optimization Theory. A final set of criticisms of optimization models is more often implicit than directly stated (Keene 1983, 1985). It implies that optimization theory is philosophically (if not morally) improper. In its worst form, this criticism notes the historical indebtedness of optimization theory to neoclassical economics and hints that users of optimization models are capitalist tools. For example one anthropologist has queried, "How does this kind of theory mirror and legitimate social practice in the modern world?" (Keene 1985:268 emphasis added). Although it is always wise to be aware of the underlying assumptions that accompany an approach borrowed from another discipline, this criticism does not seem germane. First, there is no evidence that proponents of optimization models within anthropology or biology are politically conservative (Smith 1987). Second, since the only alternative to neoclassical economics is Marxist economics (Plattner 1987:7), there is no politically untainted option for those pursuing an economic study.

In its more relevant guise, the philosophical criticism of optimization theory in anthropology emphasizes the importance of emergent phenomena in general, and of societal constraints in particular (Jochim 1983; Keene 1983, 1985). Even this, however, seems largely misguided as it confuses the analytical reductionism of model-building with a philosophical reductionism denying the importance of supra-individual factors in understanding human behavior (Richardson and Boyd 1987). Optimization modeling does not preclude a recognition of the importance of social factors, but the creation of a clearly understood, simple model requires that some complicating factors be omitted (Levins 1965). As a first approximation of a complex phenomenon, a simple model focusing on individual behavior offers the possibility of clarifying the interrelationships among human nutritional needs, resource characteristics and subsistence choices but sacrifices investigating societal constraints.

In the present study the complexities engendered by social living do get "approximated away" (Keene 1983:141) in that differential allocation and consumption of resources is not considered. Except for calculating age- and sex-dependent nutritional requirements, the population is treated as an aggregate of identical individuals. Hence, I have created just the sort of model about which Keene asks, "What is the value of subsistence studies that remove production from its social context under the guise of simplifying assumptions (1985:262)?" To this I would answer that its value is just that - studying subsistence production. Simplifying the model does preclude investigating other important cultural phenomena, but this is more than outweighed by the benefits to be gained from illuminating clearly a more circumscribed problem.

LINEAR PROGRAMMING.

The following discussion of linear programming is much simplified, touching only on its features utilized in this study. For a more thorough review written for an anthropological audience see Reidhead (1979). Various texts in operations research provide more detailed discussions and examples of linear programming (e.g. Shapiro 1984; Swanson 1980; Thie 1979).

Linear programming is a method for determining the optimal allocation of resources towards a specified goal. It should not be confused with the statistical procedure of linear regression. Linear, in the linear programming context, refers to the fact that the variables included in the model must be interrelated in a linear fashion. That is, a unit increase or decrease in a variable must always produce a constant proportional effect in other variables. Too, linear programming should not be confused with computer programming. Programming, in the linear programming context, refers to the specification of a sequence of activities, namely the allocation of resources.

Linear programming is widely used in economics, operations research and ecology, and "canned" computer codes are widely available for both mainframe and personal computers. This study uses LPSBA, a linear programming code for microcomputers developed by the University of North Carolina School of Business Administration (Neebe 1987).

Linear programming models are composed of three components: an objective function, decision variables, and constraints (Shapiro 1984: 13-15). The objective function is the goal to which the actor allocates resources. It can be expressed (in terms of some currency) as either the maximization of some return or as the minimization of costs. Decision variables are the activities (i.e. the strategy set) among which choices must be made. Constraints are the factors which limit the activities that can be undertaken.

The structure of a linear programming model is best shown by an example. Consider the following problem. A family wishes to meet its nutritional needs with the least expenditure of time. Its nutritional needs are 8000 calories and 180 grams of protein per day. It has available two resources which can be exploited, nuts and fish. A pound of nuts contains 1600 calories and 20 grams of protein. A pound of fish contains 800 calories and 60 grams of protein. A pound of nuts can be gathered and prepared in one hour, while a pound of fish can be captured and prepared in an hour and a half. Additionally, the immediate environment has limited resources, and the family knows it will not be able to obtain more than six pounds of nuts or more than five pounds of fish per day. What is the optimal diet for this family?

In the above problem the objective function is the minimization of time spent in the food quest. The decision variables are the amount of time to be spent fishing and the amount of time to be spent nut-gathering. The problem constraints are of two sorts. First there are the nutritional constraints: energy intake must equal or exceed 8000 calories per day and protein must equal or exceed 180 grams per day. Second

there are two availability constraints: The amount of nuts acquired must be equal to or less than six pounds and the amount of fish must be equal to or less than five pounds.

This can be written algebraically as:

Minimize

$$T = 1.0n + 1.5f, \quad \text{where } T = \text{total time spent in the food quest}$$

n = pounds of nuts gathered

f = pounds of fish caught

Subject to

$$1600n + 800f \geq 8000 \quad \text{the caloric constraint}$$

$$20n + 60f \geq 180 \quad \text{the protein constraint}$$

$$n \leq 6 \quad \text{the nut availability constraint}$$

$$f \leq 5 \quad \text{the fish availability constraint}$$

Additionally, in order to ensure the algorithm produces a solution that is sensible for the real world, linear programming always includes non-negativity constraints. These simply specify that

$$n \geq 0$$

$$f \geq 0$$

As the problem contains only two resources, the solution can be easily obtained graphically (fig. 2.1). In the graph the lines label "protein" and "calories" are indifference curves. Each connects all combinations of fish and nuts which exactly satisfy one of the problem constraints. Thus it can be seen that a diet consisting exclusively of either five pounds of nuts or 10 pounds of fish would meet the family's caloric requirement, as would any combination nuts and fish which fall along the calorie indifference curve. Likewise a diet consisting exclusively of nine pounds of nuts or three pounds of fish would meet the families protein requirements, as would

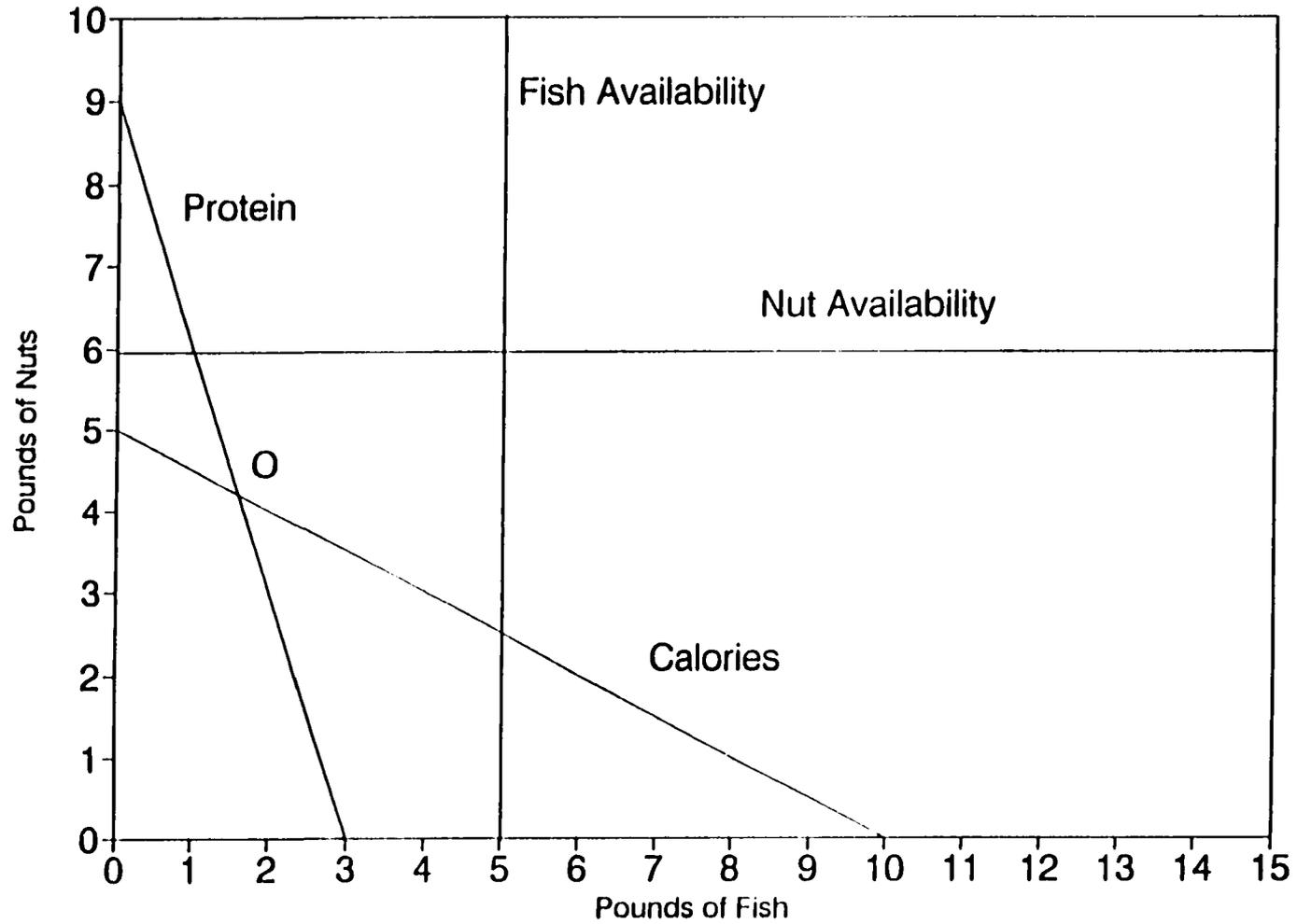


Figure 2.1: Graphical Solution of an Example Optimal Diet Problem

any combination of nuts and fish on the protein indifference curve. Since the calorie and protein requirements are greater-than-or -equal-to constraints, any point which falls to the side of the curves away from the origin also satisfies the constraint. Since the availability indifference curves are less-than-or-equal-to constraints, any point which falls on the side of the curves toward the origin will satisfy the constraints.

Those combinations of nuts and fish which simultaneously satisfy all four constraints are considered the problem's "feasible region". Any combination of nuts and fish within this region will meet or exceed the specified minimum nutrient requirements of the family and be obtainable by them in the immediate environment. In this example the feasible region is the quadrilateral region bounded by the four constraint lines.

It is a mathematically demonstrable property of simultaneous linear equations that the optimal solution will always lie at one of the corner points of the feasible region (Shapiro 1984:55). This reason for this is that no interior point can be optimal, since the objective function can be decreased by moving towards the origin until a constraint line is encountered. Likewise, a point on a constraint line can be improved by moving along it to a corner point (Shapiro 1984: 55).

For example in the example problem the protein constraint line has a slope of -3.0 indicating that a unit increase in fish will be matched by a 3.0 unit decrease in nuts. Given that each pound of nuts costs one hour and each pound of fish 1.5 hours, this means each unit increase in fish saves 1.5 hours ($1.5 \text{ hr.} - 3.0 * 1 \text{ hr.}$). Hence in regards to protein, fish utilization should be maximized. Graphically this means the objective function can always be improved by moving along the protein constraint line as far to right as possible, i.e. to the corner point. On the other hand the calorie constraint has a slope of only -0.5, indicating each unit increase in fish is matched by only a half pound reduction in nut utilization, thereby worsening the objective function by one hour ($1.5 \text{ hr} - 0.5 * 1 \text{ hr}$). Hence, in regards to calories, fish utilization should

be curtailed. Graphically, one desires to move along the calorie line as far to left as possible. Simultaneously improving the objective function along both the protein and calorie constraints brings one to the vertex of the protein and calorie constraint lines at the point defined by 4.2 pounds of nuts and 1.6 pounds of fish. This is the optimal resource mix and would require 6.6 hours to obtain.

Sensitivity or Postoptimality Analysis

Although the discovery of an optimal solution to the problem is in itself interesting, linear programming models are perhaps most useful for providing insights into the interrelationships of variables and for elucidating how changes in one variable effect other model components (Reidhead 1979). It is particularly useful to know how far one variable can be modified before a change in basic problem structure occurs. Linear programming provides these data in the form of post-optimality (Reidhead 1979) or sensitivity (Neebe 1987) analysis.

Sensitivity Analysis of Constraints. An examination of fig. 2.1 shows that the optimal solution of 4.2 pounds of nuts and 1.6 pounds of fish lies at the intersection of only the protein and calorie constraint lines. The two availability constraints are not involved. This indicates that of the four constraints investigated in this example, only the nutritional requirements are important. The absolute abundance of the two resources is irrelevant. In the jargon of linear programming, protein and calories are said to be "binding constraints" while the constraints on the availability of nuts and fish are "slack". Any change in a binding constraint modifies the objective function, whereas a change in a slack constraints has no effect unless it is so great as to modify the basic structure of the problem. An important benefit of linear programming is that it allows investigation of how changes to problem constraints affect the optimal solutions. Figure 2.2 show a modification of the example problem in which the caloric requirement is increased to 11,200 calories from 8000 calories. Now, the feasible

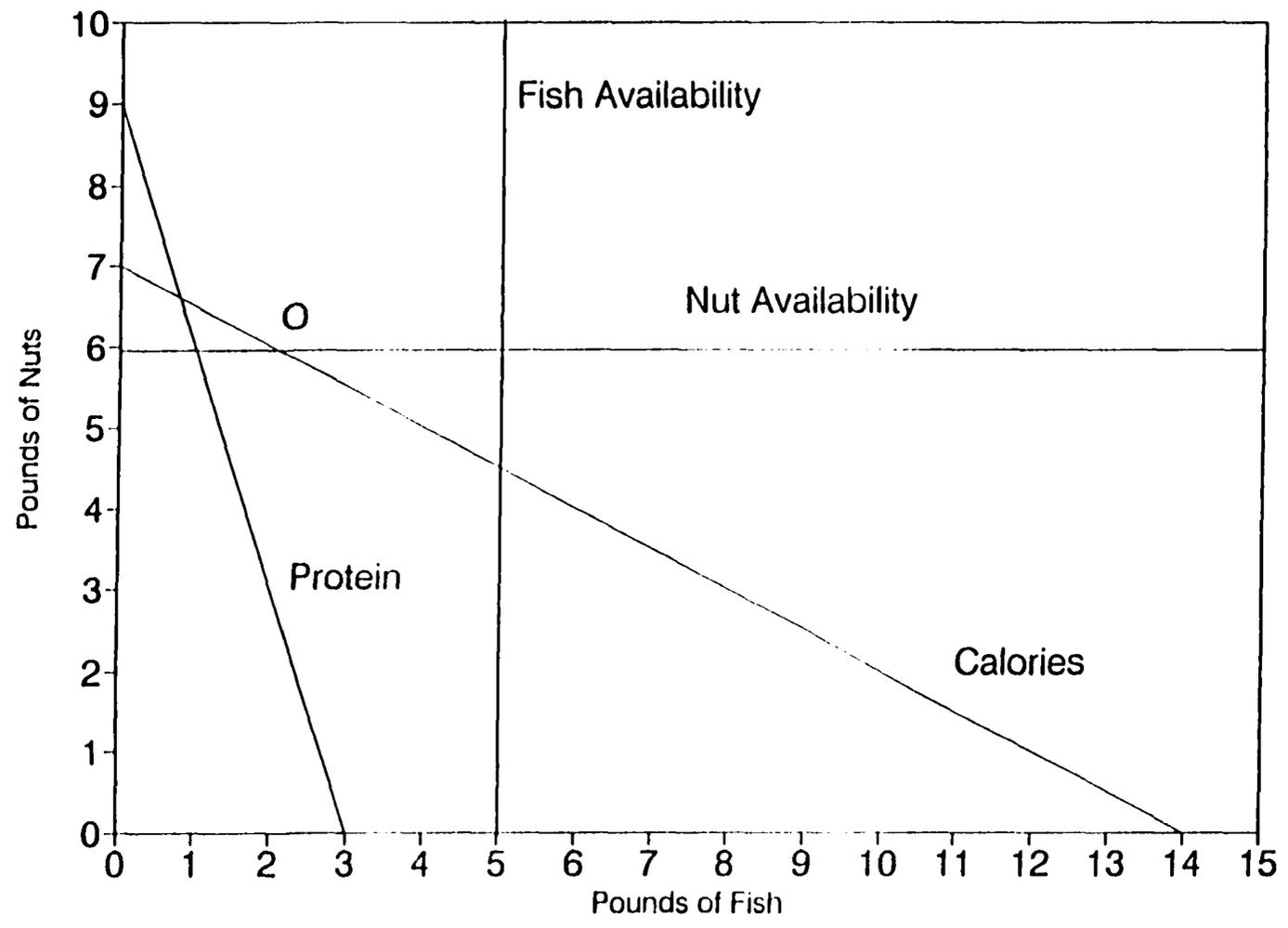


Figure 2.2: Graphical Solution of an Example Optimal Diet Problem with Modified Constraints

region has shrunk to the triangular area bounded by the calorie, nut availability and fish availability constraint lines. The optimal diet is now six pounds of nuts and two pounds of fish requiring nine hours to obtain. The new optimal solution (point O on the graph) lies at the vertex of the calorie and nut availability lines, indicating that nut availability has become a binding constraint, but protein is no longer one. This can be verified by calculating the nutrient composition of the optimal diet, which can be seen to include exactly 11,200 calories ($6 \text{ lbs} * 1600 \text{ cal/lb} + 2 \text{ lbs} * 800 \text{ cal/lb}$) but 240 grams of protein ($6 \text{ lbs} * 20 \text{ g/lb} + 2 \text{ lbs} * 60 \text{ g/lb}$). This is a surplus of 60 grams of protein.

With a caloric requirement at this level, the family should perceive its environment in a different manner than they did at the 8000 calorie level. In the first example, both calories and protein were binding constraints: thus any increase in the requirement of either would necessitate a change in the resource mix. Now, however, moderate increases in the protein requirement (up to 33%) would not require any adjustments to resource selection. An increase in the caloric requirement, which formerly could have been met by reducing fish and increasing nut exploitation, would now necessitate increased fish exploitation and a constant level of nut usage. Since all the available nuts are now exploited, they would now be perceived as a scarce commodity. Furthermore, a unit increase or decrease in nut availability, formerly of no consequence since nuts were available in excess, now results in a change in the cost of resource procurement. In a sense the former subsistence strategy of the family has broken down. They no longer maintain a balanced diet through a mixed subsistence strategy in an environment perceived as generous. Now, energy needs compel them to exploit their plant foods to the maximal extent. Any further increase in energy demands (or decrease in nut availability) will force them to intensify costly fishing even though protein is not needed.

Sensitivity Analysis of Costs. The sensitivity analyses of linear programming also provide information on how sensitive the optimal solution is to changes in (or faulty estimations of) the costs of the resources. In the above examples nuts return 1600 cal/hr and 20 g protein/hr and fish return 533 cal/hr and 40 g protein/hr. At the assigned costs, nuts are the superior source for calories and fish the superior source for protein. However, if the cost of nuts were reduced to 0.5 hr., then they too would return 40 g protein/hr. and would thereby become an equivalently cheap source of protein.

By using the modified cost of 0.5 hr for nuts and "pricing out" the corner points of fig. 2.1, one can see that point B, representing 6 lbs of nuts and 1 lb of fish now costs 4.5 hrs, the same as the formerly optimal diet at point A. Any further reduction in the cost of nuts would make point B the sole optimal diet. In terms of the fig. 2.1 graph, the optimal solution has moved upwards away from the former optimal corner point in the direction of more nut utilization. Intuitively this makes sense, as the cost of nuts decreases, more nuts are utilized.

One should also note that point B represents the vertex of the protein and nut availability constraint lines; nut availability is now a binding constraint and calories a slack one. Again, the basic structure of the problem has changed. Now the family would perceive their environment as a relatively energy-rich one, while protein would seem relatively scarce. Subsistence would key on obtaining protein and energy would be produced in excess.

Just as decreasing the cost of nuts moves the optimal solution towards the corner point representing increased nut utilization, increasing the cost of nuts would move it away from nut utilization to point D, representing 5 lbs of fish and 2.5 lbs of nuts (fig. 1). Point D becomes an optimal solution when nuts cost 3.0 hr/lb, making them no better a calorie source than fish. At costs above 3.0 hrs/lb, point D is the unique optimal diet, nut utilization should be minimized, and protein is obtained in surplus due

to increased fish exploitation. Calories and fish availability are the binding constraints. Of course, manipulating the cost of fish will produce the same sort of shifts among points A, B, and D.

The above discussions exemplify how sensitivity analyses can be of analytic interest by specifying significant variables and for determining the degree of systemic variation allowable by a particular optimal solution. However, sensitivity analyses have another important practical benefit for modelers. Namely by specifying the ranges over which a variables can vary before creating a change in the optimal solution, they indicate how sensitive the model result is to possible errors in model construction (Reidhead 1979). This is particularly important for models of prehistoric subsistence change, since so much uncertainty surrounds their quantification (Reidhead 1979; 1980; Keene 1981).

Computer Solution of the Optimal Diet Problem

Table 2.1 shows an abridged and modified version of the output generated by solving the first example problem using LPBSA (Neebe 1987). Note that the results agree with the graphical solution (Fig. 2.1). The objective function is indicated to be 6.6 hours and the basic structural variables, that is the optimal diet, are specified to be 4.2 pounds of nuts and 1.6 pounds of fish. The resource availability constraints are shown to be slack and the amounts of the "slack", 1.8 pounds of nuts and 3.4 pounds of fish, specified.

In addition the model provides "sensitivity analyses" which indicate the range over which model parameters can vary before there is a change in the basic structure of the optimization problem. The "Sensitivity Analysis on Constraints" indicates the variation that can be tolerated in the model constraints, while the "Sensitivity Analysis on Costs" indicates the acceptable range of variation in the costs of the resources.

Table 2.1: LPBSA Solution of the Example Optimal Diet Problem.

Minimal objective function value: 6.60000

Basic structural variables		Basic slack and surplus variables		
nuts	4.20000	nutamt	1.80000	Slack
fish	1.60000	fishamt	3.40000	Slack

SENSITIVITY ANALYSIS ON CONSTRAINTS

	BLOCKING	LOWER	VALUE	VARIABLE	UPPER	BLOCKING
VARIABLE	BOUND	BOUND	BOUND	BOUND	BOUND	BOUND
nuts	2400.0	8000	calories	10400	nutamt	
fish	100.0	180	protein	350	fishamt	
nutamt	4.2	6	nutamt	None		
fishamt	1.6	5	fishamt	None		

SENSITIVITY ANALYSIS ON COSTS

	BLOCKING	LOWER	VALUE	VARIABLE	UPPER	BLOCKING
VARIABLE	BOUND	BOUND	BOUND	BOUND	BOUND	BOUND
calories	0.5	1.0	nuts	3.0	protein	
protein	0.5	1.5	fish	3.0	calories	

For example the top line of the Sensitivity Analysis of Constraints shows the range over which the calorie constraint can vary. Its current value in the model is specified as 8000, its lower bound as 2400 and its upper bound as 10400. As long as other variables remain constant and the caloric requirement remains between these two extremes, the optimal diet remains 4.2 lbs of nuts and 1.6 lbs of fish. The lower bound represents the number of calories that would be gained as a consequence of fulfilling the protein requirement solely from fish. The computer output rightly flags "nuts" as the variable that would leave the solution at this point, but confusingly labels it a "blocking" variable. Raising the caloric requirement beyond the upper bound of 10,400 calories will result in nut availability becoming a binding constraint. Nutamt is flagged as the blocking variable.

The sensitivity analysis of the protein constraint mirrors that of the calorie constraint. If the requirement is lowered to 100 grams, fish leave the solution. If it is raised to 350 grams, the amount of fish becomes a binding constraint. Finally, the two slack constraints have lower bounds set by the optimally utilized amounts of the resources, but have no upper bounds. This is sensible, since a relaxation of a constraint already having no effect on the solution would likewise have no effect.

The effects of modifying the costs of the resources can also be read directly from the sensitivity analysis. The "value" of nuts, currently 1.0 hours per pound, is indicated to have an acceptable range of from 0.5 hours to 3.0 hours per pound. If its cost exceeds this range, then the structure of the problem changes and the optimal solution shifts to a new corner point. As was determined above by "costing out" the corner points, in the case of a reduction in nut costs beyond 0.5 hours, the optimal diet would shift to 6 pounds of nuts and 1 pound of fish, and calories would no longer be a binding constraint. The output flags calories as the blocking variable. The upper bound of 3.0 hrs. also agrees with the results of the "costing out" exercise and indicates the cost beyond which protein ceases to bind and fish availability begins to bind.

PRIOR LINEAR PROGRAMMING STUDIES OF EASTERN WOODLANDS PREHISTORY

In a study of Iroquoian animal procurement strategies, Webster (1983) made an interesting use of linear programming. Webster wished to illuminate the factors governing Iroquoian game selection and to explore how the historic fur trade might have created change in hunting practices.

Unlike other linear programming studies of Eastern Woodlands subsistence, Webster's optimal diet model did not investigate the mix of resources that most cheaply met an objectively derived level of nutritional intake. Rather Webster based demand on the inference that Iroquoians derived 15% of their calories from meat and fish (1983:179). Nutrients were not considered, but Webster incorporated into his model the need to acquire a certain amount of pelts for trade. He did not investigate the role of plant foods other than noting that Iroquoian hunting was performed at an energetic loss and required subsidies from agriculture (Webster 1983:iv). Webster developed costs largely by inference from ethnohistoric accounts of eastern Woodland hunting. He estimated the time cost of acquiring species during each season, then used linear programming to generate the optimal mix of seasonal strategies to meet the yearly demand for meat and pelts (Webster 1983:201).

The optimal strategy mix predicted by Webster's model was fishing during the spring fish runs, hunting deer in the fall, and hunting deer, bear and beaver in winter. As demand for pelts was increased in the model, the predicted harvest expanded to include more furbearers at the slight expense of deer (Webster 1983:203). This is a fairly good match with historic observations of Iroquoian animal procurement. The models successfully captured the importance of the spring fishing runs, fall deer hunting and winter hunting of deer, bear and beaver, and successfully noted summer as a time not devoted to animal procurement (Webster 1983:208). It failed, however, to

include elk, turkey and passenger pigeon as targeted prey even though they are known to have been pursued regularly by Iroquoians (Webster 1983:209).

Comparison of the predicted harvest to faunal remains from Susquehannock sites indicated only a very general fit. Webster ascribed the poor fit to inadequate data for creating the model, but also suggests that military risk may have constrained Iroquoian hunting practices (Webster 1983:296). However, as the faunal remains were taken from sites that were not screened (Webster 1983:277), they are unlikely to be representative of the animals actually taken.

The earliest use of linear programming in Eastern Woodlands archaeology is Reidhead's (1976, 1980, 1981) study of optimal resource selection by Native Americans during the Late Woodland and Fort Ancient periods in southeastern Indiana. For each period Reidhead used linear programming to select from 16 animals and 19 plants the resource mix for each season that was obtainable in the least amount of time and that would meet the population's demand for energy, protein, calcium, phosphorus, iron, vitamin A, riboflavin, niacin and ascorbic acid. Reidhead's study had two goals (1980:142): first, to test the hypothesis that prehistoric Native American's diet selection was guided by the principle of least effort, and secondly, to examine the implications of subsistence change by identifying the ecological and economic constraints that governed subsistence decisions.

Reidhead's model indicated that during the Late Woodland period fish would have been most in demand, followed by squash. Deer and acorns were optimal choices in the fall, and mussels, maple sugar and turtles would have been in high demand due to their rich calcium content. Calcium was determined to be the most limiting nutrient, as it was a binding constraint in all seasons. In addition, vitamin A was binding in winter and spring, ascorbic acid and thiamine in spring, and energy during the summer and fall (Reidhead 1981:80). The results of the Fort Ancient period models were generally similar (Reidhead 1980:173-174). However, corn agriculture was predicted

to be adopted, and weed seeds and fruits were more important due to increased availabilities resulting from agricultural clearance. Protein emerged as a critical nutrient, since corn consumption met energy needs cheaply but at the risk of protein deficiencies (Reidhead 1980:173-174).

Reidhead's comparison of the predicted diets against the actual faunal and botanical remains recovered from the Late Woodland and Fort Ancient components of the Leonard Haag site in southeastern Indiana demonstrated a rather limited correspondence. In particular fish, mussels, and turtles were very poorly represented at the site, in spite of the fact that these calcium-rich resources had been predicted to be the dominant portion of the diet. On the other hand, deer, elk, box turtle, and raccoon were common finds although they had been predicted to be of little importance.

Testing the accuracy of the predicted diet as regards plant foods was very difficult as the three items predicted to be most important -- maple sugar, tubers, and greens -- are not likely to be preserved archaeologically. Excluding these three resources, there is a basic presence-absence correspondence between the predicted and recovered plant remains (Reidhead 1981:94,100). Notable, however, was the failure of the model to predict the inclusion of walnuts and hazelnuts in the optimal diet; whereas both were recovered from the Leonard Haag site in abundance (Crawford 1981).

Reidhead's conclusion from the study was that in both periods food procurement was based on optimal or near-optimal strategies, although the underutilization of fish and the use of walnuts and hazelnuts were considered exceptions. Hence, strict effort-minimization was not seen to be the goal of prehistoric Native American subsistence strategies (Reidhead 1981:103). Furthermore, Reidhead concluded, rightly I think, that the greatest utility of least effort models was in their use as standards against which real life decisions can be evaluated. In this regard he noted that with the exception of the use of corn in the Fort Ancient period, both the predicted and the observed strategies of

the Late Woodland and Fort Ancient periods were similarly structured. In addition, he pointed out that the absence of calcium-rich resources in the observed diet raises important questions about the role of that nutrient in prehistoric North America (Reidhead 1981:103).

Reidhead's modeling is a credible exploration of a then untried technique for investigating prehistoric human subsistence behavior. Unfortunately, it is seriously flawed. Since the appearance of Reidhead's dissertation (1976), Maynard Smith (1978) has argued cogently that the optimization hypothesis is not subject to test by modeling. Whereas a close fit between real world events and model output is prima facie evidence that the model has captured the essential dynamics of the system under study, a discrepancy between the real world and the model cannot be ascribed to the absence of real world optimization. Rather every model contains such a plethora of assumptions about relevant components and estimations of parameter values that any discrepancies must be presumed to be the result of errors in the modeling enterprise. Therefore in retrospect, it can be seen that Reidhead set an impossible goal for himself in attempting to test the optimization assumption.

In and of itself this is of little consequence: optimization is such a thorny issue in the social sciences that one study, more or less makes, little difference. It is significant, however, in the way in that it misguided model construction. In hopes of testing the optimization assumption, Reidhead strove assiduously to make his models as realistic as possible and attempted to incorporate as many potentially relevant factors as possible. Hence, Reidhead estimated such factors as storage losses to vermin, nutrient losses to drying, seasonal changes in nutrient composition in meat due to fat fluctuation in game, poor protein quality of corn and squash, poor niacin quality in corn, differential hunting success between Fort Ancient bow and arrow hunters versus Late Woodland atlatl hunters, population growth from Late Woodland to Fort Ancient times and the increased availability of fruits and weeds due to land clearance (1976:Chapters

3-6). Although including these factors may serve to increase the realism of the model, their simultaneous inclusion in the models vitiates the utility of the models for identifying the ecological and economic constraints that govern subsistence behavior. This was, of course, Reidhead's stated secondary goal. As a result of his attempts to test the optimization hypothesis, Reidhead's models are so complex that the interrelationships of variables are obscured, and it is rarely possible to determine what constraints are significant.

In a similar study, Keene (Keene 1979, 1981) used linear programming to investigate the factors influencing food procurement decisions and the effects of environmental perturbations on subsistence decisions for Late Archaic period foragers in the Saginaw Valley, Michigan.

In some respects Keene's work is an extension of Reidhead's (1976) in that he examines the role of the same ten nutrients. It differs in adding hides (for clothing) as a constraint, in dealing only with foraging without considering food production, and most significantly in the measurement of food procurement costs. Keene rightly recognized that Reidhead, by relying on ethnohistoric accounts of successful food procurement endeavors, discounted the effects of failed attempts in inflating the cost of food acquisition. To rectify this, Keene developed an artificial coefficient of cost based on the distribution and accessibility of resources (Keene 1981:177).

In addition to the advantage of incorporating the risk of foraging failure, Keene's coefficients, he argued, are more general and less tied to a particular environment than are Reidhead's historically reconstructed costs. Although in theory such coefficients might be quite general, in practice Keene's are idiosyncratic.

Keene's basic formula for creating the coefficient is intuitively sensible. It is the sum of the costs of search, pursuit, and processing multiplied by an index of risk. For plants the search time is the reciprocal of edible biomass per square kilometer. For animals search time is considered a direct function of prey mobility (minimal seasonal

range) and an inverse function of resource density (animals per square kilometer). This is sound, although mobility can make prey more easily found if tracking is an important predator tactic (Winterhalder 1981:90)

Pursuit cost is stated to reflect the relative ease of taking clumped rather than widely distributed resources. For plants, however, it is operationalized as the reciprocal of the number of kilograms of edible biomass per hectare. Since a hectare equals 1/100 of a square kilometer, the pursuit costs of plants always equals 1/100 of the search cost. Hence, this factor adds no variability to the cost of plant food, rendering the model insensitive to differences in the distributional characteristics of plants.

For animals, pursuit cost is the reciprocal of average group size multiplied by the difference between the distance that the hunter can strike and the distance at which the prey can detect him. This is rather perplexing. First, the assumption that living in a large group makes an animal more vulnerable to predation is counter to the generally accepted interpretations of the function of herding behavior (Horn 1968). Secondly, although Keene's "critical distance" seems reasonable as a factor influencing foraging success, its operationalization is mysterious. Keene does not discuss Archaic period weapon ranges or the sensory acuity of animals, nor does he provide citations concerning either. Apparently, he assigns a critical distance value in some intuitive manner. This is unfortunate in that the values range from one meter for fish and turtles up to 395 meters for bear (Keene 1979:Table 8); thus, the measures of critical distance significantly influence the relative costs of game.

Processing cost is also assigned intuitively. Keene ranks the resources by their relative costs and assigns each a cost equal to its rank. As there are 14 resources, the processing costs vary from 1 to 14.

Risk is assigned intuitively as either 1, 1.25 or 1.5 depending on whether the resource availability is constant, predictably variable, or erratically variable.

Overall Keene's cost measure has several weaknesses. First, it is an artificial index that has no real-world referent. It cannot be translated into any meaningful unit of measurement (Keene 1979:55). Second, rather than being general, as Keene professes it to be, the index is idiosyncratic to the point of irreproducibility. Third, the various parts of the model have widely disparate effects on the final value of the index. For example, nuts have an edible biomass in the Saginaw, according to Keene, on the order of 100-1000 kg/km² (Keene 1979:Table 3). Taking the reciprocal of nut biomass to estimate search and pursuit costs provides a number with an order of magnitude of 0.001. However, Keene adjusts this figure upward by multiplying by a constant of 100 to make it more intuitively reasonable (1981:179). This adjusted search cost of an order of magnitude of 0.1 is then combined with Keene's rank order estimation of processing costs, which for nuts has an order of magnitude of 10 (Keene 1979:Table 9). Thus the processing costs of nuts are seen to have 100 times the effect of search and pursuit costs in determining the total cost of the resource.

In general, Keene's cost measure is so complex and idiosyncratic that it in essence becomes a "black box" whose influence on model output is impossible to evaluate. As it is generally conceded that the principal utility of linear programming is heuristic, allowing the anthropologist to investigate the interrelationships of system components (Reidhead 1979; Keene 1981), this is a particularly unfortunate shortcoming.

Other aspects of Keene's modeling construction detract from the clarity of the model as well. Like Reidhead, Keene attempted to increase the precision of the model by adjusting data values to compensate for nutrient instability. In particular he modifies the nutrient composition of resources to allow for losses of vitamin C, thiamine, riboflavin and phosphorus due to cooking, for storage losses of calcium, phosphorous, vitamin A, and for storage losses of the overall amount of the resource.

Since these factors are incorporated simultaneously into the model, their effects are impossible to unravel.

In addition, some of Keene's values for resources are dubious. His "average" fall deer weight is estimated at 90 kg (198 lbs.) (Keene 1979:Table 8). This weight is obtained perhaps by fully grown bucks, but these animals would be less vulnerable than younger individuals. A more reasonable estimation taking into account the age and sex structure of the deer herd would be considerably less (Smith 1975:33-34). On the other hand, Keene's figures for the average available biomass of nuts appear to be too low. To derive his estimation of available biomass, Keene based his figures on per-tree nut production figures generated by forestry and wildlife management sources but then reduced the figures by up to 90% to compensate for nuts that are immature, fungused, or lost to predation (Keene 1979:105). As the per-tree production figures cited by Keene are for sound nuts and are based on the collection of nuts from the forest floor by modern foresters, the factors enumerated by Keene, especially competition with arboreal animals, have largely already been incorporated into the modern production figures. Keene, I believe, errs in so drastically reducing the availability of nuts.

Nonetheless, the results of Keene's modeling are surprisingly reasonable. Four seasonal strategies were indicated: fall deer hunting, broad spectrum foraging in the winter and summer, and fishing in the spring. Seven resources enter the optimal diet: deer, fish, beaver, turtle, "bushfruit", greens, and raccoon (Keene 1981:183). Like Reidhead, Keene found calcium and vitamin C to be limiting nutrients. The inclusion of fish, turtle, greens and fruit in the optimal diet results from the need to fulfill calcium and vitamin C requirements (Keene 1981:186). Energy, as in Reidhead's model, also was binding in the spring and summer but had only limited influence on the final optimal diet (Keene 1981:186). Thiamine was binding in winter, but this was considered an artificial result reflecting an overly severe estimation of thiamine loss by cooking (Keene 1981:187).

Somewhat unexpectedly, Keene found the need to acquire hides for clothing to be the most limiting constraint in the model (1981:186). If nutritional needs alone were modeled, then only about one-half as many deer would be needed (Keene 1979:282). Deer, Keene concluded (1981:181) were critical resources for the Saginaw Valley Archaic period foragers more as a source of clothing than as for food.

An especially counter-intuitive result of Keene's model was the absence of nuts as a part of the optimal diet (Keene 1981:188). Keene ascribed this to their lack of calcium and vitamin C and to their relatively high processing costs (1981:188). Cost, I feel, is the key factor here. As noted above, Keene's cost index for plants is particularly sensitive to his rank order measure of processing difficulty. Notably, the only two plants to enter the diet, greens and "bushfruit", are the two with the lowest processing costs (Keene 1976:Table 9).

Keene, however, takes the exclusion of nuts from the optimal diet in the Saginaw Valley at face value and cautions those who generalize from the archeobotanical records of Illinois river and Tennessee river valleys "against the careless extension of models outside the region for which they were developed" (1981:189). Apparently observing this same caveat, he refuses to extend his conclusion as to the nonoptimality of nuts to other regions. As the nutritional composition of the nuts is not unique to the Saginaw valley, and Keene professes to have constructed an artificial cost measure (1979:413-414) in order to maximize the models generality, his hesitancy to generalize this result to other regions is troubling. By narrowing the scope of model relevancy to the Saginaw Valley alone, Keene largely removes his model from archaeological refutation.

Keene, himself, does provide a limited archaeological test by comparing the model results to the faunal and botanical remains from four Late Archaic period Saginaw valley archaeological sites. Unfortunately, preservation was so poor that faunal remains could be identified only to the level of class (Keene 1979:Chap. 7) and

recovery of plant foods was virtually nil (Cowan and Smart 1979). Ironically, nutshell was present at all sites. Keene considered that there was a relatively good fit between the model and data (1979:393) but provided no statistical tests.

Keene concluded that his model had provided three useful insights. First, it focused attention on gathering as a key strategy for maintaining the nutritional quality of the Late Archaic period diet (Keene 1979:418). Second, it determined hides to be a critical limiting factor in the Saginaw Valley, and third, it questioned the traditional importance ascribed to nuts in Late Archaic period subsistence (Keene 1979:419).

THE INTENT OF THIS STUDY

This dissertation will follow Reidhead and Keene in using linear programming to determine what resources a Native American population in southwestern Virginia should have selected in order to maintain a diet adequate in energy, protein, iron, calcium, vitamin A, thiamine, riboflavin, niacin and ascorbic acid while minimizing the time expended in the food quest.

The currency used in this study will also improve upon those of Reidhead (1976) and Keene (1979). Unlike Reidhead's ethnohistorically reconstructed costs, my currency will account for the risk of unsuccessful pursuits. Unlike Keene's complex, artificial coefficients, my currency will be an analytically simple estimation of the time costs of resource acquisition. This measure will be defined as the sum of the time required to search for, pursue and process a resource modified by the risk of a failed pursuit. This is the general tact of most biological foraging models (Stephens and Krebs 1986) and possesses the strengths of realism, simplicity and intuitive comprehensibility.

I will also improve upon the research of Reidhead and Keene principally by sacrificing some realism in order investigate a more limited set of problems. I will not attempt to estimate and quantify potential complicating factors such as differing

hunting-success rates for the bow vs. the atlatl, storage losses due to vermin or spoilage, the differentiating visual acuity of game animals, or increased weed seed availability due to agricultural clearance. Instead I will focus on illuminating the interrelationships among a more analytically tractable -- and presumable more causally significant -- set of variables; namely, resource characteristics, human nutritional needs, population pressure, and the practice of plant husbandry. The effects of these variables on prehistoric diets will be addressed directly by determining what changes they precipitate in the optimal diets. Although the effects of the omitted variables be not be addressed directly, their potential significance can be assessed by sensitivity analyses.

In addition, rather than attempting to create a single comprehensive model that simultaneously accounts for a plethora of complex interrelationships, I will create a set of simple models that differ in terms of single components. Comparison of models that differ in only one component will then allow the role of that component in shaping diet choice to be the clearly grasped. The initial model will predict the optimal diet for a population of 25 foragers who strive to meet energy needs alone. Additional nutritional requirements will then be added sequentially. In this fashion the effects of various nutrients on optimal diet choice will be illuminated. Similarly, additional models will investigate the role of population growth, and the introduction of plant husbandry. In this manner the heuristic potential of linear programming will be maximized.

In short the dissertation aims to advance our present understanding of prehistoric Eastern Woodlands subsistence by emphasizing the heuristic potential of general, simple models. Some realism is sacrificed in order to maximize analytic clarity.

CHAPTER III CONSTRUCTING THE MODELS

This study takes as its starting point the assumption that the food resources exploited by prehistoric Native Americans reflect economically optimal choices for providing energy and nutrients at the least cost of time. A set of optimal diet models will be constructed using linear programming to investigate how resource characteristics, human nutritional needs, population size and the availability of cultigens might have interacted to structure prehistoric subsistence strategies.

Constructing the optimal diet models requires information on - or estimations of - resource availability and abundance, the costs of locating, acquiring and processing the resources, human population size and structure, human nutritional requirements, and the nutrient composition of the resources. The remainder of this chapter will present the data necessary to create the optimal diet models.

DAUGHERTY'S CAVE AND SOUTHWESTERN VIRGINIA

The models developed here are constructed to be generally applicable to the Eastern Woodlands, but the particular focus of the study is southwestern Virginia and especially the site of Daugherty's Cave (44Ru14). The prehistory of southwestern Virginia has not been investigated systematically. Two professional surveys and analyses of surface collections have been done (Evans 1955; Holland 1970). In addition a few sites have been professionally excavated as cultural resource management projects (e.g. Egloff and Reid 1980; Bott 1981; McIlhany 1983), and others have been excavated by avocational archaeologists associated with the

Archaeological Society of Virginia (e.g. Bartlett 1980; Jones 1989a, 1989b; Jones and MacCord 1990; MacCord 1979, 1981). Results of this prior work are uneven but are sufficient to establish that the culture history of the region parallels that of the Tennessee River valley. This is not surprising since the principal drainages of the region - the Powell, Clinch and Holston Rivers - form the headwaters of the Tennessee River.

For modeling purposes southwestern Virginia can be taken to represent the Eastern Woodlands as a whole. Southwestern Virginia is a "typical" Eastern Woodlands environment in that exceptionally productive resource zones such as extensive riverine shoals or coastal estuaries are absent.

As a test case, Daugherty's Cave has the advantage that the initial excavations (Bentall 1969, 1975) indicated that clearly stratified deposits spanning the Early Archaic to Mississippian periods were present there and that faunal and carbonized botanical remains were well represented, although no systematic effort was made to recover them. A further excavation of Daugherty's Cave promised the opportunity to acquire zooarchaeological and paleoethnobotanical data adequate for testing the predictions of optimal diet models. In addition an excavation focused on the recovery of subsistence remains would complement the earlier artifactually focused investigations (Bentall 1969, 1975) and would provide empirical evidence of prehistoric subsistence change in the region.

Daugherty's Cave is located on Big Cedar Creek approximately five kilometers (3 mi) from its confluence with the Clinch River (Fig. 3.1). The site is located in the Ridge and Valley physiographic province (Kenneman 1938) and is characterized by rugged northeast-southwest trending ridges and karst topography with abundant caves and sinkholes. Rivers and streams generally have poorly developed floodplains and are often deeply engorged into the underlying bedrock. Floodplain soils are hence of limited extent. High quality chert is readily available from the Chepultepec and

Conococheague formation limestones which make up most of the local ridges (Woodward 1938).

MODELING THE SOUTHWESTERN VIRGINIA ENVIRONMENT

For purposes of establishing the quantity of resources that could be exploited from Daugherty's Cave, it is assumed that the inhabitants foraged within a 10 km (6.2 mi) radius of the site. Ten kilometers is something of an established standard for estimating hunter-gatherer site catchments (Roper 1979; Jarman 1972). It is derived from Lee's (1969) study of !Kung foragers and represents the maximum area they exploited in single day trips. It is used here primarily for ease of comparison with other studies.

Forest Composition

Reconstructing the aboriginal forest within this catchment is fraught with difficulties. Some empirical information on the early forest might be gleaned from the enumeration of witness trees in early land patents and meets and bounds surveys (Holland 1981; Russell 1981). However, the precision that this data source might add to the reconstruction is of limited importance for a general study of Eastern Woodlands subsistence. Therefore I have chosen to rely on studies of the modern Ridge and Valley forest to guide the reconstruction.

This too is problematic. The modern Appalachian Hardwood Forest - of which the Ridge and Valley forest is a part - reflects a history of lumbering, past agricultural and stock-raising use, wildfire and chestnut blight (Smith and Linnartz 1980:151-153). Also, it should be remembered that a forest is a dynamic entity constantly undergoing change, and that Native Americans were not passive components of the forest community but rather modified it continually. Any assertion that the aboriginal forest can be reconstructed with precision is foolhardy. It should be possible, however, to

develop an approximation of the prehistoric forest accurate enough to serve as a baseline for a general model of subsistence strategies.

Species composition of a forest in mountainous terrain is largely determined by a moisture gradient reflective of the topographic variables percent slope, slope position, and aspect (Whittaker 1956). The most mesic sites are north to northeast facing coves, and the most xeric are high ridges or adjacent steep south to southwest slopes (Whittaker 1956; McEvoy et al. 1980; Smith and Linnartz 1980; Stephenson 1982).

The variation imposed on the forest by these topographic factors was recognized in an early non-quantitative overview of Russell County forests. O'Byrne (1922) divided the forest communities into four types: Cove, comprising 15% of the forest area; Bottom, comprising 15% of forest area; Slope comprising 60% of forest area; and Ridge comprising 10% of the forest area. In constructing the models, I will follow O'Byrne (1922) and consider the site catchment to have contained these types of forest in the extents he specified.

Unfortunately, O'Byrne only mentions the important species of the forest types without noting their relative frequencies of occurrence. However, these data can be obtained from other sources. Species frequency within the slope forest type is taken from a study of Virginia Ridge and Valley slope forests conducted about 135 km (85 mi) northeast of Daugherty's Cave (Stephenson 1982). Species frequency with the cove forest type is taken from a study of mesic lower north slope/cove type communities in the Ridge and Valley of Tennessee about 185 km (115 mi) southwest of Daugherty's Cave (Skeen 1973). These data will be the foundation of the reconstruction of the Daugherty's Cave catchment forest.

It will be assumed that 60% of the Daugherty's Cave catchment was slope forest (O'Byrne 1922) with species composition as specified by Stephenson (1982). It will be further assumed that 30% of the catchment was mesic cove or bottom forest (O'Byrne 1922) with a species composition as given by Skeen (1973). The 10% of the catchment

that was ridge forest will be omitted from the reconstruction. Much of this area would have been too rugged for exploitation and may have been largely in pines (O'Byrne 1922). From these data total number of tree stems in the catchment can be calculated (Table 3.1)

Two species of economic importance, walnut (Juglans nigra) and chestnut (Castanea dentata), not included in the above studies must be mentioned. Walnut was not included in any quantitative study of Appalachian Hardwood Forests that I could find (Day and Monk 1974; Golden 1974; McEvoy et al. 1980; Skeen 1973; Ross et al. 1982; Stephenson 1974, 1982). It was, however, formerly an important tree in the Russell County forest (Boyd 1881:191; O'Byrne 1922). I suspect that the high monetary value of its timber has resulted in a serious reduction in the amount of walnut in the forests of the eastern United States. As walnut is usually a scattered tree but is more common than butternut (Fowells 1965), I will arbitrarily assign it an occurrence of 2 stems per hectare, twice that of butternut. Typically, walnut prefers mesic sites, but Boyd (1881:191) stated that few areas in Russell County were without it, and O'Byrne (1922) listed it as a formerly important tree in the slope forest. Therefore, I will include it as present in both the slope and cove/bottom forest, yielding a total figure of 56.550 trees.

Likewise, chestnut was not included as a canopy species in any of the above studies, a result of its destruction by chestnut blight in the early twentieth century. Its space in the Appalachian Hardwood Forest has been filled by various species of oaks (Stephenson 1974; Smith and Linnartz 1980). Because of the post-blight expansion of oaks, my reconstruction inflates their numbers at the expense of chestnut. Although I could arbitrarily adjust the figures, I will not do so. As a food, chestnuts probably were treated much as acorns were. They perhaps were less common, and therefore more expensive to gather, but also less costly to process due to their lack of bitter tannins. Furthermore, chestnut is rarely reported in paleoethnobotanical analyses,

Table 3.1: Species Composition and Abundance in the Daugherty's Cave Catchment Area Canopy Forest

Forest Type and Species	No./ha	Area (Hectares)	Total Count (Thousands)
Slope Type¹		18500	
Quercus prinus	162		3054
Q. rubra	159		2997
Q. velutina	30		556
Q. alba	19		338
Q. coccinea	< 1		9
Carya spp.	46		867
Noneconomic spp.	175		3289
Cove/Bottom Type²		9425	
Carya spp.	79		742
Q. velutina	25		232
Q. alba	20		186
Q. rubra	5		46
Juglans cincera	1		11
Noneconomic spp.	446		4203
Both³		28275	
Juglans nigra	2		57

¹ (Stephenson 1982)
² (Skeen 1973)
³ (My figures, see text)

suggesting, perhaps, that it is being confused with acorn remains. Hence, like the model, the archaeological record may also inflate the importance of oaks at the expense of chestnut. Since both the model and its test conflate oaks and chestnut, there seems little reason to produce an arbitrary chestnut figure. However, I should caution that any mention of oaks or acorns in the discussion of the models should be understood to include chestnuts as well.

DERIVATION OF FORAGING COSTS

Foraging costs will be considered to be the time it takes to acquire a resource. There are two components to overall foraging costs. The first is search costs, the amount of time to locate a resource. The second is pursuit costs, the time to acquire and process the resource after it has been located (cf. Winterhalder 1981; Stephens and Krebs 1986). In addition there is for most resources a risk of failing to complete a pursuit successfully. The costs of failed attempts must be averaged into the overall cost of a resource.

Gathering Costs

Search costs for plants are ignored in this study. For many species, especially the mast-bearing oaks and hickories, the plants are so common that locating them takes a negligible amount of time. Since they are stationary, their location is entirely predictable once they are found. Most other edible plants in the catchment would be early successional species utilized for potherbs, seeds and fleshy fruits. The abundance and distribution of these plants, and hence the costs of locating them, would be determined by the extent of disturbance of the forest. The Clinch River and its tributary streams would provide a considerable extent of forest edge that could support these plants. Other patch disturbances such as those created by tree falls, rock slides, or forest fires would also be present, as would some amount of anthropogenic

disturbance. Reconstructing the number, distribution and extent of the disturbances seems impossible, as does knowing the contribution of edible plants to the total flora of the disturbed patches.

To avoid the uncertainties of quantifying patch characteristics, I assume for modeling purposes that the time needed to locate the secondary successional plants is also nil. This is not unreasonable, as locating these plants could be done coincidentally with other activities. Being sessile, once located their location would be completely predictable at least for the duration of the harvesting season.

The estimation of "pursuit" costs for plants poses little difficulty as it is possible to collect and process experimentally the various plant resources and measure yield per hour directly. A considerable number of such ethnoarchaeological studies have been done (Asch and Asch 1978; Smith 1987; Munson 1984) and are used in this study.

Although it is imaginable that foragers might occasionally have journeyed to some location expecting to find edible plant products and found none, the risk of failing to complete plant food gathering successfully seems an insignificant component of gathering costs. It will be ignored in this study. That is, for modeling purposes the assumption is made that the Daugherty's Cave foragers possessed perfect intelligence about the location and harvest timing of plant resources.

Hunting Costs

Deriving reliable cost figures for prehistoric hunting activities is difficult. Reidhead (1976) and Webster (1983) attempted to derive costs from ethnohistoric descriptions of Native American hunting, while Keene (1979) created a complex, dimensionless measure of hunting cost based on perceived attributes of the resources. My approach follows Keene insofar as I rely on data on the behavioral ecology of game animals to derive a cost estimation, but I do so in a more simple, straightforward manner.

I base search costs on the reciprocal of the animal's population density, that is area/animal. This gives a general figure for the amount of space that must be searched to find an animal that is not predictably located. In estimating foraging costs I assume that the forager searches at a rate of 2.5 km/hr., a figure typical of modern Amazonian foragers (Vickers 1980). I further assume that during the fall and winter a forager could scan the area within 10 meters to each side of his path. During the spring and summer this is reduced to five meters due to obstructing foliage. These assumptions produce search rates of 5 ha/hr (12 acres/hr) and 2.5 ha/hr (6 acres/hr) respectively.

I assume that a successful search does not reveal an animal, but rather some sign (tracks, spoor, etc.) left by the animal. The animal must then be "pursued", that is followed until a shot can be taken. The distance between the initial sign of the animal and the actual location of the animal would seem to be on average a function of the home range size of the animal. The more territory an animal typically exploits, the greater the average distance between past and present locations. Thus I use as an estimation of pursuit cost, the time required to cross the animal's home range. I assume that while tracking and stalking, the hunter moves at the slow pace of 0.5 kph (0.3 mph).

Not every stalk would result in a kill: therefore the average cost of taking an animal must be inflated by the probability of failure. Although the marksmanship and woodcraft of historic period Native Americans is legendary (Swanton 1946), there is little quantifiable information on actual success rates. Studies of modern hunting peoples are a bit more informative.

In a study of modern Cree hunters, Winterhalder (1977) found the success rates of moose-caribou hunts to range from 0% in summer to 90% in early spring. Modern hunters in Amazonia have similarly variable success rates ranging from about 20% (Flowers 1983) to 90% (Vickers 1980). From Africa the !Kung are reported to have an average success rate of 23% (Lee 1979:267), and the Valley Bisa have success rates

of 0% to 50% with most falling in the 9% to 33% range (Marks 1976 cited by Lee 1979). It should be noted that these rates refer to the probability of making a kill on a given day, not to the probability of taking an individual animal. Thus it is not apparent if low success rates reflect few encounters with game or frequent failed pursuits.

Since ethnography provides little more than an order of magnitude for success rates, I shall more or less arbitrarily use two round numbers. I assume that one in three pursuits of big game are successful in fall and winter, when the absence of foliage leaves animals more exposed and lines of fire less obstructed. In spring and summer, this will be reduced to one in five. For small game I will assign success rate figures of 20% to 50% on a case by case basis dependant on the behavior of the species in question.

Transportation Costs

Since linear programming requires that all cost-benefit relationships be linear functions, it does not allow for diminishing returns. Obviously, however, resources located 10 km from the site are more costly to procure than those occurring immediately adjacent to it. To mitigate the unreasonable assumption of linearity, the catchment is subdivided into three zones, the first lying within 3.3 km of the site, the second between 3.3 and 6.7 km, and third between 6.7 and 10 km. Exploiting resources within each of these zones incurs an "up-front" transportation cost equivalent to the travel time required to reach the midpoint of the zone at the standard foraging rate of 2.5 km/hr. These costs are 0.7 hour, 2.0 hour and 3.3 hours respectively. I assume that any terrestrial animal taken could be carried back to the site in one trip. As modern hunters routinely carry large bucks single-handedly from the field (Stransky 1984), this seems a reasonable assumption. For plants, fish and shellfish I assume that the average backload was about one bushel and weighed 18.2 kg (40 lbs). A weight of 18.2 kg is convenient because it is the weight of a bushel of pignut hickory nuts

(Bonner and Maisenhelder 1974). The transportation cost for the three zones is then ascribed to each bushel of resources. This raises the cost per kilogram of these resources by 0.04 hr/kg, 0.11 hr/kg and 0.18 hr/kg for each of the zones respectively.

Summary

Cost in this study is taken to be the time required to locate, obtain and prepare resources, inflated by the probability of a failed pursuit. In addition a transportation cost is assessed to account for the increased time involved in exploiting distant resource. For plants, the cost of locating the resource is considered nil, as is the probability of a failed pursuit. The costs of obtaining and preparing plants are taken from experimental studies of Eastern Woodlands subsistence. The cost of exploiting animals is estimated from the basic ecological parameters of population density and home range size, combined with estimations of foraging search and pursuit speeds. Any estimation of prehistoric subsistence costs is, of course, fraught with difficulties and vulnerable to criticism. Although additional factors could be introduced into the estimations of subsistence cost, to do so would sacrifice analytic clarity. The cost measure used in this study focuses on important attributes of the resources while remaining simply grasped and analytically tractable. Discussions of the cost derivations for individual resources follow.

BOTANICAL RESOURCES (Table 3.2)

Availability and Cost of Wild Plant Foods

Acorns. The Daugherty's Cave catchment area is calculated to include about 7.4 million oaks (Table 2.1 above). I will assume that 50% of them are of seed-bearing age. Using Downs' and McQuilkin's (1942) average figure of 558 sound acorns per southern Appalachian oak yields an expected crop of about 2.1 billion acorns. From

Table 3.2: Cost per kilogram of plant foods

Plant	Foraging Cost (hr/kg)	Agricultural Cost (hr/kg)
Acorn	3.3	--
Beans, dry	--	1.3
Beans, fresh	--	1.3
Bramble	0.5	--
Butternut	22.6	--
Chenopod	2.2	2.9
Corn, dried	--	1.1
Corn, green	--	0.9
Grape	0.5	--
Greens	0.8	--
Hickory	2.6	--
Maygrass	1.0	2.3
Maypops	2.3	--
Squash	--	0.6
Sumpweed	3.9	5.1
Sunflower	3.9	5.1
Walnut	8.7	--

Olsen (1974) it can be calculated that the five oaks under consideration average 363 acorns to the kilogram. This produces a figure of about 5.7 million kilograms of acorns or about 182 kg/ha (162 lb/acre). Since acorns are comprised of 38% inedible shell (USDA 1984), this yields a total of about 3.5 million kilograms of edible acorn meat or about 112 kg edible acorn meat/ha (99 lbs/acre). Although intuitively this figure seems too high, it should be noted that the calculated figure of 5.7 million kilograms acorn from 3.7 million trees is equivalent to 1.5 kg/tree. This approximates the mean yield of 1.3 kg/tree measured by Goodrum et al. (1971). Further, Segelquist and Green (1968) provide a figure of 60 kg dried acorn kernel/ha for the Ozarks. Allowing for 38% moisture (Goodrum et al. 1971) produces a figure of 97 kg kernel/ha. Although 13% smaller, this is the same order of magnitude as my calculation of 112 kg kernel/ha. All things considered, I accept 112 kg acorn meat/ha as a reasonable approximation of the yield of the Daughterty's Cave area forest. Fortunately, postoptimality analysis can be used to assess the sensitivity of the model outcomes to changes in the acorn cost figure.

Certainly not all of the acorns would be available to the human collectors, since acorns are an important wildlife food (Halls 1977). Downs and McQuillin (1944) report that in the southern Appalachians acorns drop between September 1 and December 1 with 75 percent dropping within a one month period. If deer are plentiful no acorns will survive on the ground after December; if deer are scarce, acorns may still be available as late as February (Downs and McQuillin 1944). In the small population models, I assume that acorns are available for one month only and are collected by 16 people (see discussion of population characteristics below) working eight hour days for 28 days. Thus 3584 forager-hours are available to gather acorns. Petruso and Wickens (1984) report experiments where they determined that 15 kg of acorns can be collected per hour. Therefore 53,760 kg of whole acorns is the upper limit of the acorn harvest. At 112 kg/ha this is the expected yield of 480 ha of forest.

This area is available within 1.2 km of the site, so acorns occurring in the outer two zones of the catchment will not be considered. Acorns are 62 percent edible nutmeat so the total amount of edible acorn available to the site inhabitants is 33,330 kg.

In the large population models 160 people are available to collect acorns. During the same four-week period, they could potentially gather 537,600 kg of acorns. This is about 390,000 kg of whole acorns and 240,000 kg of edible nutmeat. However, this level of harvest would require trips beyond the first catchment zone; therefore increased transportation costs will be assessed to any acorns gathered from the outer catchment zones.

Petrusco and Wickens (1984) found they could collect and shell black oak, red oak, and bur oak acorns at a rate of about 2.1 hours/kg of acorn meat. (They also report a rate of 8.3 hours/kg for white oak acorns. This figure is much larger due to a collecting rate that is only 24% of that of the red and black oaks. As Petrusco and Wickens state that there is no significant difference in the number of acorns collected for the different species (1984:367), I am at a loss to explain why large white oak acorns yield a smaller weight per hour than do the much smaller red and black oak acorns. I assume their table contains a typographic error, and hence will rely only on the black, red and bur oak figures.)

To the cost of 2.1 hr/kg the transportation cost of .04 hr/kg must be added. Since acorns are 62% edible nutmeat, one kilogram of meat derives from 1.6 kg of whole acorns. Transporting the whole acorns thus raises the cost of acorn meat to 2.17 hr/kg.

A further complication with acorn is that they must be leached to remove bitter tannins in order to be palatable. Assessing the time costs of this are troublesome. If the acorns can be effectively leached by immersion in running water (cf. Petrusco and Wickens 1984:368 n.2), then the time cost might be quite low - just the time of carrying them to the creek and back. Alternatively, if as seems the common practice

(Swanton 1946; Heizer 1978) they were actively leached in heated water, then this could be time consuming and rather arduous if only small quantities were prepared at a time. For this study I will increase the time costs of acorn procurement by one-half to reflect significant costs of leaching. This makes the final cost of edible acorn meal 3.3 hr/kg.

Hickory nuts. Calculation of the total yield of hickory nuts follows that of acorns. The catchment area is considered to have included 1.6 million hickories (Table 2.1) of which 50 percent (805,000) are assumed to be of seed bearing age. As pignut (Carya glabra) is the most common hickory in the region (Stephenson 1982; Skeen 1973), and no other information on hickory species composition is available, I use pignut data throughout the calculations. Nixon et al. (1980) provide an average yield figure of 215 sound pignuts per tree. Total catchment production can then be calculated as about 173 million nuts. As pignuts average 3.7 grams/nut (Bonner and Maisenhelder 1974), I calculate a yield of about 640,000 kg for the entire catchment or about 20.4 kg/ha (18 lb/acre). As hickory nuts are 65% inedible shell (Watt and Merrill 1963), this reduces to about 224,000 kg total nutmeat production or about 7.1 kg/ha (6.3 lb/acre). This very closely approximates the average yield of 7.5 kg nutmeat/ha from Ohio reported by Nixon et al. (1975).

Talalay et al. (1984) have performed a series of collecting and processing experiments on hickory nuts, walnuts and butternuts. Unfortunately, pignuts were not a species of hickory selected by them. However, they found that they could collect mockernut and bitternut hickories at a rate of about 0.38 hr/kg of whole nuts. Assuming as with acorns that hickory nuts can be collected over a four week period by 16 people working eight hour days produces a total potential yield of whole hickory nuts of 9432 kg. This amount of hickory nuts is the projected yield of 462 ha, or the area of land within 1.2 km of the site. Adding the transportation costs gives a cost of 0.42 hr/kg for whole hickory nuts within the catchment zone nearest the site. The

hickory nuts within the more distant zones are not considered available. Assuming 35% nutmeat per nut (Watt and Merrill 1963), this translates to 1.21 hour/kg nutmeat. Crushing with a wooden mortar and pestle and then boiling the nuts to produce hickory butter required about 1.4 hour/kg (Talalay et al. 1984). Total time costs for one kilogram nutmeat are then about 2.6 hours, ignoring search costs which are assumed negligible.

Walnuts: The Daughtery's Cave catchment is assumed to contain 57,000 walnut trees. Again, 50% are assumed to yield nuts. Talalay et al. (1984) suggest that 1.9 kg nuts/tree is the average yield for a forest-grown walnut tree and that 9.5 kg of walnuts can be gathered in about one hour. During a four week collection period 34,048 kg of walnuts would be available. Approximately 11,800 kg of walnuts could be gathered from the first catchment zone. The remainder would have to be sought in the second area. Transportation costs would raise the cost of whole walnuts to about 0.15 hr/kg in the first zone and 0.21 hr/kg in the second. Walnuts are about 20% edible meat, so about 6810 kg of edible walnut would be available at a cost of 0.75 hr/kg and 1.05 hr/kg. Cracking and picking the nuts involves another 8.0 hours/kg nutmeat (Talalay et al. 1984). Crushing and boiling to produce nut butter is not possible as the bitter husk contaminates the oil (Talalay et al. 1984). Total cost of a kilogram of walnut meat is thus about 8.7 hours if collected from the first zone and 9.0 hours if collected from the second.

Butternuts: Approximately 11,000 butternut trees are assumed to occur within the coves and bottoms of the catchment area. If 50% are assumed productive, and yield 2.6 kg nuts/tree as did a mixed sample of forest and open trees (Talalay et al. 1984), then the catchment should produce about 14,300 kg of butternuts or about 2150 kg of edible meat.

Experimental studies indicate that about 0.9 hours collecting and about 21.4 hours crushing and picking are required to produce one kilogram of butternut meat

(Talalay et al. 1984), for a total cost of 22.3 hours/kilogram. Based on an edible portion of 14% (Watt and Merrill 1963) and assessing the usual transportation costs provides final costs of 22.6 hours/kilogram, 22.9 hours/kilogram and 23.2 hours/kilogram. It should be noted here that no nutritional composition analysis is available for butternut meat, so the nutrient composition of walnut is substituted in the model. Since the costs of butternut is so much higher than walnut, this means that butternut will not enter the linear programming model until all walnut is exhausted. Butternut is included largely to assess how much of a reduction in cost it would have to undergo to make it a desired resource.

Greens: In the spring of 1984 I conducted timed trials of gathering leaves from young, circa 15 cm (6 in) tall chenopod (Chenopodium sp. cf. album) plants from a fallow area of a backyard garden in Raleigh, NC. I found I could gather one kilogram of leaves in about 0.77 hours. Adding the costs of transportation raises this to 0.81 hours. For modeling purposes I will assume that greens could be harvested over a four week period in the spring and for another four weeks in the summer. A total of 4424 kg of greens is presumed to have been available for each of these two seasons. No processing costs are assigned, as nothing more than rinsing is required. Presumably the greens were eaten boiled (Williams 1930:442). For the model I use the nutritional composition of cooked lambquarters (Medical Services Branch 1985), although other species were likely eaten as well.

Blackberry. Timed trials of blackberry picking from an old field near Chapel Hill, N.C. in July 1981 indicated that one kilogram of blackberries can be gathered in about 0.44 hour. Transportation costs raise this to 0.48 hr/kg, 0.55 hr/kg and 0.62 hr/kg for the three catchment zones. During a four week harvesting period, a total of 8145 kg are presumed to have been available. No processing of blackberries are required. My model uses the nutritional content of raw blackberries (Watt and Merrill 1963).

Grape. I have been unable to find data concerning the time costs of gathering wild grapes, nor have I been able to locate a harvestable quantity of wild grapes to study myself. Presumably low growing or fallen grapes can be gathered quite efficiently; therefore I will use the bramble costs of 0.48 hr/kg, 0.55 hr/kg and 0.62 hr/kg. Grapes are not as weedy as bramble or the potherbs, and probably in the prehistoric forest were most common along stream edges and openings. To set an upper limit to grape availability I have arbitrarily set a production figure of one kilogram of grape per 100 meters of stream edge in the catchment. This produces total grape yields of 129 kg in the first zone, 290 kg in the second zone and 153 in the most distant catchment zone. The nutritional composition data in my model is derived from "raw American type" grapes (Watt and Merrill 1963).

Maypops. From an overgrown cornfield in Wake County, I collected a 10 meter by 10 meter patch of maypops in 38 minutes. This produced 95 fruits which yielded an edible portion (less rind and seeds) of 280 grams (0.6 lbs). This translates to 2.26 hours/kg of edible maypop. No processing is necessary. Transportation costs raise the total cost per kilogram to 2.30 hours.

Since there is no published data on the nutritional composition of maypops, the above fruits less rind and seeds (i.e. the edible portion of maypops) were submitted to Webb Foodlab, Inc., Raleigh, N.C. for an analysis of their nutrient content. These data are presented in table 3.5.

A fourth common southern fruit, persimmon is omitted from this study, as it does not occur in southwestern Virginia (Harvill et al. 1977), nor is any data available on its micronutrient content.

Chenopod. Considerable data are available on the time costs of collecting chenopod fruits (Smith 1987). About 1.1 hour is required to collect one kilogram of fruits. Unfortunately, the time required to process the fruits into edible seeds has not been measured. I assume that threshing, winnowing and parching would be time

consuming; therefore I will double the harvesting costs to reflect this. To the resulting figure of 2.2 hr/kg, transport costs are added to raise this to 2.24 hr/kg.

Chenopod plants are noted for retaining their seed for a considerable period of time after seed-ripening, but I will use the standard four week harvest period nonetheless. About 3140 kg of chenopod would be harvestable by 16 people. Smith considers 500-1000 kg/ha as a "relatively conservative" harvest yield estimation (1987:49), so 3140 kg would be expected to represent the yield of about three to six hectares. As this figure is less than one percent of the area of the first catchment zone, I will assume that the entire harvest was available there.

Micronutrient composition of eastern North American chenopod C. berlandieri seeds is unavailable, so calorie and protein figures are taken from C. berlandieri (Asch and Asch 1985) but the micronutrient data are taken from the South American cultivar C. quinoa (White 1955; de Bruin 1965).

Maygrass. No data are available on the economic potential of maygrass, other than an analysis of its nutritional content (Crites and Terry 1984). Harlan (1967) reports that wild einkorn, a primitive wheat, can be hand-stripped from Turkish fields at a rate of 0.49 hr/kg of husked grain. Harlan notes that parching aids in threshing, but gives no figures for the amount of time required to thresh or winnow einkorn. For lack of a better alternative, I will double the einkorn figure, to create an estimation of the cost of gathering and processing maygrass. To the resulting figure of 0.98 hours, I add transport costs to produce a final per kilogram cost of 1.02 hours. Using the standard four week harvest period indicates about 3500 kg of maygrass would be harvestable. Maygrass ripens is late spring to early summer (Cowan 1978).

No yield per area figures are available for maygrass, but its cultivated congeneric canary grass produces 30-34 bushels of seed per acre in England (Hedrick 1919:428). If, like oats, canary grass weighs 32 lbs/bu this indicates a yield of about 1100-1200 kg/ha. It is not stated if this yield is after fertilization. Wild emmer in

Israel is reported to occur at densities of 500-800 kg/ha (Zohary 1969). Wild lyme grass in Iceland yields 600-800 kg/ha (Griffin and Rowlett 1981). A conservative estimate of maygrass yield of 500 kg/ha suggests that only about seven hectares would be necessary to yield the southwestern Virginia season's harvest.

Sumpweed. The economic potential and nutritional content of sumpweed have been well studied (Asch and Asch 1978). According to their experiments, the average collection rate for a skilled collector is about 1.92 hr/kg of kernels. They report no timed trials of processing the fruits, but note that processing might require as much time as collecting. Hence, I will double their collecting costs to produce a figure of 3.85 hr/kg. Transport costs raise this to 3.89 hr/kg. In four weeks about 1870 kg of sumpweed kernels could be collected. Using the mean figure of 273 kg/ha cited by Asch and Asch in their studies of modern sumpweed productivity (1978) indicates that about seven hectares would be necessary to produce this amount.

Sunflower. Sunflower is the only member of the Eastern Agricultural Complex to survive as a domesticate after the disintegration of Native American culture in the Eastern Woodlands (Yarnell 1977). Ironically, no studies of its harvesting or processing costs have been published. For lack of a better alternative, I will use the rate for sumpweed - 3.89 hr/kg as a proxy measure for sunflower collecting.

Costs of Agricultural Production

Although there are considerable ethnographic and historical accounts of Native American agriculture, most are anecdotal and are of little help in assessing the labor costs of food production. Following Reidhead (1976), I will use data from Central American maize farmers (Clark and Haswell 1967:44-45) to estimate the costs of maintaining agricultural production. In Belize, men "assisted by their families" spend about 110 days clearing and cultivating about two hectares each year. The breakdown of costs is 45 days felling trees, five days burning the plots, five days planting, 20 days

weeding, five days breaking corn stalks, and 30 days harvesting. If days are eight hours long and the assistance of the families equals that of the men, then agricultural production requires 880 hours per hectare.

There are several problems and ambiguities with using these data. On one hand, the Belizian farmers clear new plots every year, but Native American farmers apparently farmed the same plots for several years before allowing them to fallow (Hudson 1976:290). Hence the Belize figures may overestimate Native American land clearance costs. On the other hand, the Belizians had recourse to steel tools for land clearance and cultivation. This would make their agriculture more labor efficient than that of Native Americans. Finally, the Belizians expend about 13% of their total labor input on weeding; whereas weeds do not seem to have been a serious problem in the Eastern Woodlands prior to the introduction of noxious Old World species (Wilson 1917; Will and Hyde 1917:91ff). Given the countervailing directions of these qualifications, I will make the assumption that they cancel out each other and use 880 hr/ha as the basic cost of Native American farming exclusive of time required to process the crop after harvesting (e.g. shelling dry maize).

Maize. Maize was certainly the most important crop of Native Americans but little quantitative information is available on maize productivity. Will and Hyde (1917) cite a range of 8 to 34 bu/acre as yields from Native American fields on the Upper Missouri. Following Smith (1987) I will take this to refer to bushels of maize ears which are the equivalent of 18.2 kg (40 lbs) of maize kernels. This indicates a range of yields from 360 kg/ha to 1527 kg/ha. I will use the mean figure of 940 kg/ha (837 lb/acre).

The production of green corn ("roasting ears") would require little effort beyond the basic 880 hours required to farm and harvest a hectare of land. The model thus uses 0.9 hrs/kg as the cost of green corn. The processing of dried corn would require the additional time costs of shelling and grinding. The Belize farmers spend about 13%

of their corn-producing labor in shelling the ears (Clark and Haswell 1967:44-45), but no information on the time costs of grinding corn is presented. I will estimate that this adds a period of time equivalent to that of the time-consuming shelling. The final cost of dry corn is 1.13 hr/kg, 26% greater than that of green corn.

Beans. I have been unable to find any useful quantitative information on the production of beans by Native Americans. In Central America the average yield of common beans is from 500 to 700 kg/ha (Rachie 1973:129). Temperate North America would seem a better agricultural region than Central America so I will use the higher figure. Since I could find no data on the labor investment involving in producing beans, I will use the basic 880 hrs/ha derived from the Belize study cited above. This creates a final cost figure of 1.3 hr/kg. This estimation is highly artificial and likely errs in making beans relatively less costly than the other crops. If beans prove to be substantial part of the modeled optimal diets, then postoptimality analysis will be used to assess the effect of modifying the cost figure.

Squash. As anyone who has grown zucchini in a backyard garden knows, the productivity of modern summer squashes can be phenomenal. Under modern industrialized agricultural conditions, yields of 30 metric tons of zucchini per hectare are not unusual (Hackett and Carolene 1982). In a two year study of the yields of yellow summer squash, a control plot that was not mulched or treated with insecticides, but was fertilized, irrigated and treated with herbicides yielded 4.2 metric tons of squashes per hectare (Chalfant et al. 1977).

Native American yields were undoubtedly much less, but data are scant. Reidhead, relying on an Indiana informant's recollection of pre-World War II maize-bean-squash intercropping, derived 6.3 metric tons per hectare as a typical yield (1976). This seems too high, being 50 percent greater than the modern control plot yield cited above.

Wilson (1917) provides some clues to Native American squash yields. In the pre-reservation period a Hidatsa family was able to produce 70 to 100 baskets of squash per season. The baskets are reported to have been 15 inches in diameter and 11 inches deep. If these were cylindrical, their volume would have been 1944 in^3 (32 l) or about one bushel. Yields then must have been about seventy to 100 bushels, or about 1270 to 1820 kg (assuming a squash weight of 18.2 kg/bushel).

Unfortunately the size of the typical Hidatsa field is not specified, as "the size of the garden was determined chiefly by the industry of the family that owned it, and by the number of mouths to be fed (Wilson 1917:24)." Wilson's informant did report, however, that in expanding their garden the family added a second field of 75 yards by 100 yards (1.5 acres or 0.6 ha). If this doubled the size of the families holdings, then the garden increased from 0.6 ha to 1.2 ha. This would seem to indicate that one hectare is at least the proper order of magnitude for a Hidatsa garden, so 1270-1820 kg/ha is suggested as the yield of Hidatsa squash farming. This study uses a squash yield of 1400 kg/ha. The yield is considered to be made up entirely of flesh, no attempt is made to model the contribution of squash seeds.

Squash requires a negligible amount of preparation for eating, so the cost of squash production will include only the basic 880 hours required to farm a hectare of land. This produces a final cost figure of 0.6 hrs/kg of squash.

Domesticated Native Annuals: As well as being collected from the wild, chenopod, sumpweed, sunflower and presumably maygrass were all domesticated in the prehistoric Eastern Woodlands. Estimating the time costs of producing these seed crops will be done by assuming that the standard 880 hr/ha of agricultural effort went into producing their nondomesticated per-hectare yield. By this manner the costs of the domesticated native annuals are estimated to be for chenopod, 2.9 hr/kg; for maygrass, 2.3 hr/kg, and for sumpweed and sunflower, 5.1 hr/kg.

FAUNAL RESOURCES
(Table 3.3)

Deer. The white-tailed deer was certainly the most important game animal of the Native Americans of the eastern United States (Swanton 1946; McCabe and McCabe 1984). Today it is probably the most studied of any wild animal in the world (Hesselton and Hesselton 1982). White-tailed deer are a highly variable species adapted to many different environments. At least 16 subspecies are recognized (Hesselton and Hesselton 1982). Typical adult weights range from 180 kg (397 lbs) in the northern U.S. to only about 25 kg (55 lbs) in the Florida Keys (Sauer 1984; Hesselton and Hesselton 1982). Measured population densities of white-tailed deer are likewise highly variable. Densities ranging from 3 deer/sq.km (8 deer/sq. mi) (Stransky 1969) to 50 deer/sq.km. (130 deer/sq. mi) (Hirth 1977) have been cited. To further compound matters, both body size and population densities are influenced by a number of variables including range characteristics, weather, parasites and disease, non-human predation and human hunting. So in spite of the wealth of information existing on white-tailed deer (see Hesselton and Hesselton 1982; Halls 1978, 1984 for recent synopses) characterizing the "average" modern white-tail is a difficult matter. And, of course, projecting any of these data derived from modern studies into the prehistoric past is particularly suspect. Nonetheless, some usable estimations can be derived.

Deriving an accurate figure for the prehistoric density of white-tails in the southwestern Virginia region seems the most intractable problem. In general, current methods of censusing wild populations of white-tails are not considered particularly reliable (Halls 1984), and the Appalachian region in particular lacks reliable data on modern herd sizes (Shrauder 1984). Furthermore, because white-tails are not denizens of the closed canopy forest but are principally an edge-adapted species, it is considered that the widespread conversion of the eastern forests to agricultural usages following

Table 3.3: Costs and Weights of Animals¹

Animal	Cost Weight (hr)	Live Weight (kg)	Meat Weight (kg)	Heart (g)	Liver Weight (g)	Kidneys (g)	Giblets ² Weight (g)	Edible Weight (kg)
Bear	242	100.0	70.0	790	4940	380		76.1
Beaver	9	12.1	8.5	520	367	131		9.5
Deer	29	57.0	32.0	360	910	130		33.4
Duck	7	0.7	0.5				50	0.5
Fish	13		1.0					1.0
Groundhog	5	3.9	2.7	17	117	42		2.9
Grouse	16	0.7	0.5				34	0.5
Muskrat	4	1.0	0.7	4	24	8		0.7
Mussels	13		1.0					1.0
Opossum	9	2.0	1.4	9	117	13		1.5
Otter	47	9.4	6.5	79	462	96		7.1
Rabbit	6	1.4	0.7	5	53	6		0.8
Raccoon	29	6.3	4.4	54	311	72		4.8
Skunk	22	2.3	1.6	13	62	6		1.7
Snails	93		1.0					1.0
Squirrel	6	0.7	0.5	5	16	4		0.5
Turkey	13	5.2	3.6				271	3.9
Turtle	10	3.9	2.0					2.0

¹ See text for references.

² Includes heart, liver, kidneys

³ Cost is per kilogram.

European colonization has resulted in increased numbers of white-tails. Hence estimations of modern white-tail population densities may not reflect aboriginal conditions. Since there seems to be no way to derive a more accurate figure, I will rely on wildlife managers' long-established rule of thumb of 7.7 deer per square kilometer ($20/\text{mi}^2$.) as the population density of white-tail deer in the Eastern Woodlands (Hosely 1956). Home ranges of white-tails can be estimated at about 3.2 km (2 mi) in diameter (Marchinton and Hirth 1984). At a search speed of five hectare per hour it would take an average of 2.6 hours to locate signs of a deer. To cross the home range at 0.5 kph would require another 6.4 hours. To these times are added the "startup" cost of 0.7 hours for foraging within Area 1 of the catchment. This time cost of 9.7 hours must be increased to reflect the costs of failed attempts to procure deer. Using a 33% success rate in fall and winter and a 50% success rate in spring and summer. This raises the total cost of a deer in fall-winter to 29 hours. In spring and summer the higher search costs and increased risk of failed pursuits result in a total cost of 62 hours.

The costs of acquiring deer having been estimated, the benefits must now be assayed. The food energy and nutrients yielded by a deer are dependant upon its weight. The weight of a white-tail is dependent upon age, sex, season, habitat quality, region and subspecies (Sauer 1984). To further complicate the construction of the model, two of the important variables, habitat quality and age, are themselves dependent on the level of predation (McCullough 1979). If the level of predation is too low, deer herd size will increase. Large herds degrade their habitats and result in poor quality, malnourished animals. If the level of predation is too high, few deer survive to obtain their adult weights, so the population comes to be comprised increasingly of smaller, immature animals. Hence with rising predation the average size of deer is reduced (McCullough 1979). Present-day deer herds seem to be under considerable hunting pressure with most of the bag being made up of the young of the year, a

situation that does not seem to reflect the aboriginal situation (McCullough 1979; Smith 1975). Hence weights calculated from modern harvests (e.g. Gill 1956; Robinson 1966) are likely to underestimate the size of prehistoric deer.

In estimating the average weight of a white-tail deer in the prehistoric southwestern Virginia forest, I am tempted again to avoid complexity by following traditional wisdom and using the frequently cited figure of 91 kg (200 lbs) live weight and 45 kg (100 lbs) edible weight (White 1953). This does not seem appropriate, however. Although the northern subspecies of white-tail deer (*Odocoileus virginianus borealis*) may routinely reach such weights, they do not seem to typify the smaller Virginia deer (*Odocoileus virginianus virginianus*) of the Appalachians (Sauer 1984). For this study I will assume a more modest average live weight of 57 kg (125 lbs) based on Sauer's (1984) figures of 68 kg (150 lbs) bucks and 45 kg (100 lbs) does. This is well below the average weight of 79 kg (173 lbs) obtained by mature bucks on the overpopulated Pisgah National Game Preserve (Schilling 1938). So even though the figure I use does not account directly for the contribution of immature animals to the harvest, it would seem unlikely to overestimate greatly the size of the average prehistoric deer. My acceptance of this figure is further encouraged by the fact that in the Appalachian region yearling bucks with few exceptions attain 45 kg (100 lb) hog-dressed weights (Shrauder 1984). Based on the standard conversion ratio of 1:1.32 (Sauer 1984) this indicates a live weight of 59 kg (131 lbs) that exceeds slightly the average being used. So unless the prehistoric harvest was strongly biased in favor of does or young of the year animals - both unlikely based on the archaeological evidence (Smith 1975; Waselkov 1978) - the figure of 57 kg seems a reasonable estimation for prehistoric Virginia deer in the Appalachians: It will be assumed that this weight refers to fall-killed deer.

Based on a 57% conversion ratio (Hamilton 1947; Smith 1975), a 57 kg deer yields 32 kg (71 lbs) of edible meat. The edible viscera of a deer this size would

include a .36 kg (.79 lb) heart, a .91 kg (2.0 lbs) liver and .13 kg (.31 lb) of kidneys (Robinson 1966). Other offal such as lungs, glands, and rumen contents would also be edible, but they are not included in the model calculations as insufficient information is available on their nutritional composition. For the purposes of the model, the average fall-killed deer of prehistoric southwestern Virginia forest yields 33.4 kg (73 lbs) of food.

A study of a large sample of Indiana deer (presumably O.v. borealis) documented the seasonal weight changes of white-tails (Hoeckstra 1972, cited by Reidhead 1976:96-97). Hoeckstra's study indicates winter weights for both sexes to be about 92% of fall weight, spring weights, 82%, and summer weights, 83%. Assuming that the calculation of a 57 kg live-weight refers to fall-killed deer and ignoring the one percent difference between spring and summer indicates that deer weigh 52 kg (114 lbs) in winter and 47 kg (103 lbs) in the spring and summer. It is assumed that this weight loss affects the animal uniformly and that flesh and organs diminish at the same rate.

Black Bear. In the wild, black bears prefer relatively inaccessible terrain with thick understory vegetation and abundant sources of food, particularly mast. Although they can become so locally common as to be pests, they tend to maintain sparse populations. Reported population density estimates range from 1 bear per 1.4 to 14.3 km² (1 bear/0.55.5 mi²) (Pelton 1982). A study in the Great Smoky Mountains National Park revealed a black bear population density of 1 bear per 3.4 km² (1/1.3 mi²) (Pelton and Marcum 1975). This figure is somewhat higher than Shelford's (1963) estimate of 1 bear per 5 km² (1/2 mi²) for eastern North American, but the southern Appalachians should be better than average bear habitat. I will use the Pelton and Marcum (1975) figure in this study.

Home range sizes of black bears are very variable. A study of the Great Smoky Mountains National Park determined male bears to utilize 42 km² and females 15 km²

(Pelton 1984:507). I will average these to estimate a home range of 29 km² or 6 km in diameter.

At a population density of 1 bear/3.4 km², a bear would be located with an average of 68 hours of searching plus the "startup" cost of 0.7 hours. To cross the six kilometer home range would require another 12 hours. Using the estimates of 33% success in fall and winter produces a total fall-winter cost of 242 hours per bear.

Adult black bears weigh from 40 to 140 kg (90 to 308 lbs) and attain adult weight in about four years (Pelton 1982). To estimate the size of an average bear, I begin with a sample of 179 summer-trapped black bears of both sexes and all age-classes in New York that averaged 85 kg (187 lbs) (Black 1958). Bears attain their peak weight in the fall then lose 20-27 percent of their weight in fat during the ensuing winter and spring (Pelton 1982). In the absence of other information, I assume that the pattern of weight loss is parabolic. Namely that from their maximal fall weight bears decline to 85% maximum in winter, decline further to 75% maximum in spring, then rebound to 85% of their fall weight in summer. This produces weights of 100 kg (220 lbs) for the fall, 85 kg (187 lbs) winter and summer, and 75 kg (165 lbs) spring. Black bears are 70 percent edible (White 1953) and at 100 kg would have a 790 g heart (Spector 1956 based on grizzly bear), a 4.94 kg liver (Spector 1956 based on raccoon) and 380 g of kidneys (Spector 1956 based on grizzly bear).

Beaver. Beaver are aquatic animals that rarely stray far from water; hence their population densities in rugged or mountainous terrain can be calculated best in terms of animals per kilometer of stream. One study indicated 1.24 beaver colonies per stream kilometer was the saturation density of beaver in New York, while a second study in Alabama indicated that saturation density was 1.9 colonies/km (Hill 1982). This averages to 1.6 colonies per kilometer. Given a U.S. average of 5.2 beavers per colony (Hill 1982), this indicates 8 beavers/km as the average density. This seems too high, however, for the Ridge and Valley provenience, as its engorged rivers, bedrock

streams, generally narrow valleys and a tendency for spring floods make it much less desirable beaver habitat than either New York or Alabama. I will therefore arbitrarily reduce the density by one-half to 4 beavers per kilometer of stream, or one colony per 1.3 kilometer of stream.

The Daugherty's Cave catchment area includes about 41 km (26 mi) of the Clinch River and about 16 km (10 mi) of Big Cedar Creek. Ignoring smaller, unnamed streams, this indicates an expected beaver population of 240 animals. One beaver in five is a accepted rule of thumb for the sustainable yield of beaver (Hill 1982). About 48 beaver should have been available for exploitation by the Daugherty's Cave inhabitants.

In a Canadian study a trapping harvest was found to be comprised of 27% young of the year, 28% yearlings, and 45% adults (Winterhalder 1983). Respective average weights of these age classes are 7.0 kg, 9.6 kg, and 16.8 kg (Aleksiuk and Cowan 1979). This produces an average beaver weight of 12.1 kg that will be used in this study. A beaver of this size provides a 52 g heart, a 367 g liver and 131 g of kidneys (Spector 1956). The edible portion of beaver is considered to be 70% (White 1953) yielding a weight of 8.5 edible flesh. Total edible weight of flesh and organs is 9 kg (20 lbs). Seasonal weight loss is the same as for bear.

Assuming that there is one beaver colony per 1.3 kilometer of stream and that hunters travel 2.5 km/hr indicates that the average time cost of locating a beaver colony would be 0.5 hour plus the 0.7 hour "startup" cost. As beavers are mostly nocturnal (Hall 1982; Webster 1985), colonies would most often be discovered by observing "beaver sign" - dams, lodges, gnawed trees, or trails along the stream bank. Trapping would seem the most productive way to take beaver. With modern tools and wire, setting a snare for beaver takes only about six minutes (Mason et al. 1983). I will assume that Native Americans with prehistoric technology could set four snares per hour and would set 20 traps per colony thereby investing five hours in trap-setting.

Apparently snares are roughly 50% as effective as conibear traps in taking beaver (Mason et al. 1983). A two year study of Alabama trappers indicated that 20 conibear traps yielded about a beaver per day (Hall 1982), so 20 snares can be considered to yield a beaver every two days. The second day of effort, however, would require only travel time as traps would not need to be reset. The average cost per beaver can thus be approximated as 1.2 hours search + 5 hours trap setting + 1.2 hours checking trap on first day + 1.2 hours checking trap second day for a total of 8.6 hours.

Muskrat. Muskrats are an aquatic rodent averaging 1.0 kilogram adult weight (Webster et al. 1985). They are most common in marshes, swamps, and sluggish rivers with much aquatic vegetation; they avoid swift streams (Perry 1982). Although populations in favorable habitats can reach nuisance levels, they probably were not common in the Virginia Ridge and Valley. I have found no studies of muskrats in mountain streams, but in ditches and medium sized streams in pastures about two breeding pairs per kilometer of stream are reported (Perry 1982). This probably overestimates the prehistoric muskrat population in the Daugherty's Cave catchment. The shady forested stream banks of the area would inhibit the muskrats' desired shoreline sedges and grasses more than would pasture, and the swiftly flowing riffles and rapids of the Clinch River and Big Cedar Creek would be unlikely muskrat habitat. For these reasons I will reduce the figure by one half and use a population density of one breeding pair of muskrats per kilometer of stream.

Locating a muskrat den would take about 0.4 hours plus the 0.7 hours "startup". During the fall and winter, muskrats are almost exclusively nocturnal, so trapping would be necessary to take them. In the absence of better data, I will use the trapping costs of taking beaver as a proxy measure of muskrat trapping (see above p). It is assumed that 20 traps are set at a total cost of five hours and that the trap line yields one muskrat every two days. In the fall there are about five young animals and two adult animals per den and about 50% of the population is a sustainable harvest (Perry

1982), so three muskrats could be trapped per den. This would require an average of six days checking the traps. The cost of checking the traps would be the same as finding the den or 1.1 hours per day. The total time investment of muskrat trapping would be 1.1 hour searching + 5.0 hours setting traps + 6.6 hours checking traps for a total of 12.7 hours. This yields three muskrats at an average cost of 4.2 hours each.

In the spring and summer muskrats become increasingly diurnal, allowing the possibility of hunting as well as trapping them. The cost of locating a den would remain 1.1 hours. Muskrats have very small home ranges averaging only 370 meters across, so pursuit time would be only 0.15 hours. Winterhalder (1979) indicates that modern Cree have about a 20% chance of shooting a muskrat. This suggests 6.25 hours as the time cost of taking a muskrat by hunting. Since this is higher than the cost of trapping muskrats, it will not be included in the model.

Assuming a one kilogram body weight (Webster et al. 1983) and a 70% edible portion (White 1953), a muskrat yields 700 g of meat. Heart, liver and kidney weights are 4 g, 24 g, and 8 g respectively (Spector 1956).

River Otter. River otters are rather large aquatic mammals active at any time of the day. They are most common in coastal areas, in estuaries and in the lower portions of rivers, but are found in mountainous terrain as well (Toweill and Tabor 1982). Quantitative studies of the ecology of river otters are few, and data are quite spotty. This study will use a population density estimation of one otter per 2.5 kilometer of stream and a home range size of seven kilometers in diameter (Toweill and Tabor 1982). These figures combined with a forager speed of 2.5 kph and a "startup" cost of 0.7 hours produce time costs of 1.7 hour searching and 14 hours "pursuing". Otters could be either trapped or shot, but no information on the probability of success of either endeavor is available. Otters apparently are more difficult to trap than beavers or muskrat (Toweill and Tabor 1982), but because of their natural curiosity would seem to be more vulnerable to hunting. For modeling I will assume otters were hunted with

a 33% success rate. This produces an average cost of 47 hours for taking an otter. As there is no information concerning seasonal variation in otter activity patterns, this figure will be held constant in the model. Likewise otter weights are not specified to fluctuate seasonally, so an average weight of 9.4 kg (21 lbs) will be used for all seasons (Toweill and Tabor 1982). Assuming a 70% edible portion (White 1953) produces an edible flesh yield of 6.5 kg (14 lbs). In the absence of information on otter organ weights, I use the figures for raccoon to produce estimations of a 79 g heart, a 462 g liver, and 96 g kidneys (Spector 1956). An otter's total fall edible weight is about 6.5 kg.

Raccoon. Adult raccoons weigh from 3.6 kg (8 lbs) to 9 kg (20 lbs) (Kaufman 1982). I will use the mean figure of 6.3 kg, which is probably generous. Raccoons are about 20 percent fat in the fall (Kaufman 1982), so winter and spring/summer weights of 5.7 kg (10 lbs) and 5.0 kg (9 lbs) are assumed. Edible meat is approximately 70 percent of live weight (White 1953) and edible viscera includes a 54 g heart, a 311 g liver and 72 g of kidneys (Spector 1956). Total edible fall weight is 4.8 kg.

Raccoons are common animals in the southeastern United States but reach their highest populations densities in swampy bottomlands (Nottingham et al. 1982). In upland areas population densities of about 4 raccoons/km² (10/mi²) are typical (Kennedy et al. 1975; Nottingham et al. 1982). On average a raccoon's home range has a radius of only about one kilometer (Kaufman 1982).

Given the above density and home range sizes, it is calculated that the average search cost for a raccoon is five hours and the average pursuit cost is four hours for a total of 9.7 hours including the startup cost. The probability of successfully taking a raccoon would seem to be particularly variable and difficult to estimate. Although raccoons are sometimes active in the mornings and evenings they are primarily nocturnal. Hence, Native Americans may have only rarely encountered active raccoons

but more frequently seen tracks, scats and trails. A "pursuit" based on these clues, if successful, would lead to the raccoon's sleeping site. Raccoons use rock crevices, burrows, brush piles, squirrel nests, bare limbs and hollow trees as sleeping sites (Kaufman 1982). If the den is accessible, sleeping raccoons can be pulled from it by hand or by twisting a stick in their fur (Smith 1975). This technique of capture should be relatively quick and certain.

If the den is not accessible and the raccoon not visible for shooting, snares and deadfalls could be set around it in order to trap the animal (Swanton 1946:330). Trappers equipped with wire and metal tools can set a snare in about six minutes (Mason et al. 1983), and some Native Americans report setting 50 to 100 snares a day (Cooper 1938). Presumably setting snares would be rapidly accomplished even by aboriginal trappers using stone tools but prepared cordage. I have found no evidence on the time required to set a deadfall, or on the effectiveness of snares or deadfalls as raccoon traps. Any sort of trapping would, of course, require a return trip to the den the following day (or days) to check the traps. This would require no more than the time of walking. Estimating the time costs of trapping raccoons is further confounded by the fact that a number of raccoons may share a den (Kaufman 1982). Once located, a den might yield multiple raccoons from a single search and pursuit or be productively trapped for some time with little additional time costs.

In short the techniques for taking raccoons under aboriginal conditions are exceptionally variable, poorly understood, and unilluminated by historic observation. As a result, there seems to be little concrete basis for estimating the probability of Native Americans successfully taking a raccoon. I will use a figure of 0.33 success for fall and winter hunts, as during these seasons the young of the year would be actively foraging, vegetation would be less of an obstruction to locating sleeping animals, and communal denning might occur (Kaufman 1982). During the spring and summer raccoon capture would seem to be more difficult so I will set an arbitrary success rate

of 0.25. These figures produce a average cost for procuring a raccoon during the fall and winter of 29 hours and for the spring and summer of 59 hours. Raccoons can sustain a harvest of about 40 percent of the population (Clark et al. 1989), or in this case 1.6 raccoons/km².

Opossum. The opossum is a solitary, antisocial, nocturnal omnivore favoring deciduous woodlands near streams (Gardner 1982). In suitable habitat its population density (Hunsaker 1974) averages 25 opossums per square kilometer (65/mi²) and its home range (Nowak and Paradiso 1983) averages 20 hectares (49 acres). Opossums are occasionally active diurnally during the winter months (Gardner 1982), but trapping would seem the most likely way for Native Americans to have taken them. The population density and home range figures indicate 0.8 hours and 1.0 hour as the average search and pursuit times. An account of trapping opossums in Mississippi reported an expected yield of 0.03 opossums per steel trap per night (Yeager 1953). Assuming that aboriginal trapping would be only one half as effective as modern trapping (Mason et al. 1983) and that a trap line of 20 traps would be used suggests that 3.3 nights of trapping would be required to produce a opossum. Thus the time cost of procuring the average opossum can be calculated as 0.7 hours startup + 0.8 hours search + 5 hours setting traps + (3.3 checks x 0.7 hours/check) for a total of 8.8 hours.

Opossums average about 2.0 kg (4.4 lbs) live weight (Webster et al. 1985) and are about 70% edible (White 1953) yielding 1.4 kg (3.1 lbs) of meat. An opossum of this size would possess a 9 g heart, a 117 g liver and 13 g of kidneys (Spector 1953 based on South American subspecies).

Rabbit. Today southwestern Virginia supports populations of the familiar eastern cottontail, the less familiar and poorly studied New England cottontail, and disjunct populations of the snowshoe hare (Webster et al. 1985). All three animals have similar habitat requirements, life histories and morphologies, but in the southern

Appalachians the eastern cottontail is by far the best studied. For this reason the quantitative data needed to construct the model is taken from the eastern cottontail. To avoid the appearance of affectation, all three lagomorphs will be referred to collectively as "rabbits".

Rabbits favor successional and transitional habitats and do poorly in mature forests. For this reason early Euroamerican settlers in the Eastern Woodlands found rabbits to be scarce (Chapman et al. 1982). Population densities as high as 20 rabbits per hectare (8/acre) have been reported, but densities of three to nine rabbits per hectare (1-4/acre) are typical of favorable habitats (Chapman et al. 1982). The forests of prehistoric southwestern Virginia are likely to have been poor rabbit country, so I will assume a more conservative estimate of one rabbit per hectare. Rabbits maintain home ranges of about two hectares (5 acres) (Chapman et al. 1982). Search and pursuit costs of 0.2 hours and 0.3 hours are indicated. As a small, frequently fleeing target, rabbits can be a difficult animal to shoot, so I will use a success rate of 20%. This yields a cost per average rabbit of 6.0 hours.

Rabbits weigh about 1.4 kg (3 lbs) (Webster et al. 1985) and are 50% edible (White 1953). A rabbit of this size has a five gram heart, a 53 g liver and six grams of kidneys (Chapman 1971, data for brush rabbit).

Groundhog. Groundhogs inhabit open woodlands, thickets, rocky slopes, fields and clearings. Their range has expanded following the Europeanization of the landscape, and like cottontails are more common today than in prehistoric times (Webster et al. 1985). Population densities indicated by four modern surveys in varied locales in the eastern United States range from 40 to 290 groundhogs per square kilometer (25-180/mi²) (Nowak and Paradiso 1983). As I did for rabbits, I will use one third of the lowest measurement as the prehistoric population density reflecting the lower carrying capacity for open-habitat species of the pre-Europeanized Eastern Woodlands. This is one groundhog per 7.5 hectares. A typical search cost can be

calculated as 1.5 hours plus the 0.7 hour startup cost. Groundhogs are solitary, antisocial animals, intolerant of conspecifics, that rarely stray far from their dens. Foraging travels of 75 meters are considered exceptional (Lee and Funderburg 1982). Pursuit cost would be very low, only about 0.3 hours. Groundhogs are slow, lethargic animals that are easily shot (Lee and Funderburg 1982), so a success rate of 50% will be assumed. This produces a final cost of 5.0 hours per animal.

Adult groundhogs weigh about 3.9 kg (8.5 lbs) are 70% edible (White 1953 based on other rodents) and at this size would have a 17 g heart, a 117 g liver and 42 g of kidneys (Spector 1956 based on beaver).

Groundhogs are true hibernators and generally spend the winter below ground. During hibernation groundhogs lose about 30 percent of their body weight (Lee and Funderberg 1984). Following their emergence in the early spring, they remain lean and do not begin to gain weight until late spring or early summer (Lee and Funderberg 1984). In the seasonal models, groundhogs will be unavailable in the winter, at 70 percent body weight in the spring, 85 percent in the summer and 100 percent in the fall.

Squirrels. Grey, fox, red and flying squirrels are all found in southwestern Virginia (Webster et al. 1985). Although flying squirrels are present in the archaeological record of Daugherty's Cave, it is difficult to imagine humans pursuing these tiny (less than 140 g (5 oz)), nocturnal creatures. It seems more likely that they fell prey to some nonhuman predator utilizing the cave, although they may have been taken in traps set for other animals. Red squirrels are also small weighing about 227 g (0.5 lbs) and are in the southern Appalachians are most abundant in evergreen forests at the higher elevations (Webster et al. 1985; Flyger and Gates 1982b). They, too, seem an unlikely game animal of southwestern Virginian Native Americans. Like the flying squirrel, they will not be considered in the model, although their population density and

home range size are comparable to those of fox and grey squirrels. (Flyger and Gates 1982b).

Relative to grey squirrels, fox squirrels are larger, weighing 0.8 kg (1.8 lbs) versus 0.5 kg (1.1 lb), are more terrestrial, and favor more open forests (Flyger and Gates 1982a). Reported population density and home range size figures of fox and grey squirrels are quite variable. A population density of 1.6 squirrels per hectare (0.6/acre) and a home range size of 2.6 hectares (6.4 acres) are the median figures of the range of values presented in Flyger and Gates (1982a). From these figures a search time of 0.13 hours and a pursuit time of 0.35 hours are calculated. A probability of success of 20% will be assumed yielding a total cost of 5.9 hour per squirrel.

The mean average weight of fox and grey squirrels is 0.66 kg (1.5 lbs) (Flyger and Gates 1982a), and they are assumed to be 70% edible based on White's (1953) data on other rodents. To 0.46 kg (1 lb) flesh is added a five gram heart, a 16 gram liver and four grams of kidneys (Spector 1956).

Skunk. Skunks may seem a rather dubious inclusion in a subsistence model, but their flesh is reported to be good if properly prepared (Godin 1982). However, they are known to favor caves and other natural cavities as dens, so their presence at Daugherty's Cave may be incidental to the human occupation. Skunks are mostly crepuscular and nocturnal but are sometimes active during the day. Adults average about 2.3 kg (5 lbs) and maintain home ranges of about one kilometer in radius (Godin 1982). A population density of 3.3/km² seems to be typical throughout their range (Wade-Smith and Verts 1982). Once located skunks being slow should be easy to take, so I will use a probability of success of 50 percent. Using these figures I calculate the time cost of taking a skunk in fall-winter to be 21.5 hours and in spring-summer to be 25.6 hours. A 2.3 kg skunk would yield 70% edible flesh (White 1953), a 13 g heart, 62 g liver, and 6 g of kidneys (Spector 1956).

Wild Turkey. The wild turkey was an important game species for both Native Americans and early white settlers of the Eastern Woodlands, but it was nearly extirpated from the region by the early twentieth century. Today it has been reintroduced to many parts of its range, where it exists as a carefully managed game species. Its current numbers, however, do not nearly approach those of former times. It has been estimated (Edminsten 1954) that in the early nineteenth century prime turkey habitat in the eastern United States supported one bird per 10 acres ($25/\text{km}^2$). The Ridge and Valley Province of Virginia with its expansive oak-hickory forests, ample water sources and generally mild climate would seem to be nearly ideal turkey habitat, so the figure of $25/\text{km}^2$ will be used in this study.

Using the standard search speeds and a density of $25/\text{km}^2$ it is calculated that the search cost of a turkey is about 0.8 hours in fall-winter and 1.6 hours in spring-summer. Studies of modern turkey populations have indicated home range sizes of approximately two square miles (5 km^2) to be typical (Smith 1975). A range of this size could be crossed in about five hours which will be used as the time cost of pursuit. Judging from the frequency in which historic accounts (Schorger 1966; Smith 1975) report the taking of turkeys, it seems they must have been unusually vulnerable to human hunters. For this reason I will assign a probability of success for fall-winter hunts of 50% and for spring-summer hunts of 33%. Not only would obtaining a clear shot be easier in the fall and winter, but during these seasons turkeys aggregate into large flocks to feed on mast. Native Americans reportedly were able to panic these flocks into flight, then shoot them after they came to roost in nearby trees (Schorger 1966). For this study a fall-winter cost of 13 hrs/turkey and a spring-summer cost of 21.9 hr/turkey will be used.

Adult gobblers average about 6.5 kg (14 lbs) and hens, 4 kg (9 lbs) (Edminsten 1954). This study will average these to create a figure of 5.2 (11.5 lbs) as an average turkey weight. Edible flesh represents 70% of live weight or 3.64 kg (8 lbs). In

addition an average turkey would yield a 26 g heart, a 120 g liver and a 125 g gizzard (Hanson 1962).

Ruffed Grouse. Grouse are considerably smaller than turkeys, weighing only about 670 g, but are more common, establishing in suitable habitats population densities of about 1 bird/8 ha (1/20 acres) (Johnsgard 1983). A home range of 12 hectares (30 acres) is typical (Johnsgard 1983). Search and pursuit costs of 1.6 hour and 0.8 hour are thus indicated. Grouse are retiring creatures, usually not seen until they are startled into flight, so a probability of success of 20 percent will be assigned to grouse hunting. This yields an expected cost per bird of 15.5 hours in fall and winter. Assuming a 70 percent edible portion (White 1953) and percentage organ weights comparable to turkey (Hanson 1962) allows the calculation of a return per grouse of 470 g flesh, a 3 g heart, a 15 g liver and a 16 g gizzard.

Waterfowl. Southwestern Virginia is marginal to both the Atlantic and Mississippian flyways (Bellrose 1976) and lacks large natural lakes or marshes. It does not support a large waterfowl population. Nonetheless, four species of duck are represented in the Daugherty's Cave zooarchaeological record. Of these four, the wood duck inhabits the area year round, the mallard occasionally winters there, the hooded merganser occasionally breeds there, and the blue-winged teal is found in the area only as a transient during its fall and spring migrations (Johnsgard 1975, Bellrose 1976).

Although waterfowl are subject to much wildlife management study, these studies focus on the principal breeding and wintering areas. Data on the abundance and distribution of waterfowl in marginal environments such as southwestern Virginia are scant. Wood ducks, however, favor wooded freshwater habitats such as would characterize the Daugherty's Cave area, so the data pertaining to them are perhaps more relevant than those dealing with the marsh-favoring species. For this reason the model will use wood ducks statistics to represent all waterfowl.

Wood ducks generally occur in pairs or small flocks (Bellrose 1976).

Population density estimations are few, but one nest per five hectares (1/12 acres) has been reported for Eastern Woodlands forests (Johnsgard 1975). Wood ducks typically have six young surviving to the fall (Johnsgard 1975), so I will consider one nest to represent eight ducks. This is a population density of one duck per 0.6 ha (1/1.5 acres). This suggests a typical search cost of 0.12 hours. Wood ducks do not maintain a stable home range (Johnsgard 1975), but for modeling purposes I will assume a home range equivalent to the area supporting the nest - five hectares. This suggests a pursuit cost of about 0.5 hr. Wood ducks are notoriously wary and easily spooked (Johnsgard 1975), so I will use a probability of success of only 20%. This increases the total expected cost of a duck to 3.1 hours.

Wood ducks weigh about 650 g and are 70% edible (White 1953). To 460 g of flesh are added a 4 g heart, a 18 g liver, and a 28 g gizzard (Hanson 1962).

Snapping turtles. Snapping turtles are found throughout the Eastern Woodlands in all sorts of aquatic habitats. They are common throughout their range, but do best in relatively still waters such as ponds, marshes and slow moving rivers (Ernst and Barbour 1972). The swift running Clinch River and Big Cedar Creek may not have supported particularly large snapper populations. However any of the numerous sinkholes in the area that contained water could have provided suitable habitat. A population density for snappers in the catchment is thus difficult to estimate. A population density of one turtle per 1.24 hectares (1/2 acres) has been reported for a marsh population (Ernst and Barbour 1972), and I will use this figure here, although intuitively it seems high. This indicates that about 0.25 hours would be the expected time required to locate signs of a snapper. Snappers are mobile creatures that have been captured up to 2.4 km (1.5 mi) from the nearest water (Ernst and Barbour 1972). Studies of marked and recaptured snappers indicate that they average moving about one kilometer (0.6 mi) from the initial capture point over the course of a year. Assuming

that one kilometer represents the radius of the snapper's home range, allows the calculation of 4.0 hours as the time necessary to "pursue" the average snapper. A snapper located away from water - while laying eggs for example - would be a certain capture. A snapper located in or adjacent to the water would probably require the use of traps, nets or hook-and-line to procure. Unfortunately I have been unable to locate any information concerning these techniques, their costs or effectivenesses. Somewhat arbitrarily I will assign a probability of success of taking a turtle at 50%. This raises the expected cost per turtle to 9.9 hours.

The median weight of 152 snappers caught in Michigan was 3.9 kg (8.6 lbs) (Lagier and Applegate 1943), which I will adopt for this study. Snappers dress out at about a 50% edible portion (Clark and Southall 1921), so an average snapper yields 1.95 kg (4.3 lbs) of flesh. Although the liver of snappers is reported to have been eaten by twentieth century consumers (Clark and Southall 1921), the potential contribution of snapper offal to the human diet cannot be considered due to the absence of nutritional analyses of turtle organ meat.

Fish. Compared to such areas as the Mississippi River valley or the coastal estuaries of the Mid-Atlantic, the southern Appalachians were not an area where fishing was an important subsistence pursuit (Rostlund 1952); although fish remains do appear in archaeological sites of the region, and the Cherokee are reported to have taken fish with lines, spears and weirs (Rostlund 1952:122). If Native Americans in southwestern Virginia failed to pursue fish rigorously, it is unlikely to have been for a lack of fish. About 30 species of fish greater than 125 mm (5 in) in adult length are found in southwestern Virginia today (Lee et al. 1980). In 1967 216,000 fish in a 144 km (90 mi) section of the Clinch River were killed by a fly ash spill from a power plant about 22 km (14 mi) downstream from the mouth of Big Cedar Creek (Cairns et al. 1971). This is over 1500 fish per kilometer.

Native Americans could have taken fish by hook and line, net, trap, spear, at weirs, and perhaps by poisoning the slower moving portions of the water courses (Rostlund 1952). Little information is available on which to base estimates of the time required to take fish. Modern fishermen using mostly live bait but also artificial lures on the New River in southwestern Virginia and southern West Virginia average taking about two fish per hour (Austen and Orth 1984). Assuming the fish average a pound apiece and dress out at 75 percent edible, then a net rate of about 0.75 kg/hour is estimated. Winterhalder (1979:365) reports that net fishing by the boreal forest Cree averaged 5.8 kg of fish per net-day of fishing. If the same return were produced by an eight hour day of active fishing, it would amount to 0.72 kg/hour. Finally Reidhead (1979:117) "guesstimated" that prehistoric creek fishing in Indiana would have yielded 1.85 kg/hour and river fishing 0.93 kg/hour. These estimates are not terribly confidence-inspiring but at least the order of magnitude is consistent. For lack of better data, I will use the estimate of 0.75 kg/hour based on the Austen and Orth (1984) study.

Shellfish. The shells of freshwater mussels and aquatic snails were recovered from Daugherty's Cave. Mussels were found in small numbers scattered throughout the strata. No concentrations of mussel shell were encountered. Mussel shell is used to temper the Mississippian period New River Series pottery recovered from the upper strata of the cave, and during the course of the excavation a small pile of fresh mussel shell (about six valves) was abandoned in the cave by some nocturnal predator. It cannot be stated with certainty that the mussel shells are the remains of human food. However, in other parts of the Eastern Woodlands, including the Tennessee River drainage, mussel shell middens are a prominent part of the archaeological record (Marquardt and Watson 1983; Lewis and Lewis 1961). There is no doubt that freshwater mussels were systematically exploited by prehistoric Native Americans,

although their importance to the diet and the nature and timing of their exploitation remain unsettled (Parmalee and Klippel 1974; Marquardt 1985).

Remains of aquatic snails in Daugherty's Cave are concentrated in an approximately 10 cm thick band within the Mississippian period strata. This pattern of deposition indicates a human procurement and not merely introductions via cave commensals. Some of the New River pottery from the site is tempered with aquatic snail shell, so some snails may have been acquired for technological purposes. This cannot explain, however, why literally tens of thousands of snail shells were carried to the cave and abandoned unused. The simplest explanation is that the snail shells represent the refuse from human meals. This interpretation is supported from data from other sites (Klippel and Morey 1986, and references therein).

Freshwater mussels obtain their highest population densities in streams and rivers with good current (Parmalee 1967), so the Clinch River and Big Cedar Creek should have been favorable mussel habitat. In southwestern Virginia nearly 19 small mussels per square meter of stream have been reported (Zale and Neves 1982). A 280 km (175 mi) section of the Tennessee River was estimated to harbor over 23,000 metric tons (26,000 tons) of mussels (Isom 1969). One of the two species identified from Daugherty's Cave, the elephant-ear mussel, occurred in densities of approximately one mussel per 10 m² (Isom 1969). Parmalee and Klippel (1974) report that elephant-ears yield 48 g of edible meat. These figures allow the calculation of 49 kg of edible elephant-ears per hectare of stream. To account for other species I will essentially double this density to a round 100 kg/ha of stream. Within the catchment the Clinch River and Big Cedar Creek will be estimated to have harbored 13,900 kg of edible mussel.

Estimating the time needed to collect mussels is difficult. Parmalee (cited in Reidhead 1976:129) states that collection efficiency is highly variable depending on water depth, turbidity, season and species availability. He reports collection rates

ranging from 121 kg/hour (266 lbs/hr) to 4.5 kg (10 lbs) per day. In collection experiments in the Wisconsin River, Theler (1987) calculated collection rates of about 0.2 hr/kg of edible mussel. Reidhead (1976) used a figure of 0.4 hours per kilogram of edible mussel including processing and transportation costs. Although intuitively I feel this figure is too generous, I will use it for the sake of comparability.

To assess the time-cost of collecting aquatic snails, I conducted a timed collection from an approximately 3 m X 10 m stretch of Big Cedar Creek below Daugherty's Cave in October 1983. The water is about two to three feet deep here and the bottom is rocky. Snails were quite common and easily spotted and picked from the rocks. In 2.5 hours of collecting, I gathered 0.85 kg of whole shells. After boiling, these snails yielded an edible portion of 268 g. This calculates to 9.3 hrs/kg of edible snail meat without including costs of transport or processing.

ANIMALS NOT INCLUDED IN THE MODELS

Extirpated Species. Two game animals, bison and elk, formerly inhabited southwestern Virginia but were extirpated before the era of modern ecological study (Webster et al. 1985). Because of this, insufficient evidence exists to include them in model in any meaningful way.

The bison is primarily a grazing animal of the North American grasslands. The presence of bison in the Eastern Woodlands seems to have been a result of forest clearing by Native Americans (Schmidt 1978). If suggestions that fire-drives increased with the development of Mississippian societies and especially the historic fur trade are correct (Waselkov 1978), then bison may have been relatively recent immigrants into the eastern forests. In any event bison remains are rarely recovered from Eastern Woodlands archaeological sites (Griffin 1987; Ward 1990), which suggests they were seldom taken. Thus, the omission of bison from the model is likely to be of little practical importance.

Elk, or wapiti, are more of a problem since they are more commonly represented in Eastern Woodlands archaeological sites including Daugherty's Cave. Elk remains are never abundant archaeologically, however (McCabe 1982). Little is known of the ecology of the eastern elk, but by analogy to western elk it is presumed to have been primarily a grazer exploiting meadows and forest openings. Attempts to reintroduce elk to the eastern United States have failed except for a small herd established in western Pennsylvania. This herd is plagued by brainworm (Paralaphostrongylus tenuis), a parasitic nematode causing central nervous system damage, which in some years kills up to 50 percent of the animals. Because of brainworm fatalities, the size of this herd fluctuated between 77 to 38 animals over a three year period. The herd maintained a range varying from 4 km² (1.4 mi²) in the fall rut to 62 km² (24 mi²) during the rest of the year. The nonforested part of the range was made up agricultural fields and clear-cuts instead of meadows (Eveland et al. 1979).

In exploratory model runs, I included elk using population density figures from the Pennsylvania herd, weight data from western elk, and the nutritional composition information on venison to approximate the costs and benefits of exploiting eastern elk. This resulted in elk functioning as "superdeer". Its large size combined with a rather restricted fall range made it the most profitable resource to pursue. In fact, the model predicted that all other resources should be ignored as long as elk were available. Hence the model was exceedingly sensitive to the estimation of the prehistoric population size of eastern elk. Unfortunately this is a parameter which must be set arbitrarily, since there is no information beyond that concerning the ailing Pennsylvania herd. The inclusion of elk greatly diminishes the heuristic value of the model, as its inclusion swamps the interaction of the other system components. In order to observe how other variables interact, I have foregone the inclusion of elk.

Snakes. At least six species of snake were identified in the Daugherty's Cave faunal samples. These are the black racer, rat snake, king or milk snake, northern water snake, pine snake, and the timber rattlesnake. With the exception of the water snake, which is localized to stream edges, all might have been natural occupants of the cave (Linzey and Clifford 1981). Likewise all might have represent prey taken by, or carrion scavenged by, some other cave inhabitant, such as a skunk. On the other hand, all of the species are classified as large or very large snakes (Wright and Wright 1957), so they may have had some utility to the Native Americans as food. The fact that the king snake and the milk snake are nocturnal, however, argues against these being human prey.

Intuitively, it seems unlikely that snakes were systematically sought out by Native Americans as a game animal, and certainly ethnographic accounts contain no references to snake hunts. However, since snakes are so slow, any Native American who considered them edible should have been able to take them with negligible effort after chance encounters. As a result snakes may have been taken opportunistically but with some regularity.

Modeling the possible role of snakes in Native American subsistence seems futile, however. Data on the population densities, home ranges, and average weights of snakes are exceptionally spotty (cf. Stickel et al. 1980; Fitch and Fleet 1970; Semlitsch and Gibbons 1982; Gibbons 1972) and apparently nonexistent for the southern Appalachian area. Moreover, edible portion figures and nutritional analysis of snake meat are not available. In short, to include snakes in the model I would have to invent every variable, making their role in the model little more than a measure of my ingenuity. For this reason I will forego including snakes in the model.

Box turtles. Box turtles are frequent finds in Eastern Woodlands archaeological sites, but they will not be incorporated into the optimal diet models of this study. On one hand, box turtles eat mushrooms poisonous to humans and accumulate the toxins in

their flesh making them a potentially dangerous food (Ernst and Barbour 1972). On the other hand, Native Americans used box turtle shells for a variety of utilitarian objects such as bowls and rattle boxes (Ernst and Barbour 1972). Hence box turtles probably were always a prized commodity to Native Americans, but perhaps not as a foodstuff. Excluding box turtles from a diet selection model thus seems justified.

POPULATION STRUCTURE

The amount and kind of resources a population needs to consume depends directly on the size of the population and its demographic structure, since many nutritional requirements are age and sex dependent. Archaeological data from southwestern Virginia are too limited to allow any inference about the region's prehistoric demography, so population size and structure must be estimated. For purposes of comparability, I will use Keene's (1979) figures based on a population size of 25 and with an age and sex distribution extrapolated from Weiss's Modal Life Table MT15-50 (1973). To assess the potential effects of demographic stress on diet choice, the population figure will be increased to 250 in a subsequent model run. These figures seem intuitively reasonable and will be adequate for constructing a general model (Table 3.4).

NUTRITIONAL REQUIREMENTS (Table 3.4)

Following Reidhead (1981) and Keene (1981) I will create models which specify optimal diets that meet the populations requirements for energy, protein, vitamin A, thiamine, riboflavin, niacin, ascorbic acid, iron and calcium. Although phosphorus was included in the earlier studies, I have chosen to delete it, as it is no longer included in many food composition tables. This is, I assume, because it is

ubiquitous in all natural foods, and thus, is of little practical importance in human diets (Passmore and Eastwood 1986).

The nutrients included in the study are only a small sample of the vitamins, minerals and trace elements necessary for maintaining human health. They are, however, the nutrients which are of most practical importance in that they are the ones most likely to be deficient in ordinary diets (Passmore and Eastwood 1986). As a result they are also the nutrients for which there is the best information on the amounts of the nutrients required for health and on their distributions in foods.

Knowledge of human nutritional requirements is far from complete and many different dietary standards are available (Passmore and Eastwood 1986). With the exception of the requirements for vitamin C and calcium which are taken from the FAO standard (FAO 1977), I have chosen to use as a standard Recommended Nutrient Intakes for Canadians (Bureau of Nutritional Sciences 1983), since it is the most recently revised standard. This selection was made for practical reasons. The units of measurement of Vitamin A and niacin have been changed in recent years. Most recent nutritional composition analyses measure vitamin A in Retinol Equivalents (RE) and niacin in Niacin Equivalents (NE). To take advantage of recent nutrient composition studies of game and wild foods it was desirable to use a standard employing the new units.

Two facts, however, indicate that this standard sets a level of nutrient intake that almost certainly exceeds what the prehistoric occupants of Daughterty's Cave actually required. First, for defining an adequate diet the recommended nutrient intakes (RNI) are meant to be conservative for modern Canadians, in that they are set at a level that provides a very low risk of an inadequate intake (Bureau of Nutritional Sciences (BNS) 1983:14). They are set to "maintain health in already healthy individuals" and are definitely higher than necessary to prevent clinical deficiency diseases (BNS 1983:8). For nutrients other than energy, the RNI is set at two standard

Table 3.4: Population Structure and Nutrient Requirements¹

Age	Sex	Wght. kg	No.	Energy kcal	Pro- tein g	Cal- cium mg	Iron mg	Vit. A re	Thia- mine mg	Ribo- flavin mg	Nia- cin ne	Vit. C mg
0-1		8	1	750	10.0	450	7	400	0.3	0.4	5.4	20
1-2		11	1	1100	10.9	450	6	400	0.4	0.6	7.9	20
2-9		18	7	1800	15.1	450	6	500	0.7	0.9	13.0	20
10-18	M	50	3	2800	33.5	650	12	900	1.1	1.4	20.2	30
10-18	F	48	3	2200	27.8	650	13	800	0.9	1.1	15.8	30
19-49	M	72	5	2850	41.0	450	8	1000	1.4	1.4	20.5	30
19-49	F	58	4	2000	30.2	450	14	800	0.8	1.0	14.4	30
50-74		68	1	2050	37.1	450	7	900	0.8	1.0	14.8	30
Pregnancy		1	233	18.2	110	6	100	0.3	1.5		10	
DAILY TOTAL²			25	53983	691.6	12560	240	18600	22.9	27.2	388.5	670
SEASONAL TOTAL² (thousands)				4926	63.1	1146	22	1697	2.1	2.5	35.5	61
YEARLY TOTAL² (thousands)				19704	252.4	4588	87	6789	8.3	9.9	141.8	245

¹ See text for references.

² Numbers may reflect rounding errors.

deviations above the mean requirement for the Canadian population; thus 97.5% of the population actually requires less. The energy requirement is set at the mean requirement of the population, since excess energy intake is also unhealthy (BNS 1983:8). Second, even the mean nutrient requirements of modern Canadians are likely to be higher than that of prehistoric Native Americans, since peoples from nonindustrialized nations routinely maintain health at much lower levels of nutrient intakes than do people from affluent societies (Passmore and Eastwood 1986:169).

Although the RNI used in the models are most likely too high and result in the predictions of optimal diets that are actually better than necessary, they still are heuristically satisfactory. Furthermore the sensitivity analysis provided by linear programming will allow the effects of lowering the nutrient requirements to be monitored.

Table 3.4 shows the individual nutritional requirements of each age and sex class of the model population as well as the population's seasonal and yearly totals. A brief discussion of the nutrients included in the model follows.

Energy. Energy is not actually a nutrient but is created by the metabolism of dietary carbohydrates, fats and proteins. It is required for the synthesis of the body's structures, secretions and excretions; for cell, tissue and organ activity; and for the performance of external work and the maintenance of body temperature (BNS 1983). The requirement for energy is dependent on the individual's age, level of physical activity, body size and composition, as well as climate (Passmore and Eastwood 1986). Since individual variation is so great, the "average" energy requirement of a population is of limited practical utility (BNS 1983). Extrapolation from one population to another is a questionable procedure (BNS 1983), but for creation of a referent standard for an extinct population it is the only recourse. The body size of modern Canadians is probably larger than that of the prehistoric inhabitants of southwestern Virginia, but it also likely that the Canadians are less active. It is hoped the errors cancel out. Using

the Canadian RNI for energy, the age and sex structure of Weiss's model life table MT15-50, and allowing for one pregnancy yearly results in an average daily RNI for the model population of 2157 kcal. This is within the range recommended by other modern standards (Passmore and Eastwood 1986), and closely approximates the figures of 2200 kcal/day and 2153 kcal/day used by Reidhead (1976) and Keene (1979)

Protein. This study will use a general protein requirement with a average daily RNI of 28 grams. Actually, protein per se is not required but serves as a source of amino acids which are necessary for construction and replacement of the body's proteins (BNS 1983). Eleven of the twenty common amino acids can be synthesized by humans, but nine, the essential amino acids, must be provided from dietary sources (BNS 1983). Ideally the RNI of each of the nine essential amino acids would be used as a constraint in the linear programming models, but this is not practical. Although the RNI of the essential amino acids has been estimated (Passmore and Eastwood 1986), few food composition tables provide data on their distribution in foods. Rather only a general figure for protein is provided.

Generally deficiencies in protein intake are accompanied by an overall shortage of food energy leading to a suite of disorders classified as protein-energy malnutrition (PEM). Today PEM is the leading public health problem in the third world and is responsible for much infant mortality (Passmore and Eastwood 1986). One prevalent form of PEM, kwashiorkor, is particularly associated with protein deficiencies resulting from weaning infants onto foods low in protein (Passmore and Eastwood 1986). Since Native Americans lacked dairy products as weaning foods, the threat of kwashiorkor would seem real, and, indeed, evidence of nutritional stress at the age of weaning is noted in the archaeological record of North America (Rose et al. 1991:24-25).

Retinol (Vitamin A). The role of retinol in human health is not fully explained, but it is necessary for the production and maintenance of epithelial tissue, for tissue and skeletal growth, and for the normal functioning of the retina (BNS 1983). In the Third

World, vitamin A deficiency is a leading cause of blindness, particularly in children (BNS 1983). Of the nutritional deficiency diseases, vitamin A deficiency is second only to protein-energy malnutrition (BNS 1983). Retinol is found chiefly in dairy products, egg yolk, liver and fish oils (Passmore and Eastwood 1986). The human body can, as well, produce retinol from the plant pigment carotene, common in yellow and dark green leafy vegetables (Passmore and Eastwood 1986). When well-nourished the body maintains a store of retinol in the liver sufficient to sustain health for many months to years (Passmore and Eastwood 1986). Hence, the health consequences of a seasonal shortfall in vitamin A intake may not be very great.

The Canadian daily RNI for adult males is 1000 RE (retinol equivalents) and for females 800 RE (BNS 1983). The RNI for children is less well understood, but the Canadian standard includes an arbitrary allotment for growth (BNS 1983). The average RNI in this study is 744 RE daily. These RNI are set at a level sufficient not only to preserve health but also to maintain the body's reserve of vitamin A in the liver (BNS 1983). Excess retinol is toxic at levels of 12,000 RE daily, but excess carotenes merely turn the skin yellow (BNS 1983). If the models produce optimal diets that provide per capita vitamin A intakes greater than 12,000 RE, then a maximal vitamin A constraint will be incorporated into the models.

Ascorbic Acid (Vitamin C). Ascorbic acid has many functions in human physiology but primary among them is in the manufacture of collagen, the key constituent of the intercellular substance (Robinson et al. 1986). An adequate supply of vitamin C necessary for normal growth and wound healing. A gross deficiency of vitamin C results in scurvy, a disease marked by skin disorders, swollen and bleeding gums, poor wound healing, re-opening of healed wounds and potentially lethal hemorrhages (Passmore and Eastwood 1986). Although scurvy has been stated to be the nutritional disease, excepting famine, which has caused historically the most human suffering, it is not a common disease (Carpenter 1986). This is because ascorbic acid

is nearly ubiquitous in animal and plant tissues with the exception of the mature seeds of cereals and pulses (Passmore and Eastwood 1986). Hence, a diet must be nearly devoid of fresh foods for scurvy to occur (Passmore and Eastwood 1986).

In initial model runs a weighted RNI based on the Canadian standard of 42 mg daily was used. This resulted in extreme diets focused on vitamin C acquisition. To mitigate the effects of vitamin C on the model solutions, the lower FAO RNI of 30 mg daily was substituted (FAO 1974). Even at the lower level, vitamin C still has a great influence on the models. The FAO requirement is probably also too high. A daily intake of less than 10 mg of ascorbic acid will cure and prevent scurvy (BNS 1983), and it is considered that an adequate maintenance dose of ascorbic acid is probably less than 15 mg daily (Passmore and Eastwood 1986). Moreover, since the healthy body maintains an ample reserve of ascorbic acid in its tissues, a shortfall of dietary ascorbic acid of several weeks to months can be weathered with no ill effects (Carpenter 1986).

Thiamine (Vitamin B1). Thiamine is required for the metabolism of carbohydrates, fats and proteins for the production of energy. The need for thiamine is thereby dependent on the caloric intake. Whereas 0.30 mg thiamine/1000 kcal appears adequate for preventing signs of clinical deficiency, the Canadian standard is set at 0.40 mg/1000 kcal to allow for any individual variation (BNS 1983). Given the caloric RNI of 2160 kcal used in this study, the average daily RNI of thiamine is about 0.9 mg. Thiamine is very widely distributed in foods. The best sources being meat, liver, dry beans and peas, nuts and cereal grains (Robinson et al. 1986). Fruits and vegetables generally have only small amounts of thiamine, but when eaten in bulk can be significant sources (Robinson et al. 1986). A gross deficiency of thiamine results in beriberi, formerly a plague among Asian communities subsisting nearly exclusively on polished rice, but now rarely seen among people on normal diets (Passmore and Eastwood 1986).

Riboflavin (Vitamin B2). Like thiamine, riboflavin functions in the energy cycle and is needed for cell respiration (Passmore and Eastwood 1986). The Canadian daily RNI is 0.50 mg/1000 kcal (BNS 1983), which in this study yields an average daily RNI of 1.08 mg. Organ meats are the best sources of riboflavin with green leafy vegetables being good sources (Robinson et al. 1986). Somewhat surprisingly given riboflavin's importance in cell respiration, deficiencies seem to lead only to relatively minor disorders of the lips, tongue and nasal regions without progressing to serious illness (Robinson et al. 1986).

Niacin (Vitamin B3). Niacin, also, is involved in the energy cycle and in cell respiration. The Canadian daily RNI is 7.2 NE (niacin equivalents) per 1000 kcal (BNS 1983), which yields for this study a average daily RNI of 15.5 NE. A gross deficiency of niacin results in pellagra, a life threatening disease characterized by dermatitis, diarrhea, and dementia (Robinson et al. 1986). Niacin is widely distributed in foodstuffs with organ meats, fish, wholemeal cereals and pulses being the best sources (Passmore and Eastwood 1986). As well as utilizing dietary niacin, the body is capable of converting the amino acid tryptophan to niacin. Unfortunately in many cereals, especially maize, niacin occurs in an unabsorbable form. For populations relying on maize as a staple, this is potentially a serious problem, as maize is also deficient in tryptophan. Happily, traditional maize processing techniques utilizing alkaline substances to soften the maize kernels also serve to liberate bound niacin (Katz et al. 1974). As a result, maize-centered diets did not lead to pellegra prior to the widespread adoption of commercial cornmeal processing (Roe 1973). In Europe pellegra was unknown prior to the eighteenth century and in the New World seems to have been absent until the nineteenth (Roe 1973). Today it is common only among the most grossly impoverished populations of Africa (Passmore and Eastwood 1986).

Calcium. Calcium is a fundamental constituent of the skeleton and is also involved in numerous metabolic processes (Passmore and Eastwood 1986). Initial

model runs used the Canadian standard to estimate an average daily RNI of 755 mg. This resulted in extreme diets highly sensitive to calcium intake. As with vitamin C, the FAO standard was substituted. The weighted daily RNI based on the FAO (1974) standard is 502 mg. This too is probably too high.

The human body has a tremendous ability to adapt to a wide range of calcium intakes by regulating urinary excretions and the efficiency of calcium absorption in the intestines and by drawing on the body's stores in the skeleton and kidneys (BNS 1983). Although intakes of 800 mg daily are typical of affluent societies, intakes of 400 mg daily are common worldwide (Robinson et al. 1986). In Sri Lanka growing children have been observed to maintain positive calcium balances on intakes as low as 200 mg daily (Robinson et al. 1986). In fact it has been stated that a recommended intake of calcium has no practical value, since no human on a normal diet has ever developed a primary calcium deficiency (Passmore and Eastwood 1986). I maintain calcium in the current models largely because the earlier work of Reidhead (1976) and Keene (1979) has implicated it as an important nutritional constraint in the Eastern Woodlands.

Dairy products are the best sources of calcium but shellfish, fish eaten with the bones, and green leafy vegetables are also important sources (BNS 1983). Some plant foods contain enough phytic or oxalic acid to theoretically bind all their calcium making it unabsorbable, but in practice the presence of these acids seems to have no appreciable effect (Passmore and Eastwood 1986). More importantly calcium absorption and utilization in the skeleton is dependent on an adequate supply of vitamin D. A shortage of vitamin D results in the skeletal deforming disease rickets (Robinson et al. 1986). Vitamin D can be obtained from dietary sources, but it is also synthesized by the skin in the presence of sunlight. Since there is no reason to suspect prehistoric Native Americans lacked exposure to the sun, it seems safe to assume that vitamin D synthesis was adequate for calcium metabolism. Hence vitamin D will not be included as a nutritional constraint.

Iron. Iron is a necessary element of the hemoglobin molecule and is also involved in cellular metabolism (Passmore and Eastwood 1986). Failure to maintain an adequate supply of iron results in iron deficiency anemia, a disease marked by fatigue and the inability to sustain prolonged exertion (Passmore and Eastwood 1986). It rarely occurs in people on balanced diets, but pregnant and menstruating women are at increased risk (Passmore and Eastwood 1986). The average daily RNI of iron in this study is 9.6 mg.

Iron is widely distributed in common foods, but the iron in vegetable foods often occurs in a bound inorganic form with reduced bioavailability (Passmore and Eastwood 1986). Animal products contain iron in a freely available form (haem iron), and when consumed with plant foods, increase the bioavailability of the inorganic iron (Passmore and Eastwood 1986). Although it would be possible to modify the parameters of the models to account for the reduced bioavailability of vegetable iron, I have not done so. Rather when all-vegetable diets are selected, I note the potential risk of iron deficiency.

NUTRIENT COMPOSITION OF RESOURCES (Tables 3.5 - 3.7)

The nutrient compositions of most foods considered in this study are taken from published sources. Therefore the derivation of the nutrient content of the resources is largely straightforward and evident from the tables (Tables 3.5 - 3.7). The following remarks address the areas where assumptions, estimations or substitutions were necessary.

In most cases it was possible to use analyses of cooked foods and thus eliminate the need to estimate vitamin losses to cooking (cf. Reidhead 1976; Keene 1979). The amount by which cooking destroys vitamins is dependent on the method of cooking, the

degree of heat, the length of cooking, and the pH of the cooking water (Passmore and Eastwood 1986).

If foods are boiled, some nutrients can be regained by consumption of the cooking fluids (Passmore and Eastwood 1986). I will assume that losses to cooking were only moderate. Therefore, in cases where only analyses of raw foods were available, the content of thiamine, riboflavin, and vitamin C will be reduced by 25% to reflect losses to cooking.

For a few resources lacking nutrient composition data, it was necessary to rely on nutrient composition analyses of related species. The substitution of the analysis of an Asian turtle for a North American turtle probably does not matter greatly. However, there is some possible skewing effect due to the effects of domestication. For example, the substitution of domesticated turkey and domesticated blackberries for wild turkey and wild blackberries may inflate the caloric content of each, since domestication has probably promoted increased levels of fats and sugars. In the case of wild duck, it was possible to sidestep the influence of domestication by using an analysis of wild goose rather than that of domesticated duck. On the other hand, the extinct domesticated varieties of chenopod, sumpweed and maygrass may have been more caloric than their surviving wild relatives. Overall, I do not think the substitution of nutrient composition of one resource for another is likely to influence the model outcomes greatly.

For two potential game animals, skunk and otter, no nutritional analyses were available. Their nutrient composition was estimated as the average of the nutrient composition of the mammals for which data were available.

The nutrient composition of the heart, liver and kidneys of mammals and of the heart, liver and gizzard of fowl were estimated, since organ meats are generally good sources of nutrients (Watt and Merrill 1963). Unfortunately, no nutrient analyses of

Table 3.5: Nutrient Composition of 100 g Edible Portion of Plants

	Energy (kcal)	Protein (g)	Calcium (mg)	Iron (mg)	Vit. A (RE)	Thia (mg)	Ribo (mg)	Niacin (NE)	Vit. C (mg)	Ref.
Acorn	369	6	41	1	2	0.1	0.1	3	0	1
Beans, dry	118	8	50	3	0	0.1	0.1	1	0	2
Beans, fresh	25	2	50	1	54	0.1	0.1	1	10	2
Bramble	58	1	14	4	19	0.0	0.0	1	13	2
Butternut ¹	635	21	1	6	29	0.2	0.1	1	0	2
Chenopod ²	400	17	131	7	5	0.5	0.3	3	0	3
Corn, dried	348	9	22	2	37	0.3	0.1	4	0	2
Corn, green	91	3	3	1	40	0.1	0.1	1	9	2
Grape, raw	69	1	16	0	10	0.1	0.0	0	4	2
Greens	21	2	113	1	582	0.1	0.2	1	46	4
Hickory ³	675	13	2	3	13	0.5	0.1	2	0	2
Maygrass	370	24	66	6	0	0.7	0.2	15	0	5
Maypops	40	2	7	4	10	0.0	0.0	2	21	6
Squash	14	1	25	0	39	0.1	0.1	1	10	2
Sumpweed	535	32	290	11	4	1.6	0.6	22	0	3
Sunflower	560	24	120	7	4	1.5	0.2	9	0	2
Walnut	635	21	1	6	29	0.2	0.1	1	0	2

References: 1. USDA 1984; 2. Watt and Merrill 1963; 3. Asch and Asch 1978;
 4. Medical Services Branch 1985; 5. Crites and Terry 1984;
 6. Original analysis from Webb Foodlab, Raleigh, NC;

¹ Based on walnut

² Micronutrients averaged from de Bruin (1964)

³ Vitamins based on pecan

Table 3.6: Nutrient Composition of 100 g Edible Portion of Meats (page 1)

Animal	Cooking Method	Energy (kcal)	Protein (g)	Calcium (mg)	Iron (mg)	Vit. A (RE)	Thiamine (mg)	Riboflavin (mg)	Niacin (NE)	Vit. C (mg)	Ref.
Flesh:											
Bear	Stewed	137	25.6	20	2.4	0	0.07	0.69	9	2	1
Beaver	Cooked	248	28.9	21	1.4	0	0.08	0.38	17	0	1
Deer	Roasted	146	29.5	20	3.5	0	0.37	0.28	12	0	2
Goose, Wild	Roasted	309	30.0	22	2.6	292	0.09	0.29	16	0	1
Groundhog	Cooked	216	28.9	21	1.1	0	0.04	0.07	14	0	1
Muskrat	Cooked	146	26.7	21	1.6	30	0.16	0.21	17	0	1
Mussels	Raw ¹	68	8.6	345	12.4	113	0.00	0.19	2	0	3
Opossum	Roasted	255	29.2	17	2.6	0	0.12	0.38	11	0	2
Rabbit	Stewed	216	29.3	21	1.5	0	0.05	0.07	19	0	2
Raccoon	Roasted	255	29.2	17	2.6	0	0.59	0.52	11	0	2
Snails	Boiled	39	8.2	108	8.1	150	0.02	0.04	2	0	4
Squirrel ²	Raw ¹	116	26.3	23	1.9	213	0.05	0.16	7	0	5
Trout, Brook	Cooked	196	23.5	218	1.1	96	0.12	0.06	4	1	2
Turkey, Dom	Roasted	170	28.9	26	1.8	0	0.07	0.18	11	0	1
Turtle ²	Raw ¹	76	16.8	107	1.8	4	0.18	0.33	8	0	5
Avg. Mammal ³		171	27.7	21	2.0	67	0.10	0.00	12	0	

Table 3.6: Nutrient Composition of 100 g Edible Portion of Meats (page 2)

Animal	Cooking Method	Energy (kcal)	Protein (g)	Calcium (mg)	Iron (mg)	Vit. A (RE)	Thiamine (mg)	Riboflavin (mg)	Niacin (NE)	Vit. C (mg)	Ref.
Offal:											
Giblets, Chicken	Simmered	157	25.9	12	6.4	2229	0.09	0.95	4	8	2
Heart, Beef	Braised	188	31.3	6	5.9	9	0.25	1.22	13	1	2
Liver, Deer	Cooked	229	26.7	11	8.9	16036	0.26	4.44	13	27	1
Kidney, Beef	Braised	252	33.0	18	13.1	345	0.67	4.58	18	0	2

REFERENCES: 1. Medical Services Branch (1985); 2. Pennington and Church (1985); 3. Parmalee and Klippel (1974); 4. Original Analysis, Webb Foodlab, Raleigh, NC; 5. Leung et al. (1972)

- ¹ Thiamine, riboflavin and vitamin C reduced by 25% to approximate cooking losses.
- ² Asian species used as proxies.
- ³ Used for skunk and otter.

Table 3.7: Nutrient Composition of Animals

Animal	Weight (kg)	Energy (kcal)	Protein (g)	Calcium (mg)	Iron (mg)	Vit. A (RE)	Thiamine (mg)	Riboflavin (mg)	Niacin (NE)	Vit. C (mg)
Bear	76.1	109650	19610	14665	2216	793539	66	730	7128	2725
Beaver	9.5	23228	2760	1881	199	59349	10	61	1584	103
Deer	33.4	49807	9838	6546	1239	146404	22	140	4031	246
Duck	0.5	1506	150	107	14	2130	0	2	78	3
Fish [†]	1.0	1960	235	2180	11	960	1	1	40	10
Groundhog	2.9	6238	831	589	47	18908	2	9	403	31
Grouse	0.5	852	145	126	11	758	0	1	53	3
Muskrat	0.7	1105	197	151	15	4086	1	3	124	6
Mussels [†]	1.0	680	86	3450	124	1125	0	2	20	0
Opossum	1.5	3887	447	254	49	18807	2	11	173	31
Otter	7.1	12576	1980	1438	187	78771	9	26	869	124
Rabbit	0.8	1658	223	154	16	8520	1	3	142	14
Raccoon	4.8	12215	1408	799	155	50124	27	41	545	83
Skunk	1.7	2921	466	345	39	11034	2	3	203	17
Snails [†]	1.0	390	82	1080	81	1500	0	0	20	0
Squirrel	0.5	636	139	118	12	3645	0	2	38	4
Turkey	3.9	6545	1111	969	82	6041	3	9	407	22
Turtle	2.0	1520	336	2140	36	75	4	7	160	0

[†] One kilogram portion.

wild offal were available except for that of deer liver. Hence it was necessary to substitute data from beef heart, beef kidneys, and chicken giblets.

The nutrient analyses of maypops fruit and aquatic snails were made for this study by Webb Foodlab, Inc. of Raleigh, NC. Approximately 850 g of live snails were gathered from Big Cedar Ck. in October of 1983. These were simmered in distilled water for two hours. After cooling the snails were picked from their shells with a corkscrew. A total of 53 g of snails were obtained. These along with their 215 g of cooking water were analyzed for nutrient content. Unfortunately, the size of the sample is small, so only a single, rather than the standard three, analyses could be run. Hence, the results are best considered approximate.

Maypops fruits were gathered from an overgrown corn field in Wake County, NC in September of 1983. The fruits were opened and the edible pulp removed from around the seeds. The pulp and what juice could be saved weighed 280 g. This was analyzed by Webb Foodlab. Again the sample was too small to allow multiple analyses, so the results are best considered approximate.

In general I do not think the uncertainties surrounding the nutrient composition of the resources are likely to be important sources of error for a model of prehistoric subsistence.

SUMMARY

This chapter presents the data and estimations used to construct the linear programming models of prehistoric Eastern Woodlands optimal diets. Prehistoric population size is set arbitrarily at 25 and 250 people. The demographic structure of the population follows Keene (1976) in using Weiss's Modal Life Table MT15-50 (1973). The estimation of population sizes and the choice of modal life table are rather arbitrary but nonetheless seem reasonable for a general model of Eastern Woodlands subsistence.

The nutrient requirements of the population are taken from the most recent Canadian standard (BNS 1983) with the exception of the requirements for calcium and vitamin C, which are taken from the FAO standard (1974). The calcium and vitamin C requirements were lowered after preliminary model runs indicated that the Canadian requirements produced highly artificial diets. In general the nutrient requirements used in the study are probably unrealistically high for a prehistoric Native American population. They do serve as a general, readily replicable standard however. I do not think that use of a different standard would produce qualitatively different diets.

The nutrient composition of the resources is taken primarily from published sources. Some extrapolation from related species has been necessary where data were absent, but this is not considered an important source of error.

The time costs of exploiting plants is taken for the most part from published studies of replicated harvesting and processing experiments. The search costs of plants is considered nil. The time costs of obtaining animals is based on published data on wildlife population densities and home range sizes. These are used to calculate search and pursuit costs which are then increased by the estimated probability of failed pursuits. Estimating the costs of prehistoric subsistence activities has been considered the most tenuous aspect of Eastern Woodlands optimal diet modeling (Reidhead 1976; Keene 1979) and the present efforts are no exception. The procedure used in this study does, however, have the advantage of being systematic, easily replicable, and based on significant characteristics of the resources.

CHAPTER IV MODEL RESULTS

In order to maximize the heuristic value of linear programming, the seasonal optimal diet models were run reiteratively under varying conditions of nutritional constraints, population size and cultigen availability. A total of five mixtures of nutrient requirements, two population sizes and three patterns of cultigen availability were modeled, each for four seasons of the year. This allows the influence of each of these factors on subsistence decisions to be examined in isolation from the simultaneous influence of other factors. Unfortunately it results in a glut of model output, most of which can be encapsulated in tabular form.

This chapter presents the outputs of the various models. First are presented the optimal diet models under varying nutritional constraints for a small population of 25 people using, in turn, a foraging strategy, a native agricultural strategy, and an agricultural strategy using Mesoamerican-derived maize and beans. This choice of three subsistence strategies follows the Archaic - Woodland - Mississippian sequence of subsistence change in the Eastern Woodlands. Following the optimal diet models of the small population, the models are rerun for a population ten times larger under the same sets of constraints. This will allow the potential impact of population pressure to be assessed.

Although the models incorporate nine nutritional requirements, initial model runs indicated that several nutrients rarely or never influenced diet selection. I concluded that five combinations of nutrient constraints are sufficient to illuminate the role of nutritional requirements in shaping optimal diet choice. These five combinations which will be used in the models are (1) a basic pattern in which

only energy needs must be met; (2) a B vitamin pattern in which the three B vitamins - thiamine, riboflavin and niacin - as well as iron and protein are added as constraints; (3) a vitamin A pattern in which vitamin A is added; (4) a calcium pattern in which calcium is added; and finally (5) a vitamin C pattern in which vitamin C is added to complete the suite of nutrient constraints. In addition constraints limiting the maximal intakes of vitamin A and iron were incorporated in the models on an ad hoc basis when the danger of nutrient overload (Passmore and Eastwood 1986) was indicated. Vitamin A overload was never a problem, but the maximal iron constraint was frequently binding when mussels entered the optimal diet.

A total of 120 optimal diet models were created. The output of the models is presented as a set of tables displaying the optimal diets under the varying constraints and the time costs of acquiring them. A second set of tables indicates the extent to which costs of the optimal and secondary resources would need to vary before changes in the optimal resource mix would occur. (Optimal resources are those indicated to be part of the optimal diet. Secondary resources are those that require less than a 25% reduction in cost to become part of the optimal diet.) The third set of tables indicates the percent of the Recommended Nutrient Intake (RNI) of each nutrient acquired under the varying constraints.

SMALL POPULATION: FORAGING STRATEGY (Table 4.1, 4.2, 4.3)

In this set of models the population size is 25 people of which 16 are considered potential contributors to food procurement ("Producers"). No cultigens are included in the models, and the only native weedy annual which is included is chenopod.

Basic Diet

With a population of 25 and only energy needs to fulfill, the optimal diet in fall is 697 kg of hickory nutmeat and 10 beaver. The cost in time of acquiring the optimal diet is specified as 1904 hours which calculates to 1.3 hours per day for the sixteen producing members of the band.

Table 4.1 indicates that in the basic pattern model for fall the cost of acquiring hickory nuts could be increased by 45% before hickory would cease to be a part of the optimal diet. Thus hickory seems rather firmly established as part of the optimal diet. Beaver, on the other hand, can accept only a one percent cost increase before they would exit the optimal diet. Obviously the estimation of the cost of procuring beaver is unlikely to be accurate within one percent. Hence, the inclusion of beaver in the optimal diet is highly suspect. Table 4.1 shows that in fall there are no secondary resources, that is, no resources with acceptable costs between 75% and 99%. This indicates that were the cost of beaver to be increased above 101% then no new resources would be added, but rather the consumption of hickory would increase.

Table 4.2 indicates what role the various nutrient constraints play in structuring the optimal diet. Since energy is the only nutrient constraint for the basic pattern models, it is by necessity the binding constraint. Ancillary to fulfilling the energy requirement, protein and thiamine are obtained in surplus along with moderate amounts of iron, riboflavin, niacin and vitamin A. Only trace amounts of calcium and vitamin C are obtained, however.

The optimal solutions to the winter, spring and summer strategies can be read from the tables in a similar fashion. A further examination of table 4.1 indicates that the winter, spring and summer foraging strategies are predicted to have been very similar to that of the fall. Hickory now has acceptable costs of 111% and 123% of its modeled cost indicating it remains an optimal resource. Beaver, however, is now a

secondary resource with acceptable costs of only 90% and 82% of its modeled cost. Beaver are less valuable in winter to summer because they are assumed to suffer seasonal weight losses which reduce their value as an energy source. This reduction in their value makes them relatively more expensive than hickory nuts. Thus the optimal diet shifts solely to hickory nuts.

Hickory nuts are assumed to be available fresh only during the fall. Any hickory consumed in other seasons reflects food storage. The model makes no allowance for the increased costs of preparing storage facilities or for processing food for storage. Rather the amount of time the consumers would be willing to spent on such activities can be derived from the sensitivity analysis of costs. During the fall, when game is fattest and most easily taken, an extra 1.2 hours could be spent on procuring each kilogram of hickory before taking the beaver from zone 2 would be considered cost effective. I think that storing hickory require less time than this. Of course hunting during other seasons would be even more expensive making the relative benefit of nut storage even greater.

Unfortunately the acceptable increased cost of hickory nuts in other seasons cannot be read directly from the model output due to the influence of the variable beaver. Only an 11 percent increase cost is allowable before hickory would be replaced by beaver, but beaver are actually not available due to prior exploitation in the fall. The fact that no other resources have acceptable costs that are 75% or more of their modeled costs suggests that a considerable increase in hickory costs would be allowable before other resources would enter.

Nutritionally, dropping beaver from the diet after the fall season does not make much of a difference. No vitamin C is obtained from the all-hickory diet and only trace amounts of calcium, and vitamin A. Moderate amounts of niacin, riboflavin and iron are produced as well as a surplus of protein and thiamine. Nonetheless any

population attempting to live year round on hickory nuts and a few beaver clearly would risk malnutrition.

The consistent nutritional shortfalls suggest that the basic pattern optimality model fails to incorporate all the essential factors shaping prehistoric food procurement decisions. The potential role of hickory nuts as a relatively cheap source of energy seems very clearcut, however. Given the prominent place of hickory nutshell in Eastern Woodlands archaeobotanical assemblages this is a pleasing result.

A glance at the relative time costs of the fall and winter strategies points out one of the weaknesses of linear programming as a tool for prehistoric research. Although the winter strategy of subsisting on stored plant foods is qualitatively different from the fall strategy of mixed hunting and gathering, the model opts for the change in strategy because of a seasonal time savings of about one hour for the entire band. Obviously this is a difference of no practical significance for human decision-making. Furthermore it is a degree of precision far beyond that obtained by the model's parameters. Unfortunately this slavish devotion to the arithmetic of cost-benefit relationships is part and parcel of linear programming. It is always necessary to check the models for unrealistic results, especially those that result from implausible precision. Fortunately, the sensitivity analysis aids in this regard. The fall model's indication that relative value of beaver and hickory were within one percent of each other foreshadowed a minute change in model structure.

Vitamin B Pattern

With the additional nutritional constraints of iron, protein and the B-vitamins the predicted optimal diet of an Eastern Woodlands foraging band begins to take on a more familiar look, at least insofar as deer makes its first appearance as a desired resource. The optimal diet in the fall is predicted to be 639 kg of hickory nutmeat, 10 beaver yielding 90 kg meat and 8 deer yielding 267 kg meat. The total time cost of

Table 4.1: Optimal Diets (kg) of the Small Population, Foraging Strategy Models and Their Hourly Costs (page 1).

Resource	Basic	B-vit.	Vit. A	Calcium	Vit. C ¹
Fall					
Beaver	90	90	90	189	306
Deer		267	267		1503
Fish					2374
Groundhog					
Mussels				317	
Chenopod					
Grape					572
Hickory	697	639	639	628	
Total	787	996	996	1134	4755
Costs	1904	1978	1978	1990	5345
Winter					
Bear					
Beaver					
Deer		399	399	368	
Fish					
Groundhog					
Mussels					
Chenopod				816	
Grape					
Hickory	730	643	643	163	
Total	730	1042	1042	1347	
Costs	1905	2045	2045	2605	

¹ Winter vitamin C pattern infeasible

Table 4.1: Optimal Diets (kg) of the Small Population, Foraging Strategy Models and Their Hourly Costs (page 2).

Resource	Basic	B-vit.	Vit. A	Calcium	Vit. C
Spring					
Bear					
Beaver		274	274	52	52
Deer					
Fish					
Groundhog					
Mussels					
Chenopod		19	19	674	674
Grape				218	218
Greens				304	304
Hickory	730	621	621		
Total	730	914	914	1248	1248
Cost	1905	2172	2172	2572	2601
Summer					
Bear					
Beaver		7	7	81	52
Deer		110	110		27
Fish					
Groundhog					
Mussels		572	568	589	548
Berry					105
Chenopod		2			
Grape					
Greens			84	74	83
Hickory	730	645	645	639	548
Total	730	1336	1414	1383	1363
Cost	1905	2168	2218	2119	2193

Table 4.2:
 Small Population, Foraging Strategy Models - Percentage Acceptable Hourly Costs of
 Optimal and Secondary Resources
 by Season and Dietary Pattern (page 1)

Resource	Cost	Basic	B-vit.	Vit-A	Calcium	Vit-C ¹
Fall						
Bear	242.1					75
Beaver	8.6	101	143	143	145	157
Beaver2	12.5		98	98	100	108
Beaver3	16.4		75	75	76	82
Deer	29.1		100	100	99	113
Deer2	33.0		88	88	88	88
Deer3	36.9		79	79	79	79
Fish	1.4				b	114
Groundhog	5.0					88
Mussels	0.4		99	99	126	
Chenopod	2.2		77	77		
Grape	0.5					1112
Grape2	0.6					958
Grape3	0.6					838
Hickory	2.6	145	117	117	144	
Winter						
Beaver	8.6	90	a	a	a	
Beaver2	12.5		96	96	94	
Deer	29.1		104	104	106	
Deer2	33.0		88	88	88	
Deer3	36.9		79	79	79	
Fish	1.4				b	
Mussels	0.4		b	b	b	
Chenopod	2.2		79	79	147	
Hickory	2.6	111	140	140	130	

a optimal but previously exploited

b optimal but seasonably unavailable

¹ Winter vitamin C pattern infeasible

Table 4.2:
 Small Population, Foraging Strategy Models - Percentage Acceptable Hourly Costs of
 Optimal and Secondary Resources
 by Season and Dietary Pattern (page 2)

Resource	Cost	Basic	B-vit.	Vit-A	Calcium	Vit-C
Spring						
Beaver	8.6	82	a	a	a	a
Beaver2	12.5		131	131	131	a
Beaver3	16.4		116	116	76	142
Fish	1.4				b	b
Mussels	0.4		b	b	b	b
Chenopod	2.2		157	157	108	109
Greens	0.8				158	117
Hickory	2.6	123	113	113	125	134
Summer						
Beaver	8.6	82	a	a	a	a
Beaver2	12.5		a	a	131	a
Beaver3	16.4		153	147	147	144
Deer	61.5		111	111		111
Deer2	68.0		90	90		90
Deer3	74.5		83	83		83
Fish	1.4		75	86		89
Groundhog	8.0			91		87
Mussels	0.4		108	141	114	135
Blackberry	0.5					122
Chenopod	2.2		103	75		78
Greens	0.8		89	213	158	279
Hickory	2.6	123	129	131	148	126

a optimal but previously exploited

b optimal but seasonably unavailable

Table 4.3: Small Population, Foraging Strategy Models -
Acquisition of Nutrients
by Season and Nutrient Pattern (page 1)

Nutrient	RNA (1000's)	Percent of RNA Acquired ¹				
		Basic	Bvit	VitA	Ca	VitC ²
Fall						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	164
Protein	63.1	186	297	297	261	1754
Iron	21.9	87	125	125	268	<u>417</u>
Thiamine	2.1	171	203	203	159	411
Riboflavin	2.5	59	<u>100</u>	<u>100</u>	105	438
Niacin	35.5	73	160	160	135	944
Vitamin A	1697.0	41	107	107	<u>100</u>	649
Calcium	1146.1	3	7	7	<u>100</u>	491
Vitamin C	61.1	1	5	5	3	<u>100</u>
Winter						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	
Protein	63.1	152	318	318	430	
Iron	21.9	83	140	140	336	
Thiamine	2.1	175	223	223	308	
Riboflavin	2.5	38	<u>100</u>	<u>100</u>	174	
Niacin	35.5	31	162	162	203	
Vitamin A	1697.0	6	105	105	<u>100</u>	
Calcium	1146.1	1	8	8	<u>100</u>	
Vitamin C	61.1	0	5	5	5	

¹ Binding Constraints underlined

² Winter vitamin C pattern infeasible

Table 4.3: Small Population, Foraging Strategy Models -
Acquisition of Nutrients by Season and Nutrient Pattern (page 2)

Nutrient	RNA (1000's)	Percent of RNA Acquired ¹				
		Basic	Bvit	VitA	Ca	VitC
Spring						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	63.1	152	256	256	277	277
Iron	21.9	83	<u>100</u>	<u>100</u>	259	259
Thiamine	2.1	175	166	166	249	249
Riboflavin	2.5	38	<u>100</u>	<u>100</u>	128	128
Niacin	35.5	31	154	154	<u>100</u>	<u>100</u>
Vitamin A	1697.0	6	108	108	<u>100</u>	<u>100</u>
Calcium	1146.1	1	8	8	<u>100</u>	<u>100</u>
Vitamin C	61.1	0	5	5	165	165
Summer						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	63.1	152	266	265	252	252
Iron	21.9	83	<u>417</u>	<u>417</u>	<u>417</u>	<u>417</u>
Thiamine	2.1	175	174	174	158	164
Riboflavin	2.5	38	<u>100</u>	103	104	103
Niacin	35.5	31	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Vitamin A	1697.0	6	73	<u>100</u>	<u>100</u>	<u>100</u>
Calcium	1146.1	1	175	182	187	177
Vitamin C	61.1	0	1	65	57	<u>100</u>

¹ Binding constraints underlined

procurement is 1978 hours or 1.4 hours per producer. This is only about four percent more than the time required to obtain the basic pattern optimal diet. Riboflavin joins energy as a binding constraint. Nutritionally the diet is far superior to the basic pattern diet. The only deficiencies are in vitamin C and calcium.

Table 4.1 indicates that this optimal diet is not a particularly stable result. While beaver now is rather firmly, albeit counterintuitively, ensconced as a part of the optimal diet, hickory nuts and especially deer can tolerate only minor cost increases before other resources become optimal. The "rule of thumb" that a 25 percent cost reduction marks a potentially desirable resource suggests that mussels, chenopod seeds, and the beaver and deer from all three catchment zones are likely parts of the optimal diet. Mussel collection in particular would seem a viable alternative to deer hunting.

In winter the diet is predicted to focus on hickory and deer, the available beaver having been taken in the fall. This results in a slight increase in time expenditure, but the nutritional yield is nearly identical. As in the fall, the sensitivity analyses indicate the likelihood of a broader diet being taken. Mussels are actually optimal but are precluded by a seasonal availability constraint. Chenopod and the deer from the other two catchment zones are secondary resources as are the beaver in zone 2. The beaver in zone 3 are now too thin to be worth pursuing.

In the spring hickory nuts would remain the stable food augmented by chenopod seeds and beaver. The increase in time cost would be minimal. Iron joins energy and riboflavin as a binding nutrient constraint. Given that hickory can accept only a 13 percent cost increase before leaving the optimal diet, storing nuts for spring consumption might well be suboptimal. Chenopod, on the other hand, displays a 57 percent margin for increased costs suggesting that storage of chenopod from fall to spring might be a more feasible strategy under this set of constraints.

In the summer mussels become available and enter the diet in large amounts. In fact a preliminary model run indicated that a diet of 1319 kg of mussels and 597 kg of

hickory would meet nutritional needs at a cost of 2086 hours. However, this diet requires a per capita consumption of iron of 78 mg daily, nearly twice the maximal safe level (Passmore and Eastwood 1986:119). Limiting the iron intake to 40 mg per person per day produces an optimal diet including beaver, deer, and chenopod as well as hickory and mussels.

The predicted summer foraging strategy is indicated to be reliance on stored hickory nuts and chenopod while collecting mussels and doing small amounts of deer and beaver hunting. Energy, riboflavin and niacin along with the maximal iron constraint are binding. Only a trace amount of vitamin C is obtained from this diet, but 73 percent of the vitamin A requirement and surpluses of the remaining nutrients are produced.

The sensitivity analysis of the summer strategy suggests that considerable deviation from the predicted optimal resource mix could be expected. A quite small amount of chenopod is included in the diet, and such small amounts usually indicate an unstable result. In this case the sensitivity analyses indicate that a reduction of less than one percent in the riboflavin requirement, minute increases in the maximal iron or niacin constraints, the availability of a second beaver, or a three percent increase in the chenopod cost would cause chenopod to exit the optimal diet.

The summer strategy also includes a number of secondary resources. In addition to the deer in the more distant catchment zones, fresh greens and fish are also indicated to be nearly within the optimal diet.

Vitamin-A pattern

Adding a vitamin A constraint to the Vitamin-B pattern models produces no changes in the fall, winter or spring optimal diets. In these seasons more than sufficient vitamin A was produced meeting other nutritional needs. In the summer, however, only 73 percent of vitamin A requirement was met. The optimal strategy in

summer with the added vitamin A constraint is very similar to the vitamin-B pattern one. The only notable difference is that greens replace chenopod in the optimal diet, and vitamin A replaces riboflavin as a constraint. The new strategy takes only about two percent more time. Indicated secondary resources are groundhog, fish, chenopod and the deer in the outer catchment zones.

Calcium pattern

Previous linear programming models of Eastern Woodlands diet optimization have identified calcium as an important nutritional constraint (Reidhead 1976; Keene 1979), and the present model offers some support for this conclusion. Calcium is a binding constraint in three of four seasons. The fall optimal diet under calcium constraint comprises abundant hickory and mussels augmented by beaver. Although deer does not enter the optimal diet per se, the sensitivity analysis shows it to be less than one percent more expensive than the zone 2 beaver. Hence it would be an expected part of the optimal diet, and even the deer in the outer catchment zones are suggested to be secondary resources. Essentially the fall calcium pattern diet is merely the vitamin B pattern (and vitamin A pattern) diet fortified with mussels.

In winter more profound changes are evidenced. Now mussels are unavailable and stored chenopod functions as the principal calcium source and staple food. Deer, likewise, replace beaver due to the latter's prior exploitation. Fish would be consumed but, like mussels, are assumed to be available only in summer and fall. Likely secondary resources are the beaver in zone 2, the deer from both outer catchment zones, and groundhog, although the latter is unavailable in winter. The wintertime subsistence strategy is indicated to be one of reliance on stored plant foods and deer hunting. The selection of chenopod instead of hickory as the population's staple plant food is a surprising result given hickory's prominent role in the archaeological record of the Archaic period Eastern Woodlands.

In the spring stored chenopod and hickory remain the staple foods, and greens become an important resource. Some beaver hunting is profitable. Looking at the sensitivity analyses shows that chenopod can accept only an eight percent cost increase before it ceases to be an optimal resource; hence storage of chenopod for spring use may not be optimal under these nutritional constraints. If chenopod were not available, the sensitivity analyses suggest that use of hickory and greens would increase and vitamin A would cease to be binding constraint.

In the summer calcium is not a binding constraint, as so many mussels are utilized as a B-vitamin source that a calcium surplus results. The binding nutritional constraints remain the same as those of the vitamin A pattern (energy, riboflavin, niacin and maximal iron). The calcium pattern varies slightly from the vitamin A pattern in that beaver replace deer in the optimal diet. This is possible since fewer beaver were taken in the spring due to increased consumption of chenopod. No secondary resources are indicated for this season.

Over the course of the year, the population is indicated to have consumed 292 kg of fresh greens, 29 beaver weighing 322 kg, 12 deer weighing 368 kg, 914 kg of mussel, 1490 kg of chenopod and 1734 kg of hickory nutmeat. The two staple foods, chenopod and hickory, are available only during the fall. If the harvest periods of the two staples overlapped completely and were four weeks long, then 16 people would need to work 28 consecutive 8.5 hour days to gather and transport the nuts and seeds. In all, optimization under these constraints would require that foragers expend 58 percent of their total food procurement effort in the fall, 12 percent in the winter, 15 percent in the spring and 15 percent in the summer. Such a concentration of seasonal effort is possible, of course. It characterized the salmon harvesting subsistence economies of the Northwest Coast (Suttles 1990) and presumably the wild wheat-harvesting economies of the Near Eastern Natufian period (Unger-Hamilton 1989) as well. Nonetheless, such a strategy seems unlikely for the Eastern Woodlands. In

particular the opportunity costs of additional foraging in the winter, spring and summer seasons would seem to be very low. In addition, the heavy reliance on food storage rather than on mobile foraging does not seem in accord with the archaeological record of the Archaic period Eastern Woodlands (Phillips and Brown 1983).

Vitamin C pattern

In the fall the addition of vitamin C as a constraint increases the cost of foraging by 269 percent and creates profound changes in the optimal diet. Hickory exits the optimal diet since, like all mature seeds and nuts, it is devoid of vitamin C. Grape, the only fresh fruit available in the fall, is taken to the limits of its availability. Meat, especially organ meat, from deer and beaver is the next most favored source of vitamin C. It is eaten in such large quantities, in fact, that iron overload becomes a risk causing deer consumption to be limited in favor of fish. All nutrients other than vitamin C are taken in marked excess, and the 164 percent fulfillment of the energy requirement suggests a dramatic increase in individual weight might ensue over the course of the season. The sensitivity analysis indicates that groundhog and bear, as well as the more distant deer and beaver, would be secondary resources during this season. However, nuts, seeds, and shellfish, all devoid of vitamin C, are now indicated to be essentially worthless to the population.

In short, the addition of a vitamin C constraint to the model produces an "optimal" fall diet that depends on an essentially complete focus of subsistence on Vitamin C sources in spite of the resulting dramatic imbalance in nutrient intake. Obviously the model has produced a highly artificial and suspect result.

In winter the influence of the vitamin C requirement over diet choice becomes even more dramatic. Now, with grapes entirely consumed and fish seasonally unavailable, adequate vitamin C cannot be obtained without iron overload. Hence, the

solution to the optimal diet problem becomes mathematically impossible, or in the jargon of linear programming, infeasible.

This model result is unlikely to have much relevance to the real world. First, the FAO vitamin C requirement of 30 mg/day/capita used in the model is probably too high (Passmore and Eastwood 1987). Tinkering with the model indicates that if the requirement is reduced from 30 mg to a maintenance dose of 10 mg per capita (Passmore and Eastwood 1987), then the problem becomes solvable using bear, deer, beaver and chenopod. Second, a failure to meet the vitamin C requirement for one season probably would not cause any major health problems, at least for adults (Carpenter 1986; Passmore and Eastwood 1987). Third, the model makes no provision for storage of dried fruits which might provide some vitamin C. However, vitamin C is unstable in the presence of air, heat and light (Passmore and Eastwood 1987), so drying would seriously deplete the amount of the nutrient in any stored fruit. Fourth, some food not included in the model such as persimmons, sumac fruit, greens from winter annuals, or some root or tuber might supply vitamin C. Finally vitamin C is present in conifer needles (Wing and Brown 1979:60), which are essentially ubiquitous throughout the Eastern Woodlands. Tonics made from these might contribute appreciable amounts of vitamin C. Some Native American groups did successfully treat scurvy with conifer-based remedies (Carpenter 1986).

In the spring the presence of fresh greens allows a ready fulfillment of the vitamin C requirement. The spring vitamin C pattern diet is the same as that of the calcium pattern except that the seven beavers must be taken from catchment zone 3 due to their complete exploitation in zones 1 and 2 during the fall. (For purposes of setting the parameters of the spring and summer model, it is assumed that the resources taken in winter were the same as those of the calcium pattern, i.e. chenopod, hickory and 12 deer.)

In the summer the vitamin C requirement causes little change except that blackberries enter the optimal diet for the first time. Beaver are no longer available in sufficient quantity to satisfy the niacin requirement, so a single deer is added to the diet. Fish, groundhog and chenopod are indicated as secondary resources.

Discussion

The primary goal of the small population foraging models has been to assess the extent to which nutritional constraints might have shaped prehistoric foraging decisions under conditions of minimal demographic stress. The models indicate that nutritional constraints do have an effect of optimal diet choices. Linear programming indicates that the "least effort" diet that meets energy needs is otherwise nutritionally inadequate to sustain health. Sequentially adding nutrient constraints increases the time costs of foraging by 67% and increases the number of resources eaten from two to nine (table 4.1).

Overall, however, acquiring nutrients by foraging in the prehistoric Eastern Woodlands appears to have been rather easy, although probably not so easy as the models' time expenditure figures suggest. The time costs indicated by the models range from 9 to 15 hrs/producer/week, much less than the approximately 36 hrs/producer/week recorded for the !Kung San (Lee 1979:278). Although the temperate Eastern Woodlands likely required a less arduous work effort than does the semi-arid Kalahari Desert, in retrospect it seems likely that the costs of foraging have been underestimated. I would argue that the underestimation affects all both animal and plant foods, so the pattern of resource selection is considered to be basically accurate. Comparisons between models should produce valid insights, provided the numbers are used qualitatively rather than precisely. That is they can be used to indicate the direction and scale of a change, but should not be considered to measure the difference precisely (Starfield and Blacock 1986:35).

The acquisition of all nutrients except vitamin C can be accomplished with only a moderate increase (approximately 20%) in foraging effort above that of acquiring energy. Furthermore, over one-half of the moderate increase is due to the cost of acquiring calcium. Thus it seems that the greatest impact of nutrient constraints on diet choice is generated by vitamin C and calcium, the two nutrients with the most suspect RNI's (see Chap.3). Vitamin C, especially in the cool seasons, has a particularly prominent effect. I would argue that the more bizarre conclusions of Keene's (1981a, 1981b) early linear programming such as the nondesirability of deer and hickory nuts as foods are at least partially a result the overestimation of calcium and vitamin C needs. In the large, complex single models used previously, the influence of individual components is easily overlooked. By comparison of a series of simple, parallel models such as those used here, the impact of additional single nutrient constraints is more readily visible.

Overall the optimal diets generated by the models are broadly reasonable. Certainly the prominent role of hickory nuts and deer as optimal resources was satisfying, given the well-established importance of these foods in the Eastern Woodlands. On the other hand, beaver seem to be overrated by the models. Beaver remains are often reported from prehistorical archaeological sites, but never in abundance. Smith has argued that they were precluded from becoming a staple by their relatively low annual productivity (1975:126). A partial cause of their apparent importance in the models is a result of the low population density of foragers. With only 25 people exploiting 314 km², beaver are able to make a notable contribution to the diet in spite of low annual productivity. In addition the costs of taking beaver may be underestimated.

It is interesting that mussels are prominent in the optimal diets, especially since the potential importance of shellfish as a subsistence resource has been much debated (Meighan 1969; Parmalee and Klippel 1974). The models indicate that rather than

being a dietary incidental, mussels could be an important source of vitamins, minerals and protein, but are unlikely to function as a primary energy source.

Chenopod seeds appears to be a potentially important source of B-vitamins and calcium and is particularly desired in the warm seasons when meat, the other important source of these nutrients, is more costly to acquire. The inclusion of chenopod within the optimal diet is interesting, as species of chenopod were domesticated in the Eastern Woodlands, Central America and the Andes (Pickersgill 1989). It is commonly recovered from Eastern Woodlands archaeological sites but is less common in the Archaic than Woodland periods (Yarnell and Black 1985; Asch and Asch 1985).

Greens are indicated by the models to be an important source of vitamins A and C and calcium. The archaeological record is, of course, mute on the subject, but numerous potherbs were exploited by Native Americans in the historic period (Yarnell 1964). In addition, greens were included within the optimal diet by the models of both Reidhead (1980) and Keene (1981), so this is a robust result of diet optimization modeling. Certainly there is nothing counterintuitive about it.

The principle shortcoming of the small population foraging models is that the predicted diets are all too narrow. In particular bear, turkey, small game and acorns are all ignored by the models, yet all are known to have been exploited systematically by Native Americans. Some of this may be a result of the inability to assess properly the cost of some of the resources. The cost of procuring a raccoon, for example, was very nearly a frank guess.

Second, the models assume that only a sustainable yield of each resource is taken. This assumption of prudent predation is likely to be incorrect (Vickery 1980). Were high valued resources overexploited, it would necessitate that diet broaden to include less desired species.

Third, linear programming very unrealistically assumes that the forager has perfect intelligence about the location, cost and future availability of resources. Hence

the perfect mix of resources for each season can be selected and suboptimal ones ignored. In reality decisions are always made with imperfect information, and longterm optimality is probably frequently precluded by short-term needs. For example several models indicate that hunting deer or beaver in the second catchment zone should be on average more cost effective than exploiting acorns from the immediate vicinity of the site. However, were hunger to ensue from a streak of poor hunting, the relative costs and benefits of distant, mobile resources and nearby, sessile resources would likely be appraised differently.

Finally the model unrealistically assesses the search costs of resources. The model's search cost is an inverse function of a resource's average density across the entire catchment. This is equivalent to assuming a random search. No human forager, however, would search randomly. Prior knowledge would always inform decision making and allow the areas most likely to yield resources to be visited most often. Species whose movements, aggregations, or den sites were confidently predictable would be obtainable at less cost than the model indicates. Bear and raccoons have den sites that are easily located, and turkeys aggregate into large flocks to feed on mast in the fall (Smith 1975).

Furthermore the model assesses the search costs of resources as if search for each resource was an independent event always beginning at the home base. In reality it seems that foragers search for resources simultaneously, and make decisions about whether to take a resource after encountering it (Winterhalder 1981). Thus an opossum that would not be worth leaving home to look for, might well be worth shooting if encountered on a deer-hunting trip. The inability of linear programming to deal with the encounter-contingent nature of foraging is perhaps the principal weakness of the technique. This is discussed in Chapter 7.

SMALL POPULATION: EARLY AGRICULTURAL STRATEGY
(Table 4.4, 4.5, 4.6)

This set of models is identical to the above except that squash, maygrass, sumpweed and sunflower are added as possible resources. For this set of models the heading's reference to "Early Agricultural Strategy" is something of a misnomer. The cost of squash reflects agricultural production, but maygrass, sumpweed, sunflower and chenopod have costs that reflect foraging rather than crop production. This is unrealistic, as only chenopod is likely to have been a part of the native flora of southwestern Virginia. It is advantageous, though, as it allows a more general model of Eastern Woodlands foraging and allows the costs and benefits of these important weedy annuals to be assessed along with those of the other resources of the Eastern Woodlands. In later models the cost of the weedy annuals will be raised to reflect agricultural production, thereby allowing the costs and benefits of gardening to be assessed more directly.

Basic, Vitamin B, and Vitamin A patterns

For the first three sets of nutritional constraints, the addition of native annuals and squash causes no changes in the optimal diets for the fall through spring seasons. The model indicates that under these constraints during these seasons the addition of squash or seeds to the diet would raise the costs of food procurement. The only Eastern Agricultural Complex plant to be suggested even as a secondary resource is sumpweed, which requires a 13 percent cost reduction to enter the spring diet under vitamin B constraints.

In the summer, however, the native agricultural strategy is dramatically different. Maygrass becomes the staple food during this season. By itself it is the optimal choice for meeting energy needs. With mussels it meets the vitamin B pattern needs, and with greens it meets the vitamin A pattern needs. In fact, the solution to the

Table 4.4: Optimal Diets (kg) of the Small Population,
Early Agricultural Strategy Models and Their Hourly Costs (page 1).

Resource	Basic	B-vit.	Vit. A	Calcium	Vit. C ¹
Fall					
Beaver	90	90	90	189	162
Deer		267	267		
Fish					
Groundhog					
Mussels				317	274
Berry					
Chenopod					
Grape					129
Greens					
Hickory	697	639	639	628	618
Maygrass					
Squash					542
Sumpweed					
Total	787	996	996	1134	1725
Costs	1904	1978	1978	1991	2297
Winter					
Beaver					
Deer		399	399	368	
Fish					
Groundhog					
Mussels					
Berry					
Chenopod				816	
Grape					
Greens					
Hickory	730	634	634	163	
Maygrass					
Squash					
Sumpweed					
Total	730	1033	1033	1347	
Cost	1905	2045	2045	2605	

¹ Winter Vitamin C pattern infeasible

Table 4.4: Optimal Diets (kg) of the Small Population, Early Agricultural Strategy Models and Their Hourly Costs (page 2).

Resource	Basic	B-vit.	Vit. A	Calcium	Vit. C
Spring					
Beaver		307	307		
Deer					
Fish					
Groundhog					
Mussels					
Berry					
Chenopod		19	19	506	506
Grape					
Greens				278	278
Hickory	730	621	621	377	377
Maygrass					
Squash					
Sumpweed				55	55
Total	730	947	947	1216	1216
Cost	1905	2172	2172	2560	2560
Summer					
Beaver					
Deer					
Fish					
Groundhog					
Mussels		50			
Berry					
Chenopod					
Grape					
Greens			292	292	292
Hickory					
Maygrass	1331	1322	1315	1315	1315
Squash					
Sumpweed					
Total	1331	1372	1607	1607	1607
Cost	1331	1342	1551	1551	1551

Table 4.5: Small Population. Early Agricultural Diet. Percentage Acceptable Hourly Costs of Optimal and Secondary Resources by Season and Dietary Pattern (page 1)

Resource	Cost	Basic	B-vit.	Vit-A	Calcium	Vit-C ¹
Fall						
Bear	242.1					
Beaver	8.6	100	143	143	145	145
Beaver2	12.5		98	98	100	100
Beaver3	16.4		75	75	76	76
Deer	29.1		100	100	99	99
Deer2	33.0		88	88	88	88
Deer3	36.9		79	79	79	79
Fish	1.4					
Groundhog	5.0					
Mussels	0.4		99	99	126	116
Chenopod	2.2		77	77		
Grape	0.5					101
Grape2	0.6					88
Grape3	0.6					78
Hickory	2.6	145	117	117	144	127
Maygrass	1.0	b	b	b	b	b
Squash	0.6					128
Winter						
Beaver	8.6	90	a	a	a	
Beaver2	12.5		96	96	94	
Deer	29.1		104	104	106	
Deer2	33.0		88	88	88	
Deer3	36.9		79	79	79	
Fish	1.4					b
Mussels	0.4		b	b	b	
Chenopod	2.2		79	79	106	
Hickory	2.6	111	140	140	130	
Maygrass	1.0	b	b	b	b	
Sumpweed	3.9					93

¹ Winter Vitamin C infeasible

Table 4.5: Small Population. Early Agricultural Diet. Percentage Acceptable Hourly Costs of Optimal and Secondary Resources by Season and Dietary Pattern (page 2)

Resource	Cost	Basic	B-vit.	Vit-A	Calcium	Vit-C
Spring						
Beaver	8.6	80	a	a	a	a
Beaver2	12.5		131	131	86	86
Beaver3	16.4		116	116		
Fish	1.4				b	b
Mussels	0.4		b	b	b	b
Chenopod	2.2		157	157	104	104
Greens	0.8				126	126
Hickory	2.6	123	113	113	107	107
Maygrass	1.0	b	b	b	b	b
Sumpweed					106	106
Summer						
Beaver	8.6		a	a	a	a
Beaver2	12.5		75	88	88	88
Beaver3	16.4					
Deer	61.5					
Deer2	68.0					
Deer3	74.5					
Fish	1.4					
Groundhog	8.0					
Mussels	0.4		137	82	82	82
Blackberry	0.5					
Chenopod	2.2					
Greens	0.8			122	122	122
Hickory	2.6					
Maygrass	1.0	120	125	112	112	112

a optimal but previously exploited
b optimal but seasonably unavailable

Table 4.6: Small Population, Early Agricultural Strategy Models - Acquisition of Nutrients by Season and Nutrient Pattern (page 1)

Nutrient	RNA (1000's)	Percent of RNA Acquired ¹				
		Basic	Bvit	VitA	Ca	VitC ²
Fall						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	63.1	186	297	297	261	251
Iron	21.9	87	125	125	268	252
Thiamine	2.1	171	203	203	159	172
Riboflavin	2.5	59	<u>100</u>	<u>100</u>	105	114
Niacin	35.5	73	160	160	135	137
Vitamin A	1697.0	41	107	107	<u>100</u>	<u>100</u>
Calcium	1146.1	3	7	7	<u>100</u>	<u>100</u>
Vitamin C	61.1	1	5	5	3	<u>100</u>
Winter						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	
Protein	63.1	152	318	318	430	
Iron	21.9	83	140	140	336	
Thiamine	2.1	175	223	223	308	
Riboflavin	2.5	38	<u>100</u>	<u>100</u>	174	
Niacin	35.5	31	162	162	203	
Vitamin A	1697.0	6	105	105	<u>100</u>	
Calcium	1146.1	1	8	8	<u>100</u>	
Vitamin C	61.1	0	5	5	5	

¹ Binding constraints underlined

² Winter vitamin C pattern infeasible

Table 4.6: Small Population, Early Agricultural Strategy Models - Acquisition of Nutrients by Season and Nutrient Pattern (page 2)

Nutrient	RNA (1000's)	Percent of RNA Acquired ¹				
		Basic	Bvit	VitA	Ca	VitC
Spring						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	63.1	152	256	256	253	253
Iron	21.9	83	<u>100</u>	<u>100</u>	242	242
Thiamine	2.1	175	166	166	267	267
Riboflavin	2.5	38	<u>100</u>	<u>100</u>	115	115
Niacin	35.5	31	154	154	<u>100</u>	<u>100</u>
Vitamin A	1697.0	6	108	108	<u>100</u>	<u>100</u>
Calcium	1146.1	1	8	8	<u>100</u>	<u>100</u>
Vitamin C	61.1	0	5	5	267	267
Summer						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	63.1	500	503	504	504	504
Iron	21.9	383	409	362	362	362
Thiamine	2.1	420	418	424	424	424
Riboflavin	2.5	97	<u>100</u>	115	115	115
Niacin	35.5	563	562	565	565	565
Vitamin A	1697.0	0	3	<u>100</u>	<u>100</u>	<u>100</u>
Calcium	1146.1	77	91	104	104	104
Vitamin C	61.1	0	0	219	219	219

¹ Binding constraints underlined

vitamin A pattern diet - 1315 kg of maygrass and 292 kg of greens - is the optimal diet under calcium and vitamin C constraints as well.

Maygrass dominates the models for two reasons. First, it is a nutritious food particularly rich in B vitamins, calcium and iron (Crites and Terry 1983). Second, as modeled it has a quite low cost. This cost estimation is mostly a guess (see Chapter 3), and, after seeing these results, I suspect may be a serious underestimation. Sensitivity analysis, however, indicates that even with cost increases of circa 25 to 30 percent, maygrass would still be a desirable resource.

Calcium pattern

The availability of squash and additional weedy annuals makes no difference to the calcium pattern optimization problem for the fall and winter seasons. In the fall hickory, beaver and mussels remain the optimal diet. In winter it is chenopod, deer and hickory. In spring sumpweed enters the diet replacing beaver, but the sensitivity analysis indicates that only a six percent cost increase is necessary for it to exit. This may not be sufficient to justify the costs of storage. All of the stored plant foods for this season, hickory, chenopod and sumpweed have narrow ranges of acceptable costs. Considerable substitution among them might be expected, and increased beaver hunting might replace some of them as well.

In summer the vitamin A pattern diet of maygrass and mussels is again indicated as the optimal solution, as calcium is available in surplus.

Vitamin C pattern

In the fall squash enters the optimal diet as an economical source of vitamin C. This causes a dramatic change from the foraging diet. Hickory and mussels are now predicted to be eaten in abundance. Fish, deer and grapes from the outer two catchment zones are no longer part of the optimal diet, although deer and grape are

secondary resources. Energy, vitamins A and C, and calcium bind. Iron is taken in surplus, but not in health-threatening amounts. Overall, the optimal diet of hickory, squash, mussels, grape and beaver predicted for this season seems essentially reasonable save for the absence of deer. The cost of acquiring the "early agricultural" diet is only 44 percent of the cost of the foraging diet.

In the models squash is not available in winter. As a result the solution to the winter diet optimization problem remains infeasible. It can be questioned whether the absence of squash is entirely appropriate, as squash was sometimes stored in dry form (Wilson 1917). As is the case with other fruits, however, drying would certainly reduce considerably its vitamin C content. It seems safe to assume, however, that squash might well have been worth drying for winter consumption and may still have retained some vitamin C.

In the spring and summer, the vitamin C constraint makes no difference in diet selection. Fresh greens provide a surplus of vitamin C.

Discussion

Rather than being models of an early agricultural strategy, this set of models represents an ideal Eastern Woodlands locale where maygrass, sunflower, sumpweed and chenopod could be gathered. This set of models allows the evaluation of the potential role of squash and nondomesticated native weedy annual grains in prehistoric Eastern Woodlands foraging strategies. Significantly four of the five plants under consideration entered the optimal diet of at least one model. Only sunflower was not selected.

Chenopod, the only member of the Eastern Agricultural Complex included in the previous foraging models, is again selected as a major calcium source in winter and spring. Under calcium constraints chenopod actually displaces hickory as the staple food in winter. Chenopod, as in the foraging models, is also a minor but important

source of iron in the spring. However, it is no longer taken in the summer due to the availability of less costly maygrass.

Sumpweed is selected in the spring in the calcium and vitamin C models as a niacin source. Given the eventual domestication of sumpweed in the Eastern Woodlands, the qualitative result of sumpweed entering the optimal diet is thought provoking. The quantitative aspects of its selection are less reassuring. Comparison to the calcium pattern foraging models shows that the utilization of sumpweed results in only a 12 hour lessening of foraging effort over the 13 week season. Under vitamin C constraint, utilization of sumpweed saves 41 hours over the course of the season. This is still only about a 2% improvement in subsistence effort. Again the hyper-precision of linear programming is highlighted. But too, the inclusion of potential cultigens as nutrient sources in the optimal diet points out how optimization modeling can lead to nonapparent heuristic insights even when the "least effort" aspects of the results are trivial. Heuristically it draws attention to the potential advantages of storable grains as nutrient sources during seasons when meat is costly to procure.

Maygrass totally dominates the summer models, the only ones in which it is available. Although maygrass has the most dramatic impact on the early agricultural models, it is likewise the most suspect part of the optimal diets. Although maygrass is a nutritious food (Crites and Terry 1983), I suspect the result has more to do with the estimation of its cost, which is essentially a guess based on the harvesting of Near Eastern wild wheat. It is probably not a coincidence that this method of cost estimation has generated a level of cereal exploitation rivaling that of the Natufian. In models considered later in this study, a higher estimation of maygrass production costs results in a much diminished level of maygrass exploitation.

Squash, the only member of the Eastern Agricultural Complex to be incorporated into this set of models with costs reflecting agricultural production, is selected by only the fall season vitamin C pattern model. Its impact is dramatic,

however. With squash available all nutrient requirements can be met in 44% of the time required to meet them with foraged food only. This is a dramatic result. Of course the nutritional composition and yield data of squash used in constructing the model is that of modern domesticate squash. Early domesticate varieties would have had less flesh and hence been less nutritious. It would be naive to suggest that squash was domesticated to provide vitamin C, especially since predomesticate squash would have had such obvious utility as a source of containers or even of edible seeds. Nonetheless, the provision of vitamin C might well have been a latent function of squash exploitation. While not causing its initial husbandry, this might well have reinforced its movement along the trajectory towards domestication.

Nutritionally the structures of the optimal strategies remain the same except for the summer models and the vitamin C pattern model for fall. In summer the combination of maygrass and greens cheaply satisfies all nutrient requirements. In particular it produces surpluses of niacin and vitamin C, whereas the foraging diet of hickory, mussels, greens and game did not. In the fall vitamin C pattern model, vitamin A, calcium and energy are now binding constraints whereas formerly they were obtained in surplus. The decreased number of surpluses in the early agricultural models does not bespeak a lessening of diet quality. Rather, the abundance of nutrient surpluses in the foraging diet reflects the highly imbalanced diet necessitated by meeting vitamin C needs in the near-absence of abundant vitamin C sources. As the early agricultural diet involves much less food (only 36% of the weight of the foraging diet), it is not surprising that there are fewer nutrient surpluses.

SMALL POPULATION: LATE AGRICULTURAL STRATEGY (Table 4.7, 4.8, 4.9)

This set of models adds to the early agricultural models the resources of maize and common beans in fresh and dried forms. In addition the costs of acquiring

Table 4.7: Optimal Diets (kg) of the Small Population,
Late Agricultural Strategy Models and Their Hourly Costs (page 1).

Resource	Basic	B-vit.	Vit. A	Calcium	Vit. C ¹
Fall					
Dry Corn	1415	1275	1273	1269	1271
Squash					599
Maygrass					
Sumpweed					
Berry					
Grape					
Greens					
Chenopod					
Hickory					
Beaver		90	90	90	90
Deer			100	67	33
Groundhog					
Fish					
Mussels		391	193	241	200
Total	1415	1756	1656	1667	2193
Cost	1557	1645	1645	1649	1957
Winter					
Dry Corn	1415	1279	1279	796	
Squash					
Maygrass					
Sumpweed				313	
Berry					
Grape					
Greens					
Chenopod					
Hickory					
Beaver					
Deer		307	307	307	
Groundhog					
Fish					
Mussels					
Total	1415	1586	1586	1416	
Cost	1557	1704	1704	2428	

¹ Winter Vitamin C Pattern infeasible

Table 4.7: Optimal Diets (kg) of the Small Population,
Late Agricultural Strategy Models and Their Hourly Costs (page 2).

Resource	Basic	B-vit.	Vit. A	Calcium	Vit. C
Spring					
Dry Corn	1415	1258	1258	1370	1370
Squash					
Maygrass					
Sumpweed					
Berry					
Grape					
Greens				747	747
Chenopod					
Hickory					
Beaver		257	257		
Deer					
Groundhog					
Fish					
Mussels					
Total	1415	1515	1515	2117	2117
Cost	1557	1793	1793	2113	2113
Summer					
Dry Corn	1415	1280	1292	1265	1300
Squash					
Maygrass					
Sumpweed					
Berry					
Grape					
Greens			80		133
Chenopod					
Hickory					
Beaver		44	22	118	7
Deer					
Groundhog					
Fish					
Mussels		511	506	243	503
Total	1415	1835	1900	1626	1943
Cost	1557	1704	1739	1689	1757

Table 4.8: Small Population. Late Agricultural Diet. Percentage Acceptable Costs of Optimal and Secondary Resources by Season and Dietary Pattern (page 1)

Resource	Cost	Basic	B-vit.	Vit-A	Calcium	Vit-C ¹
Fall						
Bear	242.1					
Beaver	8.6	82	140	140	144	144
Beaver2	12.5		96	97	99	99
Beaver3	16.4				76	75
Deer	29.1		99	103	101	101
Deer2	33.0		88	88	88	88
Deer3	36.9		79	79	79	79
Fish	1.4					
Groundhog	5.0				75	75
Mussels	0.4		100	100	373	355
Chenopod	2.9					
Grape	0.5					90
Grape2	0.6					78
Grape3	0.6					
Hickory	2.6	82	80	80	79	79
Maygrass	2.3					
Squash	0.6					121
Dry Corn	1.1	122	106	106	120	121
Green Corn	0.9					86
Winter						
Beaver	8.6		a	a	a	
Beaver2	12.5		95	95	90	
Deer	29.1		106	106	110	
Deer2	33.0		88	88	88	
Deer3	36.9		79	79	79	
Fish	1.4					b
Mussels	0.4		b	b	b	
Chenopod	2.9				76	
Hickory	2.6	82	80	80		
Maygrass	2.3					
Sumpweed	5.1				142	
Drycorn	1.1	122	124	124	137	

¹ Winter Vitamin C Pattern infeasible

Table 4.8: Small Population. Late Agricultural Diet. Percentage Acceptable Costs of Optimal and Secondary Resources by Season and Dietary Pattern (page 2)

Resource	Cost	Basic	B-vit.	Vit-A	Calcium	Vit-C
Spring						
Beaver	8.6			a		
Beaver2	12.5			131		
Beaver3	16.4			143		
Fish	1.4				b	b
Mussels	0.4			b	b	b
Chenopod	2.9					
Greens	0.8				192	192
Hickory	2.6	82		77		
Maygrass	2.3					
Sumpweed	5.1					
Drycorn	1.1	122		127	135	135
Summer						
Beaver	8.6		a	a	a	a
Beaver2	12.5		a	a	114	131
Beaver3	16.4		187	187	76	76
Deer	61.5					
Deer2	68.0					
Deer3	74.5					
Fish	1.4					
Mussels	0.4		140	110	133	103
Blackberry	0.5					97
Chenopod	2.9					
Greens	0.8			118	79	104
Hickory	2.6	82	79	78	79	80
Maygrass	2.3					
Drycorn	1.1	122	125	126	124	106

a optimal but previously exploited

b optimal but seasonably unavailable

Table 4.9: Small Population, Late Agricultural Strategy Models. Acquisition of Nutrients by Season and Nutrient Pattern (page 1)

Nutrient	RNA (1000's)	Percent of RNA Acquired ¹				
		Basic	Bvit	VitA	Ca	VitC ²
Fall						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	63.1	200	275	292	292	275
Iron	21.9	136	352	255	280	261
Thiamine	2.1	190	175	191	189	196
Riboflavin	2.5	51	<u>100</u>	<u>100</u>	102	110
Niacin	35.5	160	209	230	228	228
Vitamin A	1697.0	31	89	<u>100</u>	<u>100</u>	<u>100</u>
Calcium	1146.1	27	144	86	<u>100</u>	<u>100</u>
Vitamin C	61.1	0	2	3	3	<u>100</u>
Winter						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	
Protein	63.1	200	329	329	422	
Iron	21.9	136	177	177	294	
Thiamine	2.1	190	227	227	403	
Riboflavin	2.5	51	<u>100</u>	<u>100</u>	154	
Niacin	35.5	160	253	253	394	
Vitamin A	1697.0	31	109	109	<u>100</u>	
Calcium	1146.1	27	30	30	<u>100</u>	
Vitamin C	61.1	0	4	4	4	

¹ Binding constraints underlined

² Winter vitamin C pattern infeasible

Table 4.9: Small Population, Late Agricultural Strategy Models. Acquisition of Nutrients by Season and Nutrient Pattern (page 2)

Nutrient	RNA (1000's)	Percent of RNA Acquired ¹				
		Basic	BviT	VitA	Ca	VitC
Spring						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	63.1	200	279	279	219	219
Iron	21.9	136	140	140	166	166
Thiamine	2.1	190	179	179	205	205
Riboflavin	2.5	51	<u>100</u>	<u>100</u>	101	101
Niacin	35.5	160	247	247	176	176
Vitamin A	1697.0	31	114	114	286	286
Calcium	1146.1	27	28	28	<u>100</u>	<u>100</u>
Vitamin C	61.1	0	4	4	562	562
Summer						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	63.1	200	243	267	278	262
Iron	21.9	136	<u>417</u>	<u>417</u>	271	<u>417</u>
Thiamine	2.1	190	174	177	176	179
Riboflavin	2.5	51	<u>100</u>	<u>100</u>	101	<u>100</u>
Niacin	35.5	160	197	190	225	185
Vitamin A	1697.0	31	81	<u>100</u>	<u>100</u>	112
Calcium	1146.1	27	179	186	<u>100</u>	190
Vitamin C	61.1	0	1	61	3	<u>100</u>

¹ Binding constraints underlined

chenopod, maygrass, sumpweed and sunflower are raised to reflect agricultural production rather than gathering as they did in the previous early agricultural models.

Basic pattern

In all seasons the optimal diet is predicted to consist solely of 1415 kg of dried corn or about 0.6 kg (1.4 lb) per person per day. Hickory and beaver are suggested as secondary resources. The selection of corn to meet the population's energy needs is in keeping with the well established role of maize as one of the world's most important food crops.

Of course, any population attempting to live solely from corn would become malnourished. The model indicates that no vitamin C, and insufficient amounts of calcium, vitamin A and riboflavin would be produced by this diet. Except for thiamine, even the nutrients indicated to be produced in surplus are somewhat suspect. Considerable iron is contained in maize, but it is poorly absorbable unless accompanied by fresh greens, fruit or meat (Passmore and Eastwood 1987:117). Niacin, likewise, is contained in a poorly absorbable form unless the maize is pretreated with alkali. However, pretreatment with alkali is almost universally a part of traditional maize processing wherever dried maize forms a significant part of the diet (Katz et al. 1974). In the Eastern Woodlands corn was traditionally processed with ash to make hominy (Katz et al. 1974; Swanton 1946:352, 354). A more important shortcoming of maize is that its amino acid content is imbalanced with the essential amino acids lysine and especially tryptophan being limiting (Passmore and Eastwood 1987:190).

Vitamin B pattern

In the fall dried corn is the staple with mussels and beaver also desired resources. Deer is less than one percent too costly to replace mussels, so for all intents and purposes it is part of the optimal diet. Hickory nuts and the more distant deer and

beaver are secondary resources. Energy and riboflavin bind. Surpluses of all other nutrients except vitamin C and vitamin A are obtained, and nearly 90 percent of the vitamin A requirement is met.

In winter dried corn and deer form the optimal diet with beaver and hickory as secondary resources. Energy and riboflavin bind, vitamin A is now acquired in surplus but calcium along with vitamin C is in deficit. It is worth noting here that corn and deer are the archetypal Eastern Woodlands Native American foods. While certainly not nutritionally complete in the proportions favored here, their combination can be seen to form a solid foundation for a diet.

In the spring beaver replace deer as the targeted game animal, but corn remains the staple food. Chenopod and hickory are secondary resources. Nutritionally the diet is nearly identical with the wintertime corn and deer mix.

In summer dried corn, beaver and mussels form the optimal diet with hickory a secondary resource. Energy, riboflavin and maximal iron are the binding constraints.

Vitamin A pattern

The addition of a vitamin A requirement causes relatively little change in the optimal diets. In the fall the diet adds three deer and in compensation drops about 200 kg of mussels. (While 200 kg of mussels sounds impressive it amounts to only about 3 oz. per person per day). Corn remains the staple food and beaver rival deer as a meat source. Hickory along with the more distant deer and beaver are secondary resources. Vitamin A joins energy and riboflavin as binding constraints.

The winter and spring vitamin A pattern diets are the same as those of the vitamin B pattern, since a surplus of vitamin A was acquired in the course of meeting the riboflavin requirement.

In the summer the addition of a vitamin A constraint causes greens to be added to the vitamin-B pattern optimal diet while mussels and beaver become less important.

Hickory is a secondary resource. Energy, riboflavin, vitamin A and maximal iron bind. The result is not entirely convincing, however, as a 10% increase in mussel costs would move the diet into beaver and away from mussels.

Calcium pattern

For the fall optimal diet the model merely "fine-tunes" the quantities of dried corn, mussel, beaver and deer taken in order to bring calcium intakes up to the required level. Hickory and the more distant deer and beaver remain secondary resources. Significantly, the addition of the vitamin and mineral requirements to this point has caused the total cost of the fall diet to rise only about six percent, or less than four minutes per producer per day. This points out both the nutritional and economic advantages of a corn-mussels-game diet and the unreasonable degree of precision to which linear programming is subject.

Happily, the winter model provides a more interesting result. To the expected dried corn and deer a substantial quantity of sumpweed is added to the optimal diet. In addition chenopod along with beaver and deer are secondary resources. The prominent role of sumpweed in the late agricultural diet is counterintuitive, as sumpweed seems to have diminished in importance during the Mississippian period (Yarnell and Black 1985; Asch and Asch 1978). Surprising, too, is the complementary nutritional role of sumpweed and corn. This results in sumpweed being more important in the late agricultural than the early agricultural subsistence strategy. Traditionally ethnobotanists have looked to increased corn production as a causative factor in sumpweed's demise (Black 1963; Asch and Asch 1978).

In spring corn and greens combine to produce the optimal diet. Energy and calcium are the binding nutrient constraints, but riboflavin essentially binds as well, being only one percent above the minimal requirement.

As a consequence of fewer beaver having been taken during the spring, the calcium pattern diet in summer is actually slightly less costly than that of the vitamin A pattern. The addition of beaver to the diet allows greens to be ignored and less than half as many mussels taken. Dried corn is the staple food. Energy, calcium and vitamin A bind and only trace amounts of vitamin C are produced.

Vitamin C pattern

Vitamin C continues to play a dominant role in shaping the models' optimal diets. In the fall vitamin C, vitamin A, calcium and energy bind. The diet consists of large quantities of dried corn, squash, and mussels augmented by beaver and a single deer. The secondary resources are extensive, however. As well as the more distant beaver and deer, groundhog, grapes, hickory, and green corn are all secondary resources. It is notable that green corn, so celebrated in Eastern Woodland Native American ceremony, never comes closer to the optimal diet than this.

In winter the problem remains infeasible, since the two new possible vitamin C sources, green corn and fresh beans, are not allowed as part of the winter diet. In spring the diet remains the same as the late agriculture calcium pattern, namely corn and greens. In summer the optimal diet returns to the vitamin A mix of dried corn, mussels, greens and beaver, but now only a single beaver is desired. Blackberry needs only a 3% cost reduction before it can substitute for greens or corn. Hickory is also a secondary resource.

Discussion

The goal of this set of models has been to illuminate the potential utility of corn agriculture as a least-effort solution to diet optimization under conditions of no demographic pressure. The results have been dramatic; corn was selected as the primary energy source in every model run. Hickory, the staple food of the two

previous sets of models, never enters an optimal diet, and chenopod and maygrass are ignored as well. The absence of maygrass and chenopod from the models, however, is a result of the higher "agricultural" costs assigned to these foods and not solely a direct result of competition with corn. Two Eastern Agricultural complex crops, squash and sumpweed, remain optimal under certain constraints. Squash remains a critical source of vitamin C in the fall, and sumpweed provides calcium in the winter.

The prominent role of corn in the optimal diets supports Reidhead's (1980) finding that corn could have been adopted as a cheap energy source. However, in calculating the cost of corn production, an estimation of harvest yield for historic period corn was used by necessity. By the Historic period, corn had undergone over a millennium of husbandry in the Eastern Woodlands, and almost surely its yields must have been improved over that of the varieties initially introduced to the area. Contrarily, the costs of chenopod, and sumpweed (and by extension, sunflower) were based on collection from wild plants; hence their yields likely underestimate those of domesticated varieties. Thus the competitive advantage of corn displayed in these models is probably exaggerated. It does suggest, however, that were a highly productive cultivar of corn to appear, its potential for widespread adoption by Native Americans might well be dramatic.

The models do suggest that corn agriculture might result in a notable reduction in the costs of subsistence. The basic pattern models indicate that as a means of obtaining food energy corn agriculture is only 82% as costly as foraging or 88% as costly as gardening. Adding nutrient constraints raises time costs at a rate closely parallel to that of the Early Agricultural strategies (fig. 4.1).

Nutritionally the diet appears to be somewhat improved. As corn replaces hickory and chenopod, iron and niacin are produced in surplus. In the spring calcium models, vitamin A production is increased as corn provides most nutrients cheaply, thereby allowing vitamin A-rich greens to form a larger part of the diet. Although

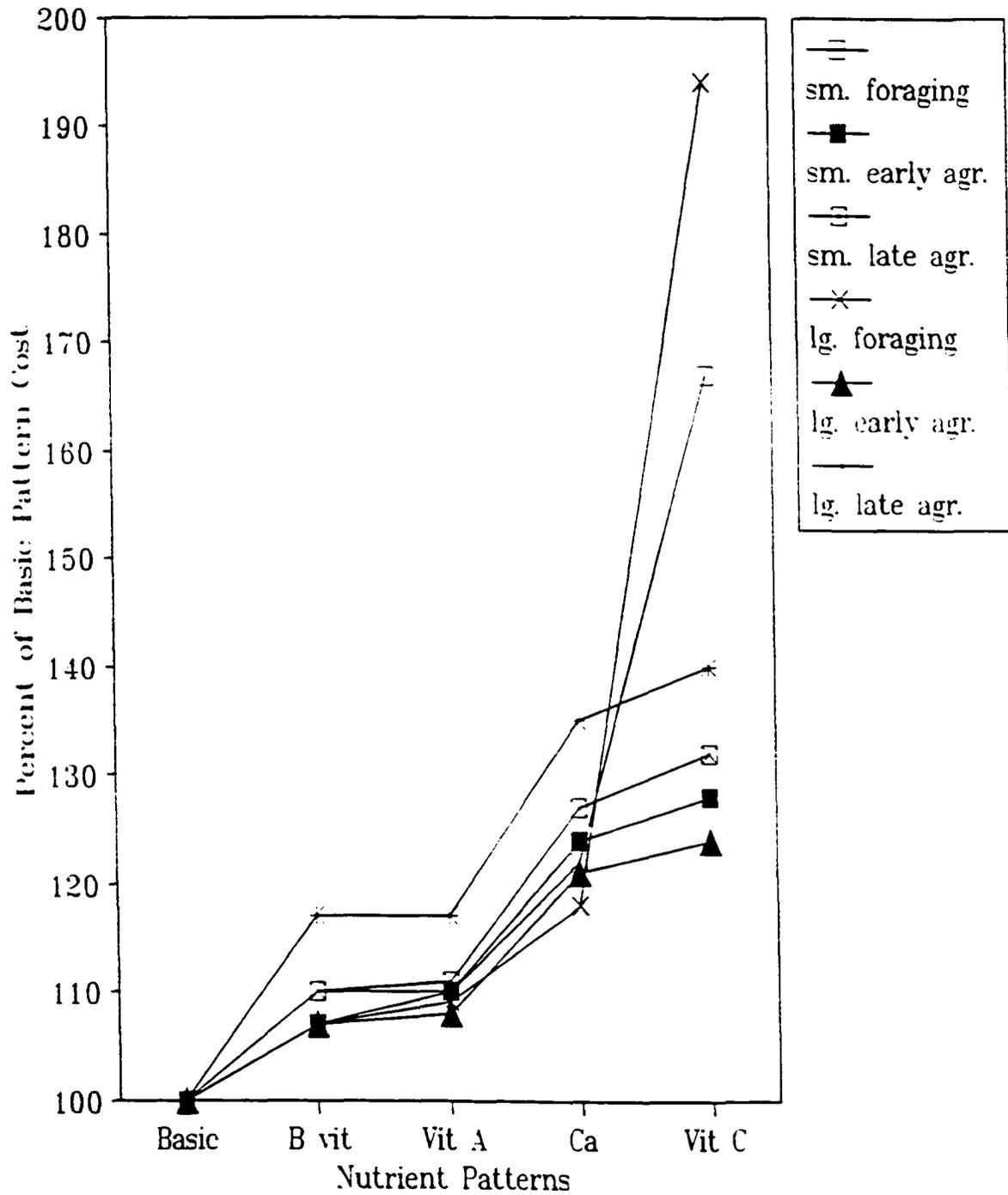


Figure 4.1: Time Costs of Diet Strategies as Percentage of Basic Pattern Cost

there is some pleasure in seeing the classic soul food combination of cornbread and greens selected as an optimal diet, to reiterate a point made previously, it is doubtful that such a narrow all-vegetable diet would supply all essential amino acids or nutrients in a usable form.

Maximal iron is a binding constraint in three of the five summer models due to the large amounts of mussels acquired. Iron overload is rarely a risk from dietary sources (Passmore and Eastwood 1984), but the maximal iron constraint serves as a useful tool for precluding an absurd level of shellfish exploitation. Interestingly freshwater mussels do not seem to have been a particularly important food to Native Americans after the Archaic period (Griffin 1984:256), but in the coastal regions of the Eastern Woodlands corn and estuarine shellfish were both highly important foods in the Late Prehistoric and Historic periods. Since mussels and estuarine shellfish should be nutritionally quite similar, the models may reflect the general attractiveness of the corn-shellfish combination. The scant exploitation of freshwater mussels after the Archaic period may reflect a limited availability of mussels in the localities of agricultural villages or mussels' inability to sustain for long a yield in the face of exploitation by larger Woodland period populations.

LARGE POPULATION: FORAGING STRATEGY (Table 4.10, 4.11, 4.12)

In the "large population" set of models the size of the population is increased from 25 to 250 people. This raises the population density of the catchment to 0.8 people/km² (2.0 people/mi²). This is at the upper end of the range for foragers but is at the low end of the range for food producers (Hassan 1981). No allowance is made for any change in demographic structure. The nutrient requirements for the population are merely increased tenfold. The number of producers is considered to be 160. As in the small population foraging models, chenopod is the only weedy annual available and

Table 4.10: Optimal Diets (kg) of the Large Population, Foraging Strategy Models and Their Hourly Costs (page 1).

Resource	Basic	B-vit.	Vit. A	Calcium	Vit. C ¹
Fall					
Beaver	306	90	306	306	306
Deer		1035	2973	2405	8951
Fish					51923
Groundhog					
Mussels		5734	995	3128	
Chenopod	1662				
Grape					
Hickory	6200	6455	6421	6328	
Total	8168	13314	10695	12167	61180
Costs	20292	20128	20208	20281	81977
Winter					
Bear					
Beaver		199			
Deer		3591	3899	3715	
Fish					
Groundhog					
Mussels					
Chenopod	1852			8157	
Grape					
Hickory	6200	6418	6426	1627	
Total	8052	10208	10325	13499	
Costs	20331	20783	20947	26526	

¹ Winter Vitamin C Pattern infeasible

Table 4.10: Optimal Diets (kg) of the Large Population, Foraging Strategy Models and Their Hourly Costs (page 2).

Resource	Basic	B-vit.	Vit. A	Calcium	Vit. C
Spring					
Bear					
Beaver		102	104	104	104
Deer		1178	1260	603	603
Fish					
Groundhog					
Mussels					
Chenopod	1852	4334	2958	6679	6679
Grape					
Greens			1702	2221	2221
Hickory	6200	4429	5169	3099	3099
Total	8052	10043	11193	12706	12706
Cost	20331	34398	24865	26563	26563
Summer					
Bear					
Beaver					
Deer		1150	438	1096	630
Fish					
Groundhog			796		509
Mussels		5681	5804	5655	5398
Berry					1144
Chenopod	1852	54			
Grape					
Greens			664	850	788
Hickory	6200	6434	6410	6455	6369
Total	8052	13319	14112	14056	14838
Cost	20331	22038	22594	22513	22898

Table 4.11:
Large Population, Foraging Strategy Models - Percentage Acceptable Hourly Costs of
Optimal and Secondary Resources
by Season and Dietary Pattern (page 1)

Resource	Cost	Basic	B-vit.	Vit-A	Calcium	Vit-C ¹
Fall						
Bear	242.1					77
Beaver	8.6	146	143	163	164	161
Beaver2	12.5	100	98	112	113	111
Beaver3	16.4	76	75	85	86	85
Deer	29.1	97	102	113	113	118
Deer2	33.0	86	88	112	112	104
Deer3	36.9	77	79	89	89	93
Fish	1.4	78				107
Groundhog	5.0			77	84	90
Mussels	0.4	95	100	113	313	
Chenopod	2.2	103	77			
Grape	0.5	80				1167
Grape2	0.6					1018
Grape3	0.6					903
Hickory	2.6	145	106	130	130	
Winter						
Beaver	8.6	a	a	a	a	
Beaver2	12.5	90	108	a	a	
Beaver3	16.4		82	82	81	
Deer	29.1	89	113	a	a	
Deer2	33.0	79	112	112	112	
Deer3	36.9		89	89	89	
Fish	1.4	78			b	
Mussels	0.4	95	b	b	b	
Chenopod	2.2	105	82	82	145	
Grape	0.5	80			75	
Hickory	2.6	145	134	134	132	

¹ Winter Vitamin C Pattern infeasible

Table 4.11:
Large Population, Foraging Strategy Models - Percentage Acceptable Hourly Costs of
Optimal and Secondary Resources
by Season and Dietary Pattern (page 2)

Resource	Cost	Basic	B-vit.	Vit-A	Calcium	Vit-C
Spring						
Beaver	8.6	a	a	a	a	a
Beaver2	12.5	80	a	a	a	a
Beaver3	16.4		158	159	156	156
Deer	61.5		a	a	a	a
Deer2	68.0		110	110	110	110
Deer3	74.5		91	91	91	91
Groundhog	8.0				77	77
Fish	1.4	78	85	83	b	b
Mussels	0.4	95	b	b	b	b
Chenopod	2.2	105	115	115	113	113
Grape	0.5	80				
Greens	0.8			187	375	375
Hickory	2.6	145	119	125	131	131
Summer						
Beaver	8.6	a	a	a	a	a
Beaver2	12.5	80	a	a	a	a
Beaver3	16.4		a	a	a	a
Deer	61.5		a	a	a	a
Deer2	68.0		110	110	101	a
Deer3	74.5		91	112	91	103
Fish	1.4	78	81	93	92	98
Groundhog	8.0		77	108	99	104
Mussels	0.4	95	210	184	150	170
Blackberry	0.5					112
Chenopod	2.2	105	104	85	76	84
Grape	0.5	80				
Greens	0.8		88	235	110	327
Hickory	2.6	145	122	117	113	106

a optimal but previously exploited

b optimal but seasonably unavailable

Table 4.12: Large Population, Foraging Strategy Models.
Acquisition of Nutrients by Season and Nutrient Pattern (page 1)

Nutrient	RNA (1000's)	Percent of RNA Acquired ¹				
		Basic	Bvit	VitA	Ca	VitC ²
Fall						
Energy	49259	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	264
Protein	631	<u>188</u>	<u>265</u>	<u>301</u>	<u>303</u>	2373
Iron	219	<u>125</u>	<u>417</u>	<u>183</u>	<u>294</u>	<u>417</u>
Thiamine	21	<u>191</u>	<u>173</u>	<u>208</u>	<u>196</u>	<u>410</u>
Riboflavin	25	<u>61</u>	<u>100</u>	<u>100</u>	<u>107</u>	<u>371</u>
Niacin	355	<u>55</u>	<u>100</u>	<u>150</u>	<u>143</u>	<u>910</u>
Vitamin A	16970	<u>17</u>	<u>73</u>	<u>100</u>	<u>100</u>	<u>537</u>
Calcium	11461	<u>21</u>	<u>176</u>	<u>37</u>	<u>100</u>	<u>1005</u>
Vitamin C	611	<u>1</u>	<u>1</u>	<u>3</u>	<u>3</u>	<u>100</u>
Winter						
Energy	49259	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	
Protein	631	<u>179</u>	<u>313</u>	<u>318</u>	<u>430</u>	
Iron	219	<u>128</u>	<u>137</u>	<u>140</u>	<u>336</u>	
Thiamine	21	<u>194</u>	<u>218</u>	<u>223</u>	<u>308</u>	
Riboflavin	25	<u>56</u>	<u>100</u>	<u>100</u>	<u>174</u>	
Niacin	355	<u>42</u>	<u>161</u>	<u>162</u>	<u>203</u>	
Vitamin A	16970	<u>5</u>	<u>106</u>	<u>105</u>	<u>100</u>	
Calcium	11461	<u>22</u>	<u>8</u>	<u>8</u>	<u>100</u>	
Vitamin C	611	<u>0</u>	<u>5</u>	<u>3</u>	<u>5</u>	

¹ Binding constraints underlined

² Winter vitamin C pattern infeasible

Table 4.12: Large Population, Foraging Strategy Models.
Acquisition of Nutrients by Season and Nutrient Pattern (page 2)

Nutrient	RNA (1000's)	Percent of RNA Acquired ¹				
		Basic	Bvit	VitA	Ca	VitC
Spring						
Energy	49259	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	631	179	269	258	285	285
Iron	219	128	206	181	264	264
Thiamine	21	194	235	225	258	258
Riboflavin	25	56	<u>100</u>	<u>100</u>	128	128
Niacin	355	42	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Vitamin A	16970	5	39	<u>100</u>	<u>100</u>	<u>100</u>
Calcium	11461	22	53	54	<u>100</u>	<u>100</u>
Vitamin C	611	0	2	130	168	168
Summer						
Energy	49259	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	631	179	267	262	266	258
Iron	219	128	<u>417</u>	<u>417</u>	<u>417</u>	<u>417</u>
Thiamine	21	194	176	164	177	169
Riboflavin	25	56	<u>100</u>	<u>100</u>	104	<u>100</u>
Niacin	355	42	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Vitamin A	16970	5	72	<u>100</u>	<u>100</u>	<u>100</u>
Calcium	11461	22	175	184	182	<u>100</u>
Vitamin C	611	0	1	52	65	<u>100</u>

¹ Binding constraints underlined

its cost reflects that of gathering rather than farming. In the early agricultural and late agricultural models, the native weedy annuals and squash will be incorporated with costs reflecting agricultural production.

Rather than discussing each table in detail, the model results will be compared to the small population foraging models and the changes resulting from increased population size examined. The obvious prediction about the effects of increased population size is that highly valued resources will be used in increased amounts, and that less valued resources will be added to the diet as the higher valued resources are exhausted (Earle 1980). This is in fact what the models indicate.

Basic Pattern

When run under the same constraints as the small population model, the model predicts that the same 10 beaver be taken in fall and the remainder to the diet be fulfilled with a tenfold increase in hickory nuts. This reflects the trivial insight that a population ten times larger needs ten times the calories. Although sufficient labor would be available to procure the nuts in the allotted four weeks, the amount needed, approximately 29,000 kg, exceeds the production of the first catchment zone.

To produce a more interesting result, I limited the population's yearly intake of hickory to 28,000 kg, the production of the first catchment zone, and mandated that no seasonal consumption could exceed one quarter of this. The revised models indicate that the maximal amount of hickory should be taken each season and 34 beaver should be taken in the fall. The remainder of the population's energy requirement each season is then fulfilled by consumption of chenopod seeds. Secondary resources are deer, mussels, fish and grapes. Judging by the sensitivity analyses, deer are particularly likely to be taken in the fall, and mussels in the summer.

Nutritionally, the diets are quite similar. Energy binds (of course), and thiamine and protein are obtained in surplus, but now iron is as well. The usual

caution applies, however, that the all-vegetable diets likely would not yield the proper amino acids, or minerals in a biologically usable form. Nonetheless, the potential role of chenopod as an energy source is a counterintuitive result and interesting in light of its exploitation and domestication by Native Americans.

Vitamin B Pattern

In these models the constraints on hickory consumption were again relaxed. As a result about 95% of the total hickory production of the first catchment zone is utilized. The staple foods of the small population, hickory, deer, beaver and mussels, are all taken in increased amounts. All available beaver are taken, but are now so few relative to the population's nutritional needs that they play a much less significant role in the diet. As a result deer hunting increases throughout the year, and the consumption of chenopod increases dramatically in the spring. Mussels are marginally optimal in the fall, but can be replaced by further exploitation of deer with no meaningful increase in the total time expenditure of foraging. Groundhog joins fish and greens as a secondary resource in summer.

The resulting diet is nutritionally very similar to the small population foraging diet except that niacin is a binding constraint in the fall and spring. This leads to appreciable deer hunting in the second catchment zone.

Vitamin A Pattern

In the fall and winter, hickory and deer are the staple foods with mussels and beaver also taken in the fall. With harvestable beaver too few to make much of an impact on the population's nutritional needs, the diet in spring broadens markedly. Hickory remains the staple, but deer, chenopod and greens become important parts of the diet. Just as was the case with the small population, the summer optimal diet includes hickory and mussels as the staple foods, augmented by greens. Now,

however, all beaver and all but the most distant deer have been harvested in prior seasons. As a result groundhog become a targeted species. This is the first occurrence of small game other than beaver within the optimal diet. Fish are quite close to entering the optimal diet, requiring only about a 7% cost reduction..

The nutritional constraints play much the same role as they did in the small population models, but vitamin A now binds in the fall and spring as well as in the summer. This is a consequence of the diminished role of game in the diet.

Calcium Pattern

The increase in population causes no great changes in the structure of the diet optimization solutions. This is because mussels and chenopod, the two most important calcium sources in the models, are modeled as occurring in great abundance. In spite of a likely overabundance of these two resources, the summer and fall strategies, which emphasize hickory, deer and mussel exploitation, seem quite acceptable. The winter and spring strategies, in which chenopod serves as the staple food, are dubious. Hunting would seem more important than the model reflects.

Nutritionally the large population calcium models are quite similar to the small population ones. The only notable difference being that vitamin C is no longer a surplus nutrient in summer; rather only 65% of the RNI is met.

Vitamin C pattern

The addition of a vitamin C constraint to the large population diet optimization models causes the same dramatic changes that it did to the small population ones. Again the fall optimal diet is specified to include all available grapes, all beaver, and massive amounts of deer and fish. Now, however, the diet is even more unbalanced, as grapes and beaver are very scarce relative to the total population. As a consequence fish comprise nearly 85% of the diet. To meet the vitamin C RNI with this diet, a per

capita daily consumption of 2.7 kg (6 lbs) is required. While this is within the limits of physiological possibility at least for adults, it further highlights the implausibility of the result.

Nutritionally the diet is equally unnatural; all nutrients including energy are obtained in substantial excess. (The diet shown in table 4.10 actually exceeds the maximal iron constraint by 0.4%. Adding the constraint would shift the diet from deer further into fish. As the change would probably be only one deer and the new results even more suspect, rerunning the model with the added constraint was not undertaken.)

In winter the diet optimization problem remains infeasible. In spring the increased population size results in a broadening of the chenopod-hickory-greens-beaver diet to include deer. In summer, as it was with the small population, the diet remains based on hickory, mussels, berries, greens and deer. Now, as in the vitamin A pattern, beaver have been completely exploited and are replaced by groundhog. Interestingly, fish are indicated by the sensitivity analysis to approximate hickory nuts in desirability. Since the hickory cost does not reflect the cost of storage, fish is probably the more desirable resource. A summer strategy combining fishing, shellfishing, gathering fresh fruits and greens, along with some hunting seems eminently reasonable.

Discussion

The primary goal of this set of models has been to illuminate how increased population size would effect subsistence choices of Eastern Woodlands foragers. The obvious predicted outcome was that high valued resources would be taken in increased amounts and lower valued resources would be added to the diet as higher valued ones were exhausted. Higher valued resources were indeed taken in increased amounts. In all except the basic pattern diet all available beaver were consumed. In the small population forager models only under vitamin C constraints were all beaver taken. Similarly, whereas the small forager models never selected more than 85% of the deer

from zone 1, the large forager models, except in the basic pattern, never selected less than 100% of the zone 1 deer and 83% of the zone 2 deer.

As predicted, increased population size did cause the diet to broaden as a result of pressure on the higher valued resources. The average number of optimal and secondary resources in the large population model solutions is 5.9 compared to 4.7 for the small population models. This includes one additional optimal resource, groundhog.

In truth the expansion of the diet is not as dramatic as I had anticipated. This is due, first, to the low forager population densities built into the models: resources are abundant relative to consumers. Secondly, the model puts a high premium on plant foods and mussels, and these are modeled as essentially infinite in abundance. The possible impact of limiting the availability of high valued resources is made evident by a comparison of the two forager basic pattern models. Although the large population models add only one additional optimal resource to the two selected by the small population models, the number of secondary resources increases from one to five. Of course, were further availability constraints imposed on hickory and chenopod, the secondary resources would begin to enter the optimal diet.

With increased population size, an increase in the time spent foraging is indicated. In the large population models, the per producer time ranges from 1.4 to 5.6 hours compared to 1.3 to 3.7 hours for the small population models. Time costs increase with the addition of nutritional constraints and the pattern of increase parallels that of the small forager models (fig. 4.1). Vitamin C remains by far the nutrient most difficult to obtain.

The nutritional requirements except that of vitamin C are met rather easily. Protein and thiamine are always obtained in surplus. Iron is now also always a surplus nutrient due to the increased consumption of chenopod in the basic and B-vitamin pattern diets. Population pressure does have some noticeable effect on nutrient

acquisition, however, as niacin, riboflavin and vitamin A are less frequently acquired in surplus. Hence the models suggest that as population increases, the need to achieve adequate nutritional intakes might play a more important role in shaping foraging decisions.

LARGE POPULATION: EARLY AGRICULTURAL STRATEGY (Table 4.13, 4.14, 4.15)

In this set of models, the population is set at 250 people and the crop plants, maygrass, chenopod, sunflower, sumpweed and squash are available, but at costs that reflect agricultural production. By comparison with the small population early agricultural models, the effects of population growth on subsistence strategies can be assessed. However, the comparison of the two foraging strategy models has already indicated that the primary effect of population growth on subsistence choice is a broadening of diet. More interesting is a comparison between the large population early agricultural models and the previous large population foraging models. Now that the Eastern Agricultural Complex cultigens are incorporated with costs reflecting food production, the potential nutritional and economic implications of pre-maize gardening can be examined.

Basic Pattern

Hickory consumption was again limited to 6200 kg per season. In the fall and winter an all-foraging diet was preferred. Chenopod, taken in large quantities in the large population foraging models, is not exploited at the higher agricultural costs. Rather hickory, deer, beaver and, in the fall, mussels are the optimal choices. Not surprisingly, the broader "agricultural" diets combining hickory nuts and meat are nutritionally superior. All nutrient requirements except for calcium and vitamin C are met.

Table 4.13: Optimal Diets (kg) of the Large Population,
Early Agricultural Strategy Models and Their Hourly Costs (page 1).

Resource	Basic	B-vit.	Vit. A	Calcium	Vit. C ¹
Fall					
Beaver	306	90	306	306	306
Deer	1937	1035	2973	2405	2004
Fish					
Groundhog					
Mussels	5477	5730	997	3128	2720
Berry					
Chenopod					
Grape					129
Greens					
Hickory	6200	6454	6419	6327	6327
Maygrass					
Squash					5882
Sumpweed					
Total	13920	13309	10695	12166	17368
Cost	20438	20124	20204	20277	23318
Winter					
Beaver		216			
Deer	4912	3592	3899	3715	
Fish					
Groundhog					
Mussels					
Berry					
Chenopod				8157	
Grape					
Greens					
Hickory	6200	6418	6426	1627	
Maygrass					
Squash					
Sumpweed					
Total	11112	10226	10325	13499	
Cost	21406	20783	20947	31910	

¹ Winter Vitamin C pattern infeasible.

Table 4.13: Optimal Diets (kg) of the Large Population,
Early Agricultural Strategy Models and Their Hourly Costs (page 2).

Resource	Basic	B-vit.	Vit. A	Calcium	Vit. C
Spring					
Beaver		104	104		
Deer		1480	1480		
Fish					
Groundhog					
Mussels					
Berry					
Chenopod	1852				
Grape					
Greens		5363	5363	7959	7959
Hickory	6200	6762	6762	6411	6411
Maygrass					
Squash					
Sumpweed				807	807
Total	8052	13708	13708	15177	15177
Cost	21556	25871	25882	27293	27293
Summer					
Beaver				104	104
Deer		192		384	356
Fish					
Groundhog					
Mussels	5616	4771	4703	5628	5621
Berry					
Chenopod		2126	234		
Grape					
Greens			1889	1248	1320
Hickory	6200	5166	5193	6323	6316
Maygrass	970	636	2615	427	451
Squash					
Sumpweed					
Total	12786	12891	14634	14113	14168
Cost	20660	23489	23658	21945	21954

Table 4.14: Large Population. Early Agricultural Diet. Percentage Acceptable Hourly Costs of Optimal and Secondary Resources by Season and Dietary Pattern (page 1)

Resource	Cost	Basic	B-vit.	Vit-A	Calcium	Vit-C ¹
Fall						
Bear	242.1					
Beaver	8.6	149	143	163	164	146
Beaver2	12.5	103	98	112	113	100
Beaver3	16.4	78	75	85	86	76
Deer	29.1	108	102	113	113	113
Deer2	33.0	88	88	112	112	88
Deer3	36.9	79	79	89	89	79
Fish	1.4	80				
Groundhog	5.0			77	84	
Mussels	0.4	100	100	113	313	116
Chenopod	2.9	79				
Grape	0.5	83				101
Grape2	0.6					88
Grape3	0.6					78
Hickory	2.6	148	100	130	130	127
Maygrass	2.3	93				
Sumpweed	5.1					
Squash	0.6					128
Winter						
Beaver	8.6	a	a	a	a	
Beaver2	12.5	a	108	a	a	
Beaver3	16.4	87	82	82	79	
Deer	29.1	113	113	a	a	
Deer2	33.0	101	112	112	112	
Deer3	36.9	89	89	89	89	
Fish	1.4	99			b	
Mussels	0.4	b	b	b	b	
Chenopod	2.9	98			100	
Grape	0.5	b			91	
Grape2	0.6	89			79	
Grape3	0.6	79				
Hickory	2.6	184	134	134	130	
Acorn	3.3	80				
Maygrass	2.3	b			91	
Sumpweed	5.1				99	
Sunflower	5.1	78				
Squash	0.6					

a optimal but previously exploited

b optimal but seasonably unavailable

¹ Winter Vitamin C pattern infeasible.

Table 4.14: Large Population. Early Agricultural Diet. Percentage Acceptable Hourly Costs of Optimal and Secondary Resources by Season and Dietary Pattern (page 2)

Resource	Cost	Basic	B-vit.	Vit-A	Calcium	Vit-C
Spring						
Beaver	8.6	a	a	a	a	a
Beaver2	12.5	a	a	a	a	a
Beaver3	16.4	79	159	174	93	93
Deer	61.5		a	a		
Deer2	68.0		105	110		
Deer3	74.5		91	106		
Fish	1.4	b	77	83	b	b
Mussels	0.4	b	b	b	b	b
Chenopod	2.9	110	89	90	84	84
Grape	0.5	b			78	78
Grape2	0.6	91				
Grape3	0.6	81				
Greens	0.8		108	107	123	123
Hickory	2.6	188	123	122	134	134
Acorn	3.3	82				
Maygrass	2.3	b	92	b	b	b
Sumpweed	5.1	76	85	94	103	103
Sunflower	5.1	80				
Squash	0.6					
Summer						
Beaver	8.6	a	a	a	a	a
Beaver2	12.5	a	a	a	a	a
Beaver3	16.4	85	a	a	208	273
Deer	61.5		a	a	a	a
Deer2	68.0		101	91	110	110
Deer3	74.5		91	83	91	91
Fish	1.4	87	97	99	83	82
Groundhog	8.0		77	75	82	78
Mussels	0.4	106	274	260	251	258
Blackberry	0.5					
Chenopod	2.9	86	102	104		76
Grape	0.5	90	93	96		
Grape2	0.6	78	81	84		
Grape3	0.6			75		
Greens	0.8		99	107	171	166
Hickory	2.6	161	143	154	143	143
Maygrass	2.3	111	108	100	134	141
Sumpweed	5.1		88	84	82	84

a optimal but previously exploited
b optimal but seasonably unavailable

Table 4.15: Large Population, Early Agricultural Strategy Models. Acquisition of Nutrients by Season and Nutrient Pattern (page 1)

Nutrient	RNA (1000's)	Percent of RNA Acquired ¹				
		Basic	Bvit	VitA	Ca	VitC ²
Fall						
Energy	49259	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	631	<u>309</u>	<u>265</u>	<u>301</u>	<u>303</u>	<u>286</u>
Iron	219	<u>417</u>	<u>417</u>	183	294	274
Thiamine	21	<u>184</u>	<u>173</u>	208	196	203
Riboflavin	25	117	<u>100</u>	<u>100</u>	107	116
Niacin	355	139	<u>100</u>	150	143	143
Vitamin A	16970	103	73	<u>100</u>	<u>100</u>	<u>100</u>
Calcium	11461	170	176	37	<u>100</u>	<u>100</u>
Vitamin C	611	3	1	4	3	<u>100</u>
Winter						
Energy	49259	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	
Protein	631	<u>361</u>	<u>313</u>	<u>318</u>	<u>430</u>	
Iron	219	155	137	140	336	
Thiamine	21	235	218	223	308	
Riboflavin	25	116	<u>100</u>	<u>100</u>	174	
Niacin	355	196	161	162	203	
Vitamin A	16970	131	106	105	<u>100</u>	
Calcium	11461	10	5	5	<u>100</u>	
Vitamin C	611	6	3	3	5	

¹ Binding constraints underlined

² Winter vitamin C pattern infeasible

Table 4.15: Large Population, Early Agricultural Strategy Models. Acquisition of Nutrients by Season and Nutrient Pattern (page 2)

Nutrient	RNA (1000's)	Percent of RNA Acquired ¹				
		Basic	Bvit	VitA	Ca	VitC
Spring						
Energy	49259	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	631	179	234	234	202	202
Iron	219	128	128	128	152	152
Thiamine	21	194	204	204	238	238
Riboflavin	25	56	<u>100</u>	<u>100</u>	106	106
Niacin	355	42	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Vitamin A	16970	5	231	231	278	278
Calcium	11461	22	57	57	<u>100</u>	<u>100</u>
Vitamin C	611	0	405	405	599	599
Summer						
Energy	49259	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	631	242	262	283	253	252
Iron	219	<u>417</u>	<u>417</u>	<u>417</u>	<u>417</u>	<u>417</u>
Thiamine	21	179	200	218	176	176
Riboflavin	25	85	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Niacin	355	99	<u>100</u>	167	<u>100</u>	<u>100</u>
Vitamin A	16970	42	41	<u>100</u>	<u>100</u>	102
Calcium	11461	176	173	179	186	187
Vitamin C	611	0	0	142	95	<u>100</u>

¹ Binding constraints underlined

A large array of secondary resources are indicated including three crops, chenopod, maygrass and sunflower. In addition acorn, an exceedingly common archaeobotanical find in the Eastern Woodlands, enters as a secondary resource in winter.

In the spring, chenopod is again optimal and combines with hickory to form the optimal diet. Of the five crop plants, only squash is not indicated as a desired or secondary resource, so gardening is suggested as a potentially advantageous way of acquiring calories for warm season consumption. Of course, the costs of storing the garden products are not assessed, but then, neither are the costs of hickory storage. In fact, except for the zone 3 beaver suggested as a secondary resource, all of the optimal or secondary resources for spring are stored plant foods.

In the summer hickory and mussels are the staple foods, but now maygrass enters the optimal diet. Maximal iron joins energy as a binding constraint.

B-Vitamin Pattern

The addition of B-vitamin requirements causes more of a premium to be placed on animal resources, so cultigens play less of a role in the indicated diets. In fall and winter, there is little change from previous models. Hickory, deer, mussels and beaver are the optimal resources. In the spring chenopod, and sumpweed are secondary resources, but hickory, greens, deer and beaver constitute the optimal diet. Only in summer do cultigens enter the optimal diet. Then maygrass and chenopod join hickory, mussels and deer in the optimal diet and sumpweed is a secondary resource.

Vitamin A Pattern

The vitamin A pattern is in most respects the same as the B-vitamin pattern. The quantities of the optimal resources included in the optimal diets change but there are few qualitative differences. In the fall and winter hickory, deer, beaver and

mussels remain the optimal choices, but mussels now are relatively less important than game. In the spring the optimal diet is the same as it was in the B-pattern model. Hickory, greens, deer and beaver are the optimal resources with chenopod and sumpweed secondary resources. In the summer hickory and mussels remain the staple foods but deer are no longer pursued. Greens enter the optimal diet, while the exploitation of chenopod is greatly reduced and that of maygrass greatly increased. Interestingly, this diet fulfills all the nutrient requirements included in this study. As was the case with the B-pattern models, the consumption of cultigens is suggested to be more advantageous economically in the warm seasons when game is more expensive.

Calcium pattern

In the fall the diet remains the foraging-derived one of hickory, mussels, deer and beaver. This is not surprising as mussels provide a ready calcium source. In winter an interesting result is produced. As was the case in the foraging model diet, chenopod replaces hickory as the staple food. Not only is chenopod selected as the staple food in spite of its higher agricultural costs, but the sensitivity analysis indicates that sumpweed is only minutely more expensive. Hence, the production and storage of native grain crops as a wintertime source of nutrients appears to be robust result of the optimality modeling.

In spring greens provide a cheap source of calcium, so chenopod becomes a secondary resource. Sumpweed is still desired in small quantities and hickory nuts rival greens in importance. A diet in which greens comprise over 50% of the food seems very doubtful, and again one must wonder if this all-vegetable diet would deliver all the necessary nutrients in a biologically usable form.

In the summer the availability of mussels produces the usual hickory and mussels staple food combination. This time augmented by greens, maygrass, deer and beaver.

Vitamin C pattern

The addition of vitamin C to the suite of required nutrients causes no changes not seen before. In the fall the optimal diet is essentially that of the small population early agricultural model except that deer join the previously desired squash, hickory, mussels, beaver and grape. In winter the solution remains infeasible. In spring the optimal diet is the same as that of the calcium pattern, as sufficient greens are eaten in meeting vitamin A needs that surplus vitamin C is obtained. In summer the calcium pattern diet met only 95% of the vitamin C needs, so minor adjustments in the amounts of the resources taken are made. The optimal diet remains, however, hickory, mussels, greens, maygrass, beaver and deer.

Discussion

The results of the large population early agricultural models are much the same as those of the large population forager ones. The increased population size incorporated into the models does not greatly increase the time-costs of subsistence. They remain a quite modest 1.4 to 5.6 hours per producer. Due to the increased costs of chenopod, the early agricultural basic, B-vitamin, vitamin A, and calcium pattern diets are from 2% to 3% more costly than their foraging counterparts. Because of the availability of squash, however, the cost of meeting the vitamin C constraint falls to only 66% of its foraging cost.

Nutritionally the early agricultural and foraging diets are very similar. The only marked difference is that vitamin A is obtained in greater abundance in the early agricultural models. This is not, however, due to the beneficial nutritional contribution of cultigens. Rather, in spring chenopod is replaced by increased amounts of greens which, although more costly to procure than wild chenopod, yield much greater amounts of vitamin A.

Significantly, however, even with higher production costs, all of the Eastern Agricultural Complex plants except sunflower were incorporated into one or more models. Squash played its usual role as a fall vitamin C source and sumpweed continued as a spring calcium source. During summer, the only season of its availability, maygrass was selected as part of the optimal diet of each of the models. Its inclusion in the basic pattern model suggests a possible importance as a source of food energy as well as nutrients. Not surprisingly chenopod was less favored as a cultigen than as a more cheaply gathered wild food, but it continued to be part of the optimal diet in spring as an energy source and in the summer as a B-vitamin source.

Interestingly each of the Early Agricultural complex cultigens except squash was selected at least as a secondary resource in the basic pattern models. This indicates that the native cultigens would have had considerable potential as basic sources of food energy. In years of poor hickory or game production, or as population pressure began to stress the wild food sources, gardening would have become an increasingly attractive alternative as a means of obtaining food. This result also suggests that improving the yield or availability of the weedy annuals would have considerable potential for improving subsistence efficiency and stability by creating an additional set of optimal resources. Although gardening might not compete favorably with hunting and gathering in most years, efforts that would improve the yield or accessibility of the weedy annuals such as creating or maintaining disturbed habitats near the human habitations might well be accomplished at low cost to the consumers in terms of energy expended or opportunities lost. The longterm consequences of such resource management can be quite dramatic. The establishment of disturbed weedy habitats ("domestilocalities") near human habitations has been pointed to as a crucial initial step in the origins of Eastern Woodlands agriculture (Smith 1987).

LARGE POPULATION: LATE AGRICULTURAL DIET
(Table 4.16, 4.17, 4.18)

The final set of models incorporates corn and beans in dried and fresh forms. In other respects the models are identical to the large population early agricultural diet models. Likewise, the models are identical to the small population late agricultural models except for having a population size ten times larger.

Basic pattern

Dried corn is selected as the only food with hickory and beaver as secondary resources. The total yearly consumption of corn is 56620 kg. At 940 kg/ha (Smith 1987a), about 60 ha would be required to yield this much corn. Assuming an average family size of five suggests that 1.2 ha (3 acres) would be the size of the average family corn field. This is the correct order of magnitude for historic period Eastern Woodland Native Americans (Will and Hyde 1917). Of course a broader diet could be generated by incorporating an availability constraint on corn. Actually running such a model is unnecessary, however, as an examination of the sensitivity analyses shows that the result would be the addition of all zone 1 beaver in the fall then the use of hickory nuts to fulfill any caloric needs not met by the maximal allowable corn consumption.

B-vitamin, Vitamin A and Calcium Patterns

The optimal diets of these three patterns are very similar both to one another and to the small population late agriculture models. In the fall the optimal resources for all three patterns are dry corn, mussels, deer and beaver. In winter the optimal diet is corn, deer and beaver until the calcium constraint is added at which time sumpweed replaces beaver. In spring corn, chenopod and beaver satisfy the B vitamin and vitamin A requirements and 95% of the calcium requirement. Fulfilling the last 5% of the calcium requirement causes less than a 1% increase in the cost of subsistence but has a

Table 4.16: Optimal Diets (kg) of the Large Population,
Late Agricultural Strategy Models and Their Hourly Costs (page 1).

Resource	Basic	B-vit.	Vit. A	Calcium	Vit. C ¹
Fall					
Beaver		90	99	90	90
Deer		635	2238	2037	1603
Fish					
Groundhog					
Mussels		4975	1591	2387	1976
Berry					
Chenopod					
Dry Corn	14152	12835	12800	12731	12757
Grape					
Greens					
Hickory					
Maygrass					
Squash					5985
Sumpweed					
Total	14152	18535	16728	17245	22411
Cost	15568	16758	16760	16829	19911
Winter					
Beaver		199	191		
Deer		2855	2855	3162	
Fish					
Groundhog					
Mussels					
Berry					
Chenopod					
Dry Corn	14155	12772	12773	7964	
Grape					
Greens					
Hickory					
Maygrass					
Squash					
Sumpweed				3130	
Total	14155	15826	15819	14256	
Cost	15570	17235	17423	28107	

¹ Winter vitamin C pattern infeasible

Table 4.16: Optimal Diets (kg) of the Large Population,
Late Agricultural Strategy Models and Their Hourly Costs (page 2).

Resource	Basic	B-vit.	Vit. A	Calcium	Vit. C ¹
Spring					
Beaver		104	104		
Deer					
Fish					
Groundhog					
Mussels					
Berry					
Chenopod					
Dry Corn	14155	13661	13661	13704	13704
Grape					
Greens		6994	6994	7474	7474
Hickory					
Maygrass					
Squash					
Sumpweed					
Total	14155	20759	20759	21178	21178
Cost	15570	20922	20922	21129	21129
Summer					
Beaver					
Deer					
Fish					
Groundhog					
Mussels		5001	5001	5001	5001
Berry					
Chenopod					
Dry Corn	14155	13070	13070	13070	13070
Grape					
Greens		1785	1785	1785	1785
Hickory					
Maygrass					
Squash					
Sumpweed					
Total	14155	19856	19856	19856	19856
Cost	15570	17823	17823	17295	17565

Table 4.17: Large Population. Late Agricultural Diet. Percentage Acceptable Hourly Costs of Optimal and Secondary Resources by Season and Dietary Pattern (page 1)

Resource	Cost	Basic	B-vit.	Vit-A	Calcium	Vit-C ¹
Fall						
Bear	242.1					
Beaver	8.6	82	140	145	144	144
Beaver2	12.5		97	110	99	99
Beaver3	16.4			76	76	75
Deer	29.1		103	103	101	101
Deer2	33.0		88	91	88	88
Deer3	36.9		79	81	79	79
Fish	1.4					
Groundhog	5.0				75	75
Mussels	0.4		100	104	373	355
Chenopod	2.9					
Grape	0.5					90
Grape2	0.6					78
Grape3	0.6					
Hickory	2.6	82	80	80	79	79
Maygrass	2.3					
Sumpweed	5.1					
Squash	0.6					121
Dry Corn	1.1	122	106	124	120	121
Green Corn	0.9					86
Winter						
Beaver	8.6		a	a	a	
Beaver2	12.5		106	106	99	
Beaver3	16.4		81	81	76	
Deer	29.1		113	a	113	
Deer2	33.0		112	112	100	
Deer3	36.9		89	89	89	
Fish	1.4					b
Mussels	0.4		b	b		b
Chenopod	2.9				92	
Grape	0.5				79	
Grape2	0.6					
Grape3	0.6					
Hickory	2.6	82	79	79		
Acorn	3.3					
Maygrass	2.3					
Sumpweed	5.1				112	
Sunflower	5.1					
Squash	0.6					
Dry Corn	1.1	122	125	125	103	

a optimal but previously exploited

b optimal but seasonably unavailable

¹ Winter vitamin C pattern infeasible

Table 4.17: Large Population. Late Agricultural Diet. Percentage Acceptable Hourly Costs of Optimal and Secondary Resources by Season and Dietary Pattern (page 2)

Resource	Cost	Basic	B-vit.	Vit-A	Calcium	Vit-C
Spring						
Beaver	8.6		a	a		
Beaver2	12.5		a	a		
Beaver3	16.4		143	143		
Deer	61.5		99	99		
Deer2	68.0		90	90		
Deer3	74.5		82	82		
Fish	1.4				b	b
Mussels	0.4		b	b	b	b
Chenopod	2.9		76	76		
Grape	0.5					
Grape2	0.6					
Grape3	0.6					
Greens	0.8		101	101	192	192
Hickory	2.6	82				
Acorn	3.3					
Maygrass	2.3					b
Sumpweed	5.1					
Sunflower	5.1					
Squash	0.6					
Dry Corn	1.1	122	104	104	135	135
Summer						
Beaver	8.6	82	a	a	a	a
Beaver2	12.5		a	a	131	131
Beaver3	16.4		a	a	187	76
Deer	61.5		97	97		
Deer2	68.0		88	88		
Deer3	74.5		80	80		
Fish	1.4					
Mussels	0.4		260	260	110	103
Blackberry	0.5					97
Chenopod	2.9					
Grape	0.5					
Grape2	0.6					
Grape3	0.6					
Greens	0.8		103	103	118	104
Hickory	2.6	82	77	77	78	80
Maygrass	2.3					
Sumpweed	5.1					
Dry Corn	1.1	122	119	119	126	106

a optimal but previously exploited

b optimal but seasonably unavailable

Table 4.18: Large Population, Late Agricultural Strategy Models. Acquisition of Nutrients by Season and Nutrient Pattern (page 1)

Nutrient	RNA (1000's)	Percent of RNA Acquired ¹				
		Basic	Bvit	VitA	Ca	VitC ²
Fall						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	63.1	200	284	313	313	296
Iron	21.9	136	<u>417</u>	252	293	274
Thiamine	2.1	190	184	212	207	214
Riboflavin	2.5	51	<u>100</u>	<u>100</u>	103	112
Niacin	35.5	160	200	235	232	232
Vitamin A	1697.0	31	81	<u>100</u>	<u>100</u>	<u>100</u>
Calcium	1146.1	27	176	77	<u>100</u>	<u>100</u>
Vitamin C	61.1	0	1	3	3	<u>100</u>
Winter						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	
Protein	63.1	200	325	325	422	
Iron	21.9	136	173	173	294	
Thiamine	2.1	190	223	223	403	
Riboflavin	2.5	51	<u>100</u>	<u>100</u>	154	
Niacin	35.5	160	252	252	394	
Vitamin A	1697.0	31	109	109	<u>100</u>	
Calcium	1146.1	27	30	30	<u>100</u>	
Vitamin C	61.1	0	4	4	4	

¹ Binding constraints underlined

² Winter vitamin C pattern infeasible

Table 4.18: Large Population, Late Agricultural Strategy Models. Acquisition of Nutrients by Season and Nutrient Pattern (page 2)

Nutrient	RNA (1000's)	Percent of RNA Acquired ¹				
		Basic	Bvit	VitA	Ca	VitC
Spring						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	63.1	200	222	222	219	219
Iron	21.9	136	164	164	166	166
Thiamine	2.1	190	204	204	205	205
Riboflavin	2.5	51	<u>100</u>	<u>100</u>	101	101
Niacin	35.5	160	179	179	176	176
Vitamin A	1697.0	31	274	274	286	286
Calcium	1146.1	27	95	95	<u>100</u>	<u>100</u>
Vitamin C	61.1	0	526	526	<u>562</u>	<u>562</u>
Summer						
Energy	4925.9	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Protein	63.1	200	259	259	267	262
Iron	21.9	136	<u>417</u>	<u>417</u>	<u>417</u>	<u>417</u>
Thiamine	2.1	190	180	180	177	179
Riboflavin	2.5	51	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>
Niacin	35.5	160	181	181	190	185
Vitamin A	1697.0	31	123	123	105	112
Calcium	1146.1	27	193	193	186	190
Vitamin C	61.1	0	134	134	61	<u>100</u>

¹ Binding constraints underlined

large qualitative effect. The calcium model optimal diet drops beaver from the optimal diet in favor of increased consumption of greens. Beaver from zone 3, which had been an optimal resource before the imposition of the calcium constraint, now drops to thirteenth place among the nondesired resources. Thus the potential utility of beaver as a optimal source of some nutrients is completely disguised by the more complex calcium pattern model. This provides another example of how the use of multiple models, although tedious, provides more insight than does reliance on a single model outcome.

In summer a diet of corn, mussels and greens provides all required nutrients included in the study.

Vitamin C pattern

The increase in population size causes few changes from the small population late agriculture solutions. Although all available beaver and grapes are exploited, the primary resources utilized -- squash, greens, and mussels -- are modeled as virtually infinite. The predicted adjustment to increased population pressure is merely to increase consumption of already favored foods.

Discussion

At this point there is little left unsaid about the diet optimization models. The large population late agriculture results are very similar to the small population models due to the open-ended availability of corn, squash, greens and mussels. The roles of the nutrient constraints in the large population and the small population late agricultural models are basically the same. There is a slight improvement in the acquisition of vitamin A, but this results from the increased use of greens in the summer as a consequence of prior consumption of easily captured beaver.

DISCUSSION

The solution by linear programming of 120 varied diet optimization problems has provided insight into the potential influence on diet choice of nutritional requirements, population pressure and the availability of weedy and domesticated plants.

The Small Population (0.1 person/km²), Foraging Strategy Models investigated how nutrient requirements might have influenced diet choice under conditions of low demographic stress. The diets selected were quite narrow, focusing on hickory nuts, deer, beaver, potherbs and mussels. In general the models suggest that nutrient constraints may have played only a limited role in shaping diet choice. Although the least-effort diet designed to meet energy needs alone (hickory nuts and beaver) would be nutritionally inadequate, expanding the diet to meet most other nutrient needs could be done at low cost. Calcium and vitamin C, however, are indicated to be more costly to acquire. In fact, the resources included in the models may have been insufficient to meet vitamin C needs in the winter. Interestingly, chenopod, a native weed that was eventually domesticated, was selected as a B-vitamin or calcium source in all seasons but the fall.

The Small Population, Early Agricultural Strategy Models were designed to allow the assessment of the potential costs and benefits of exploiting native weedy annuals. Significantly maygrass, chenopod, sumpweed and squash each entered the optimal diet of at least one model. Maygrass was selected as the staple food during summer, but this is felt to result from an underestimation of its cost of procurement. Squash was selected as a fall vitamin C source. When compared to the foraging strategy model, its availability can be seen to have decreased the time spent in the fall food quest by 56%. Chenopod was selected as a calcium source in winter and spring, and sumpweed as a niacin source in spring. These last two results suggest the potential importance of stored seeds as a source of nutrients during seasons when meat is costly

to procure. Overall, it seems that the exploitation of native weeds could have been beneficial to a population doing so, although it is not suggested that these plants were domesticated as nutrient sources.

The Small Population, Late Agricultural Strategy Models add maize and beans to the available resources and increase the costs of the native annuals to reflect agricultural production. As a result of their increased costs of production, the use of native weedy annuals declined. However, squash and sumpweed remained part of seasonal optimal diets as vitamin C and calcium sources respectively. Most importantly, maize was selected as the staple food in every model run, pointing to a potential utility in a least-effort subsistence strategy. This suggests that demographic pressure is not necessary to explain the adoption of maize agriculture.

The Large Population models incorporate a tenfold increase in population size. This produces a population density of about 1 person/km². In the Large Population, Foraging Strategy Models, the expected changes are seen. The exploitation of first line foods increases, and diet broadens to include less desired resources. As a result, the time spent in the food quest increases.

The Large Population, Early Agricultural Strategy Models incorporate the larger population size and include the native annuals with costs reflecting agricultural production. All the native domesticates except sunflower are included in at least one optimal diet. Squash is a fall vitamin C source, sumpweed a spring calcium source, and chenopod a summer B-vitamin source. Maygrass enters the summer diet as an energy source, in spite of its higher production costs. In addition, when hickory nut availability is limited, chenopod is an optimal energy source in spring, and the other native cultigens except squash are secondary energy sources. Thus the native cultigens might be expected to play more important roles in the diet, if energy demands were to increase due to increased population growth, or if the availability of first line foods such as nuts or deer were to diminish. Also the model's result suggests that some

casual management of the plants might be beneficial. These results tend to support coevolutionary explanations of the origin of agriculture.

The Large Population Late Agriculture Strategy Models are very similar to the Small Population, Late Agricultural Strategy Models. The diets emphasize maize, mussels, potherbs and squash, which are all abundant in the models. Hence an increased population size merely results in increased consumption of the same resources. Of course, the cost of acquiring the diet increases.

CHAPTER V TESTING THE MODELS

I stressed in the first chapter that testing the proposition that prehistoric Native Americans were economic optimizers is not the purpose of the optimization modeling. Rather the modeling is a heuristic endeavor designed to illuminate the factors that influence diet choice, in particular to determine the extent to which nutritional constraints may have shaped resource selection. A comparison between the predictions of the model and archaeological subsistence remains illuminates how well the model captures the essential dynamics of the prehistoric decision making process. This chapter will compare the results of the models to the archaeological record of the Eastern Woodlands in general and to the site of Daugherty's Cave, Virginia (44Ru14) in particular.

Optimization models are frequently found to be broadly correct but inadequate in accounting for the particulars of the phenomenon studied (Maynard Smith 1978). This is certainly the case with the models constructed here. The models incorporate white-tailed deer, corn and hickory nuts, three staple resources of the Eastern Woodlands, but fail to include other resources such as raccoon and turkey that are known archaeologically and ethnohistorically to have been important. Furthermore the models' selection of beaver as a first line food seems at odds with the archaeological and ethnographic information concerning that animal's limited importance in the diet of Eastern Woodlands Native Americans (Smith 1975; Swanton 1946). In short, even a casual consideration of the models shows them to reflect rather poorly the subsistence strategies characteristic of the Eastern Woodlands. Nonetheless, a more rigorous test of the models is of some interest. To provide the data necessary to test the models, an

excavation was undertaken at the Daugherty's Cave site, Virginia (44Ru14), a multicomponent rockshelter with excellent preservation of faunal and botanical remains. A site report covering the 1982-1983 excavations is presented in Appendix A. In order to provide context for the tests of the models which follow, a brief synopsis of the site follows.

SYNOPSIS OF THE DAUGHERTY'S CAVE SITE

Daugherty's Cave (44Ru14) is located on Big Cedar Creek, a tributary fo the Clinch River in Russell County, Virginia. It lies in the Ridge and Valley geographical province at elevation of 1860 feet AMSL. Although Daugherty's Cave is a true cave extending some 500 feet into the ridgetside, only the rock shelter portion contains evidence of Native American utilization. Daugherty's Cave is not a dry shelter. Quite to the contrary, water drips from the shelter roof more frequently than not. Nonetheless the cave has particularly good preservation of bone and carbonized plant remains.

Daugherty's Cave was first excavated in 1967 by Joe Benthall, then of the Virginia State Library, aided by local volunteers, many of them members of the Archaeological Society of Virginia. Benthall excavated a 30 ft by 10 ft trench and revealed stratified deposits extending to about 10 feet beneath the surface. Chronologically the deposits spanned the Early Archaic to Mississippian periods (Benthall 1969). Having only six weeks in the field and an inexperienced crew, Benthall dug the site in relation to rather gross stratigraphic divisions and did not attempt any fine scale recovery of subsistence remains. In fact the mucky deposits of the shelter soon forced him to abandon screening altogether (Joseph L. Benthall, personal communication 1983). In spite of this, Benthall did recover a substantial amount of bone and some carbonized plant remains (Benthall 1975).

For 18 weeks in the fall of 1982 and the spring of 1983, I and a crew of one to three people conducted a second excavation at Daugherty's Cave aimed particularly at recovering subsistence remains. Unlike Benthall's earlier work, the excavations emphasized waterscreening and flotation recovery methods at the expense of uncovering wide areas. In the 1982-83 seasons four 1.5 m squares near the mouth of the shelter were excavated adjacent to Benthall's old units. The squares were dug in 10 cm levels with individual strata within the levels kept separate where possible. Diagnostic artifacts were individually piece-plotted. From each level 20 l of soil were floated using a modified SMAP machine (Watson 1976). This machine captured light fraction charcoal on 0.5 mm mesh and the heavy fraction on 1/16" window screen. Also from each level, an additional 20 l of soil were waterscreened through window screen. The remainder of the fill was screened thru 1/4" mesh. The 1982-83 excavations extended only to the Late Archaic strata.

Site Components

Based on the material recovered in 1982-83, five components can be defined at Daugherty's Cave.

Component 1. The first component represents strata disturbed historically by fisherman digging for worms and by cattle and sheep churning the wet soil. This uppermost zone of the site contains a few historic Euroamerican artifacts such as iron kettle fragments and bottle glass and a melange of prehistoric (mostly Mississippian period) material. This component will not be considered in testing the optimal diet models as the subsistence remains recovered from it have too uncertain a provenience.

Component 2. The second component represents the Mississippian period. Three radiocarbon dates are available for this component: AD 1470 \pm 60, AD 1480 \pm 70 and AD 900 \pm 60. The characteristic pottery of this component is the shell-

tempered New River series (Evans 1955). Smooth, cordmarked and knot-and-net-roughened surface treatments predominate. Also common in this component are limestone tempered ceramics, also with smooth, cordmarked and knot and net roughened surface treatments. The characteristic projectile point of this component is a small triangular point. Pentagonal points and a few small corner-removed points are also present. All of these point types have been recovered from Mississippian period contexts in the Tellico Reservoir area (Kimball 1985).

The faunal assemblage of this component is dominated by white-tailed deer, bear and aquatic snails. The food plant remains recovered from this component are comprised of hickory, walnut, butternut, acorn and hazelnut shell, grape seeds, and the remains of two cultigens, corn and beans.

Component 3. The third component at the site can be assigned to the late Middle Woodland period. Four radiocarbon dates are available: AD 580 \pm 60, AD 580 \pm 70, AD 380 \pm 70, and AD 370 \pm 70. I view this component as roughly contemporaneous - ca. fifth century A.D. - with the Connestee Phase of eastern Tennessee and western North Carolina (Chapman and Keel 1979). The ceramics of this component are dominated by limestone tempered types referable to the Candy Creek complex of Tennessee (Kneberg 1961). Mulberry Creek plain is the most common in the upper levels of this component, and Candy Creek Cordmarked is most common in the lower levels. Wright check-stamped and Bluff Creek simple-stamped are minority types in this component, and a small amount of a granite-tempered plain-plaited fabric-impressed ware is also found. A few Longbranch fabric-impressed sherd were recovered from the lowest levels of this component, but this may reflect mixing from a lower component. The characteristic projectile points of this component include medium sized triangular points and small expanded stemmed Swan Lake points. This component also contained a number of prismatic blades manufactured of local cherts

and a small amount of cut mica. Apparently at this time the inhabitants of Daugherty's Cave participated in the long distance trade characteristic of the Hopewell Interaction Sphere.

Deer, elk and raccoon are the most common faunal remains in this component. The food plants represented in this component include all the nuts found in the Mississippian component, but no corn or beans. Instead there are native cultigens, chenopod, sumpweed, maygrass, and squash and two fleshy fruits, blackberry and grape.

Component 4. The fourth component at Daugherty's Cave is assigned to the Early Woodland period and has two radiocarbon dates: 140 BC \pm 80 and 570 BC \pm 80. The ceramics of this component are primarily Longbranch fabric-impressed along with some Candy Creek cordmarked. The projectile points are Nolichucky and Swannanoa stemmed types. Deer and raccoon dominate the faunal remains, but surprisingly, waterfowl are the third most prevalent animal represented. The plant foods represented include all the above mentioned nuts plus grape and the cultigens, squash, chenopod and maygrass. In addition this component also yielded one corn cupule, but this is thought to be a contaminate from a higher level. It will not be included in the tests of the models.

Component 5. The final component defined by the 1982-83 excavations is assigned to the Late Archaic period. Five radiocarbon dates are available: 1630 BC \pm 70, 1650 BC \pm 70, 1850 BC \pm 70, 2350 BC \pm 80, and 2740 BC \pm 70. There are no ceramics from the levels of this component, and Savannah River projectile points are the most common. Deer, elk, and raccoon dominate the faunal assemblage. Plant food remains include only hickory, walnut and butternut shell and traces of squash rind. Bottle gourd is also present but presumably was not eaten.

PROBLEMS IN CONSTRUCTING AN ARCHAEOLOGICAL TEST

Representativeness

One troubling problem with the Daugherty's Cave material results from the fact that the emphasis of the 1982-1983 excavation was on fine recovery, especially flotation recovery of plant and animal remains. Given the small size of the crew, usually two people, this resulted in only about 11 m³ of the site being excavated. This has not created a particular problem with sample size, as abundant subsistence remains were recovered. Several kilograms of charcoal were gathered along with nearly 55,000 identified specimens of faunal material (excluding terrestrial snails). Over 24,000 specimens were derived from vertebrates.

There is a problem, however, in that since only a small area of the cave was opened, there can be little assurance that the remains from all the subsistence activities that took place in the cave have been sampled. It is always possible that the disposal of subsistence remains was in some ways spatially patterned, and that the excavation missed significant deposits. Of course, this is a concern at all archaeological sites, but the small size of the Daugherty's Cave excavations makes the problem perhaps more acute. The problem is lessened somewhat by the fact that the rockshelter is itself spatially limited with only about 200 m² within its confines sufficiently level for comfortable habitation.

Commensals and Other Excluded Species

Caves tend to accumulate bones even in the absence of human occupants (Butzer 1982:81). Daugherty's Cave is no exception. A number of taxa identified from Daugherty's Cave, particularly salamanders, shrews, and bats, are almost certainly commensal species that are unlikely to have entered the human diet. The owl and hawk

recovered from the site are also likely commensal species. Another set of taxa, however, are of dubious but uncertain dietary importance. These include snakes, flying squirrels, and passerine birds. These may have been eaten, but are probably more likely the prey of some nonhuman predator using the cave as a den. As these taxa were not included in the models, they are by necessity excluded from the test, but it seems unlikely that any of these species would have made much of a contribution to prehistoric diets.

The remains of box turtle, fox, mink, dog and elk were also recovered from the cave, but are not included in the model. As discussed in chapter 3, box turtles were most likely prized as a source of bowls more than as a source of meat, so they are appropriately omitted from an optimal diet model. Fox and mink may have been taken by humans intentionally or in traps set for other game. On the other hand the fox may well have used the cave as a lair when people were absent, and the mink could have been taken by some nonhuman predator. Again they are unlikely to have been important food resources for humans. Dogs do not seem to have been eaten routinely in the Eastern Woodlands (Swanton 1946). Furthermore, since they are a domesticated species, the factors governing their exploitation are not likely the same as those governing wild game; thus the exclusion of dogs from the models seems warranted. Elk, as was discussed in chapter 3, were excluded from the models due to a lack of ecological information on this extirpated species. This is unfortunate, as elk apparently were an important prey species during the Middle Woodland and Late Archaic periods at Daugherty's Cave. Elk was never as important as deer, however. Furthermore, if elk remains are lumped with deer remains to produce a general cervid figure, it makes no difference in the rank order of the taxa. This is because deer is already the top-ranked species.

Multiple-Strata Components

Another problem with the Daugherty's Cave data is that the stratification of the site proved to extremely complex. Although every attempt was made to excavate by natural strata, it often proved impossible to trace thin lens even across a single square, much less from one square to another. As a result the five components recognized from the excavations are not natural units but lump together many discrete strata. This makes it inappropriate to use the components as units of aggregation for calculating the minimum number of individuals (MNI) represented by the bones in the sample (Grayson 1984). Fortunately this problem is easily circumvented, as the relative contribution to the total diet of each animal species can be obtained by using allometric formulae relating bone weight to meat weight to calculate the amount of meat that would be contributed by each bone recovered from the excavations. Formulae for these calculations are presented in Reitz and Quitmyer (1988:97).

Evaluating Plant Remains

Archaeological food plant remains are a diverse set of plant parts, ranging from dense nutshells to minute seeds and fragile rind fragments. Although one fragment of hickory nutshell, one corn cupule, one chenopod seed and one fragment of squash rind each represent one fruit, they do not represent similar amounts of food. Certainly there seems to be no way to estimate the amount of food which each item represents.

(Theoretically one could calculate a "minimum number of plants" for each taxon, but plants are generally such prolific producers of seeds and fruits that a single plant would almost always be sufficient to account for all the archaeological remains of its taxon).

Further militating against the comparison of archaeological plant remains is the fact that they include different classes of material culture. A corn kernel, for example, is food, almost certainly meant for consumption, not disposal in a midden. Its presence

as an carbonized archaeological remain is likely the result of a sequence of accidental and fortuitous events. Hickory nutshell, on the other hand, is refuse, a by-product of obtaining food that must have been discarded deliberately and routinely. Furthermore, it is useful as fuel so it may have been burned with some regularity. Clearly the relative proportions of hickory nutshell and corn kernels in a site reflects many things other than the relative contribution of hickory nuts and corn to the diet. There is nothing similar to the zooarchaeological concept of "minimum number of individuals", or an allometric biomass formula that allows these items to be translated into comparable units of measurement. And, of course, some plant foods such as succulent greens are highly unlikely to carbonize at all, making their importance in prehistory unmeasurable. (For further discussion of archaeobotanical taphonomy see Dimbleby (1978); Yarnell (1982)).

At best it is possible to compare rigorously the dietary contribution those plants which represent the same sort of material item, e.g. nutshell with nutshell, seeds with seeds. This is, in fact, what is commonly done in paleoethnobotanical reports and is what will be done here.

Seasonality of Occupation

The archaeological record of Daugherty's Cave included remains of bramble seeds, maygrass, turtles and grebes. Bramble and maygrass fruit in the summer (Radford et al. 1968), turtles are active only in the warm seasons (Ernst and Barbour 1974), and grebes inhabit southwestern Virginia only during the breeding season (Palmer 1962). Hence, there is evidence that Daugherty's Cave was occupied during the warm seasons. However, the subsistence record of Daugherty's Cave is dominated by nutshell and deer bone. Nuts fall in late fall and early winter (Fowells 1965), and fall and winter seem to have been the principal seasons of Eastern Woodlands deer

hunting (Swanton 1946; Waselkov 1978). Although nuts could have been stored and deer hunted during any season, the relative abundance of mast and deer bone at the site probably indicates that the site was occupied primarily in the fall and winter. If this is the case, then a comparison of the archaeological subsistence remains to the models' yearly diets will be misleading. Nonetheless, this is the comparison I will make.

My reasons for not performing a test restricted to the fall-winter seasons are several. First, there are some warm season remains at the site. Rather than arbitrarily removing them from consideration, it seems preferable to include them in the tests to explore how well the model can account for them. Secondly, although there is a strong qualitative agreement between the abundance of deer and mast at the site and in the models' predicted diets, the archaeological diet is actually broader than the predicted diets. This pattern is the opposite of what a seasonally restricted occupation should produce. Thus, removing the warm season resources from consideration would worsen, not improve, the fit. Finally, if I remove the warm season resources from consideration, the number of resources remaining will be too small to allow statistical tests of correlation between the archaeological and modeled diets. I hesitate to decrease so dramatically the rigor of the tests.

Statistical Tests

This chapter will rely on Spearman's r_s test of rank-order correlation (Blalock 1972:416-418). Although the outcomes of the linear programming models are very precise, they do not allow for the use of statistical tests more sensitive than rank-order comparisons. For one reason the model results represent exactly one year's subsistence for exactly 25 or 250 people, while the subsistence remains from the site derive from both an unknown span of time and from an unknown number of people. Hence the absolute amounts of the resources cannot be expected to match. Furthermore, it has

been argued forcibly that quantification of archaeological faunas produces at best ordinal level measures (Grayson 1984). The case against plant remains producing interval level data seems at least as strong.

The statistical test of the fit between the predicted and observed animal foods is straightforward, but that of the plant foods is more problematic. As mentioned above, it is necessary to treat nut remains separately from seed remains. Unfortunately the resulting sample sizes become quite small as there are only four nuts included in the models. There are up to 12 types of seeds in the models, but no more than six were recovered from any component of the site. Hence construction of rank orders produces numerous ties for last place. This tends to diminish the power of the tests for correlation (Blalock 1972). Finally in the case of the Late Archaic component of the site, with the possible exception of squash rind, no plant food remain other than nutshell was recovered. Therefore this component is omitted from the tests of seed data.

COMPARISON OF PREDICTED AND OBSERVED ANIMAL FOODS

In order to perform the comparisons with the archaeological record, it was necessary to combine the outcomes of the seasonal models into a single annual result. The following procedures were used to calculate the rank orders of the animal foods predicted by the models to be exploited. Animals included within the optimal diet were ranked by the total amount of meat they were projected to contribute to the diet over the course of the year. These data are presented in table 5.1. Animals not included within the optimal diet were ranked by their average acceptable percentage of cost for the four seasons. These data and the rank orders of all resources in the models are presented in tables 5.2 - 5.7.

Table 5.1: Amounts of Game (kg) Predicted by the Models to be Consumed Annually (page 1).

	Diet Pattern				
	Energy	B-vit	Vit-A	Cal	Vit-C
Small Population Models					
Foraging Strategy					
Beaver	90	371	372	322	416
Deer		776	776	401	1931
Fish					2374
Mussels		572	568	906	548
Early Agricultural Strategy					
Beaver	90	364	364	189	162
Deer		666	666	368	368
Fish					
Mussels		50		317	274
Late Agricultural Strategy					
Beaver		363	341	208	97
Deer		307	407	376	340
Fish					
Mussels		902	699	484	703

Table 5.1: Amounts of Game (kg) Predicted by the Models to be Consumed Annually
(page 2).

	Diet Pattern				
	Energy	B-vit	Vit-A	Cal	Vit-C
Large Population Models					
Foraging Strategy					
Beaver	216	393	410	410	410
Deer		6116	8570	7819	13899
Fish					51923
Groundhog			797		509
Mussels		11415	6799	8783	5398
Early Agricultural Strategy					
Beaver	306	393	410	410	410
Deer	6818	6299	8352	6504	6075
Fish					
Mussels	11093	10501	5700	8756	8342
Late Agricultural Strategy					
Beaver		393	394	319	194
Deer		3490	5093	5477	5043
Fish					
Mussels		9976	6592	7450	7006

Table 5.2: Acceptable Percentage of Cost and Rank Order of Game --
Small Population Foraging Strategy Models (page 1).

Energy Pattern			B-Vitamin Pattern			Vitamin A Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Beaver	100	1	Deer	100	1	Deer	100	1
Mussels	66	2	Mussels	100	2	Mussels	100	2
Fish	55	3	Beaver	100	3	Beaver	100	3
Deer	46	4	Fish	64	4	Fish	67	4
Groundhog	32	5	Groundhog	58	5	Groundhog	64	5
Turkey	25	6	Opossum	39	6	Turkey	40	6
Muskrat	17	7	Turkey	38	7	Opossum	38	7
Opossum	17	8	Muskrat	35	8	Muskrat	35	8
Otter	12	9	Bear	34	9	Otter	30	9
Raccoon	11	10	Raccoon	33	10	Bear	30	10
Bear	11	11	Otter	31	11	Raccoon	28	11
Rabbit	10	12	Rabbit	19	12	Rabbit	22	12
Turtle	6	13	Turtle	17	13	Turtle	15	13
Skunk	5	14	Squirrel	10	14	Squirrel	10	14
Squirrel	4	15	Skunk	10	15	Skunk	10	15
Duck	2	16	Duck	4	16	Duck	4	16
Snails	2	17	Grouse	3	17	Snails	3	17
Grouse	2	18	Snails	2	18	Grouse	3	18

**Table 5.2: Acceptable Percentage of Cost and Rank Order of Game --
Small Population Foraging Strategy Models (page 2).**

Calcium Pattern			Vitamin C Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Mussels	100	1	Fish	100	1
Deer	100	2	Deer	100	2
Beaver	100	3	Mussels	100	3
Fish	83	4	Beaver	100	4
Groundhog	64	5	Groundhog	76	5
Turkey	36	6	Turkey	43	6
Opossum	34	7	Opossum	40	7
Muskrat	29	8	Bear	35	8
Otter	26	9	Muskrat	35	9
Bear	25	10	Otter	34	10
Rabbit	22	11	Rabbit	29	11
Raccoon	20	12	Raccoon	24	12
Turtle	13	13	Turtle	16	13
Squirrel	10	14	Skunk	11	14
Skunk	9	15	Squirrel	11	15
Snails	6	16	Snails	5	16
Duck	3	17	Duck	4	17
Grouse	2	18	Grouse	3	18

**Table 5.3: Acceptable Percentage of Cost and Rank Order of Game --
Small Population Early Agricultural Strategy Models (page 1).**

Energy Pattern			B-Vitamin Pattern			Vitamin A Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Beaver	100	1	Deer	100	1	Deer	100	1
Mussels	61	2	Beaver	100	2	Beaver	100	2
Fish	50	3	Mussels	100	3	Mussels	95	3
Deer	43	4	Fish	55	4	Fish	57	4
Groundhog	34	5	Groundhog	42	5	Groundhog	48	5
Turkey	24	6	Turkey	32	6	Opossum	34	6
Muskrat	16	7	Opossum	30	7	Turkey	32	7
Opossum	15	8	Bear	28	8	Bear	28	8
Otter	11	9	Muskrat	27	9	Muskrat	27	9
Bear	11	10	Raccoon	26	10	Raccoon	26	10
Raccoon	10	11	Otter	23	11	Otter	26	11
Rabbit	9	12	Rabbit	14	12	Rabbit	17	12
Turtle	6	13	Turtle	13	13	Turtle	11	13
Skunk	5	14	Skunk	8	14	Squirrel	9	14
Squirrel	4	15	Squirrel	8	15	Skunk	9	15
Duck	2	16	Duck	3	16	Duck	3	16
Snails	2	17	Snails	3	17	Snails	3	17
Grouse	2	18	Grouse	2	18	Grouse	2	18

**Table 5.3: Acceptable Percentage of Cost and Rank Order of Game --
Small Population Early Agricultural Strategy Models (page 2).**

Calcium Pattern			Vitamin C Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Deer	100	1	Deer	100	1
Mussels	100	2	Mussels	100	2
Beaver	100	3	Beaver	100	3
Fish	77	4	Fish	78	4
Groundhog	58	5	Groundhog	58	5
Opossum	31	6	Turkey	32	6
Turkey	31	7	Opossum	31	7
Muskrat	24	8	Muskrat	24	8
Bear	24	9	Bear	24	9
Otter	24	10	Otter	24	10
Rabbit	19	11	Rabbit	19	11
Raccoon	19	12	Raccoon	19	12
Turtle	11	13	Turtle	11	13
Squirrel	9	14	Squirrel	9	14
Skunk	8	15	Skunk	8	15
Snails	6	16	Snails	6	16
Duck	3	17	Duck	3	17
Grouse	2	18	Grouse	2	18

**Table 5.4: Acceptable Percentage of Cost and Rank Order of Game --
Small Population Late Agricultural Strategy Models (page 1).**

Energy Pattern			B-Vitamin Pattern			Vitamin A Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Beaver	76	1	Mussels	100	1	Mussels	100	1
Mussels	54	2	Beaver	100	2	Deer	100	2
Fish	44	3	Deer	100	3	Beaver	100	3
Deer	37	4	Fish	51	4	Fish	51	4
Groundhog	30	5	Groundhog	43	5	Groundhog	50	5
Turkey	21	6	Opossum	32	6	Opossum	35	6
Muskrat	14	7	Bear	32	7	Bear	32	7
Opossum	14	8	Turkey	32	8	Turkey	31	8
Otter	10	9	Raccoon	30	9	Raccoon	29	9
Raccoon	9	10	Muskrat	28	10	Muskrat	28	10
Rabbit	9	11	Otter	26	11	Otter	27	11
Bear	8	12	Rabbit	15	12	Rabbit	17	12
Turtle	5	13	Turtle	14	13	Turtle	12	13
Skunk	4	14	Squirrel	8	14	Squirrel	9	14
Squirrel	3	15	Skunk	8	15	Skunk	9	15
Duck	2	16	Duck	3	16	Duck	3	16
Grouse	2	17	Grouse	2	17	Snails	2	17
Snails	1	18	Snails	2	18	Grouse	2	18

**Table 5.4: Acceptable Percentage of Cost and Rank Order of Game --
 Small Population Late Agricultural Strategy Models (page 2).**

Calcium Pattern			Vitamin C Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Mussels	100	1	Mussels	100	1
Deer	100	2	Deer	100	2
Beaver	100	3	Beaver	100	3
Fish	77	4	Fsih	77	4
Groundhog	53	5	Groundhog	51	5
Opossum	28	6	Turkey	27	6
Turkey	26	7	Opossum	26	7
Bear	25	8	Bear	25	8
Otter	21	9	Muskrat	20	9
Muskrat	20	10	Otter	20	10
Raccoon	18	11	Raccoom	18	11
Rabbot	17	12	Rabbit	16	12
Turtle	13	13	Turtle	14	13
Squirrel	9	14	Squirrel	8	14
Snails	7	15	Snails	7	15
Skunk	7	16	Skunk	7	16
Grouse	4	17	Grouse	4	17
Duck	2	18	Duck	2	18

**Table 5.5: Acceptable Percentage of Cost and Rank Order of Game --
Large Population Foraging Strategy Models (page 1).**

Energy Pattern			B-Vitamin Pattern			Vitamin A Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Beaver	100	1	Mussels	100	1	Deer	100	1
Mussels	95	2	Deer	100	2	Mussels	100	2
Fish	78	3	Beaver	100	3	Groundhog	100	3
Deer	66	4	Fish	71	4	Beaver	100	4
Groundhog	47	5	Groundhog	68	5	Fish	74	5
Turkey	36	6	Turkey	46	6	Opossum	49	6
Opossum	24	7	Opossum	44	7	Turkey	48	7
Muskrat	24	8	Muskrat	43	8	Muskrat	45	8
Otter	17	9	Bear	37	9	Otter	40	9
Raccoon	16	10	Otter	36	10	Bear	39	10
Bear	15	11	Raccoon	36	11	Raccoon	35	11
Rabbit	15	12	Rabbit	24	12	Rabbit	29	12
Turtle	8	13	Turtle	21	13	Turtle	20	13
Skunk	8	14	Skunk	12	14	Squirrel	13	14
Squirrel	6	15	Squirrel	11	15	Skunk	13	15
Duck	3	16	Duck	4	16	Duck	5	16
Grouse	3	17	Grouse	3	17	Grouse	4	17
Snails	2	18	Snails	2	18	Snails	3	18

**Table 5.5: Acceptable Percentage of Cost and Rank Order of Game --
Large Population Foraging Strategy Models (page 2).**

Calcium Pattern			Vitamin C Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Mussels	100	1	Fish	100	1
Deer	100	2	Deer	100	2
Beaver	100	3	Mussels	100	3
Groundhog	87	4	Groundhog	100	4
Fish	77	5	Beaver	100	5
Turkey	50	6	Turkey	52	6
Opossum	46	7	Opossum	48	7
Muskrat	44	8	Muskrat	44	8
Otter	38	9	Otter	41	9
Rabbit	34	10	Bear	40	10
Bear	33	11	Rabbit	35	11
Raccoon	26	12	Raccoon	28	12
Turtle	20	13	Turtle	20	13
Squirrel	13	14	Skunk	13	14
Skunk	12	15	Squirrel	13	15
Snails	6	16	Snails	5	16
Duck	5	17	Duck	5	17
Grouse	4	18	Grouse	4	18

**Table 5.6: Acceptable Percentage of Cost and Rank Order of Game --
Large Population Early Agricultural Strategy Models (page 1).**

Energy Pattern			B-Vitamin Pattern			Vitamin A Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Mussels	100	1	Mussels	100	1	Deer	100	1
Deer	100	2	Deer	100	2	Mussels	100	2
Beaver	100	3	Beaver	100	3	Beaver	100	3
Fish	89	4	Fish	73	4	Fish	76	4
Groundhog	51	5	Groundhog	66	5	Groundhog	73	5
Turkey	42	6	Opossum	48	6	Opossum	50	6
Muskrat	29	7	Turkey	44	7	Turkey	45	7
Opossum	28	8	Muskrat	43	8	Muskrat	44	8
Otter	20	9	Bear	41	9	Bear	42	9
Raccoon	18	10	Raccoon	40	10	Otter	40	10
Bear	17	11	Otter	39	11	Raccoon	40	11
Rabbit	17	12	Rabbit	23	12	Rabbit	25	12
Turtle	10	13	Turtle	21	13	Turtle	20	13
Skunk	8	14	Skunk	12	14	Squirrel	13	14
Squirrel	7	15	Squirrel	12	15	Skunk	12	15
Duck	4	16	Duck	4	16	Duck	5	16
Grouse	3	17	Grouse	3	17	Grouse	3	17
Snails	3	18	Snails	2	18	Snails	2	18

**Table 5.6: Acceptable Percentage of Cost and Rank Order of Game --
 Large Population Early Agricultural Strategy Models (page 2).**

Calcium Pattern			Vitamin C Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Mussels	100	1	Mussels	100	1
Deer	100	2	Deer	100	2
Beaver	100	3	Beaver	100	3
Fish	73	4	Fish	74	4
Groundhog	71	5	Groundhog	66	5
Turkey	44	6	Turkey	44	6
Opossum	41	7	Opossum	39	7
Muskrat	38	8	Muskrat	37	8
Bear	33	9	Otter	32	9
Otter	33	10	Bear	31	10
Raccoon	28	11	Raccoon	27	11
Rabbit	26	12	Rabbit	24	12
Turtle	23	13	Turtle	23	13
Squirrel	12	14	Squirrel	11	14
Skunk	11	15	Skunk	11	15
Snails	7	16	Snails	7	16
Duck	4	17	Duck	4	17
Grouse	3	18	Grouse	3	18

**Table 5.7: Acceptable Percentage of Cost and Rank Order of Game --
Large Population Late Agricultural Strategy Models (page 1).**

Energy Pattern			B-Vitamin Pattern			Vitamin A Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Beaver	76	1	Mussels	100	1	Mussels	100	1
Mussels	54	2	Deer	100	2	Deer	100	2
Fish	44	3	Beaver	100	3	Beaver	100	3
Deer	37	4	Groundhog	58	4	Groundhog	59	4
Groundhog	30	5	Fish	55	5	Fish	55	5
Turkey	21	6	Opossum	46	6	Opossum	46	6
Muskrat	14	7	Bear	43	7	Bear	43	7
Opossum	14	8	Raccoon	41	8	Raccoon	41	8
Otter	10	9	Muskrat	39	9	Muskrat	39	9
Raccoon	9	10	Turkey	37	10	Turkey	38	10
Rabbit	9	11	Otter	37	11	Otter	37	11
Bear	8	12	Turtle	21	12	Turtle	21	12
Turtle	5	13	Rabbit	19	13	Rabbit	20	13
Skunk	4	14	Squirrel	12	14	Squirrel	12	14
Squirrel	3	15	Skunk	11	15	Skunk	11	15
Duck	2	16	Duck	4	16	Duck	4	16
Grouse	2	17	Grouse	3	17	Grouse	3	17
Snails	1	18	Snails	2	18	Snails	2	18

Table 5.7: Acceptable Percentage of Cost and Rank Order of Game -- Large Population Late Agricultural Strategy Models (page 2).

Calcium Pattern			Vitamin C Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Mussels	100	1	Mussels	100	1
Deer	100	2	Deer	100	2
Beaver	100	3	Beaver	100	3
Groundhog	57	4	Fish	53	4
Fish	53	5	Groundhog	53	5
Opossum	32	6	Turkey	28	6
Turkey	29	7	Opossum	27	7
Bear	28	8	Bear	27	8
Otter	24	9	Muskrat	21	9
Muskrat	22	10	Otter	21	10
Raccoon	20	11	Raccoon	19	11
Rabbit	19	12	Rabbit	16	12
Turtle	16	13	Turtle	16	13
Squirrel	10	14	Squirrel	8	14
Snails	8	15	Snails	8	15
Skunk	8	16	Skunk	7	16
Duck	3	17	Duck	2	17
Grouse	2	18	Grouse	2	18

In calculating the relative contribution of each animal taxon to the diet as observed from the Daugherty's Cave faunal remains, the following procedure was used. First, all the bones of a taxon from a component were weighed, then this weight was divided by the number of bones to produce an average bone weight for that taxon. The allometric formulae (Reitz and Quitmyer 1988:97) were then used to calculate the meat represented by the average bone of the taxon. This weight was then multiplied by the number of bones contributing to the bone weight to get the total amount of meat contributed by that taxon in that component. Unfortunately, for each component the majority of the meat weight was contributed by bones that due to their fragmentary nature could be identified only to class, especially unidentified mammal. Omitting this data created a bias in that mussels and especially snails can be identified beyond the class level much more readily than can mammals: hence their contribution to the diet was artificially inflated. To rectify this problem, for each component, the meat weight ascribed to a class was allocated to the species of that class identified in that component based on their relative contribution to the diet. For example, a component having 100 kg of unidentified mammal, 60 kg of deer and 20 kg of beaver would be recalculated as having 135 kg deer and 45 kg beaver, the 100 kg of unidentified mammal being split between the two identified taxa at a ratio of 3:1.

For the animals included in the models, the meat weights they contributed in each of the four undisturbed components is given in table 5.8, their percentage contribution in table 5.9 and their rank orders in table 5.10.

The results of the Spearman's r_s rank order correlation between the predicted and the observed animal foods are presented in tables 5.11 - 5.16. For a sample size of 18 the critical value of the 0.05 significance level is 0.399. The tables show that the only significant correlations between predicted and observed meat weights are those between component 4 and the large population, late agricultural strategy models with B-vitamins and vitamin A constraints (Table 5.16).

Table 5.8: Calculated Meat Weights by Component

Animal	Component 2	Component 3	Component 4	Component 5
Bear	3.9	1.6	0.0	0.2
Beaver	0.2	0.6	0.4	0.5
Deer	15.1	36.3	10.5	0.3
Duck	0.2	0.5	0.8	0.1
Fish	0.2	0.8	0.1	0.1
Groundhog	0.3	1.9	0.2	2.4
Grouse	0.2	0.0	0.0	0.2
Muskrat	1.4	0.2	0.0	0.0
Mussels	0.5	0.1	0.4	0.0
Opossum	0.0	0.1	0.0	0.2
Otter	0.0	0.1	0.2	0.2
Rabbit	0.5	0.7	0.0	0.2
Raccoon	1.4	2.0	1.5	0.9
Skunk	0.0	0.2	0.0	0.2
Snails	3.9	0.7	0.0	0.1
Squirrel	0.7	0.6	0.3	23.9
Turkey	1.2	1.7	0.0	0.1
Turtle	0.5	0.7	0.1	0.6
Total	30.0	48.8	14.5	30.0

Table 5.9: Percentage Contribution of Meat
by Animal and Component.

Animal	Component 2	Component 3	Component 4	Component 5
Bear	12.9	3.3	0.0	0.8
Beaver	0.6	1.2	2.5	1.6
Deer	50.1	74.4	72.4	1.1
Duck	0.6	1.1	5.5	0.2
Fish	0.6	1.7	0.8	0.2
Groundhog	1.1	3.9	1.2	8.1
Grouse	0.5	0.1	0.0	0.6
Muskrat	4.7	0.4	0.0	0.0
Mussels	1.7	0.1	2.8	0.0
Opossum	0.0	0.2	0.0	0.6
Otter	0.0	0.1	1.3	0.8
Rabbit	1.7	1.5	0.0	0.5
Raccoon	4.8	4.1	10.7	2.8
Skunk	0.0	0.3	0.0	0.5
Snails	12.9	1.5	0.1	0.3
Squirrel	2.3	1.2	2.0	79.6
Turkey	3.8	3.4	0.0	0.2
Turtle	1.5	1.3	0.7	2.1
Total	100.0	100.0	100.0	100.0

Table 5.10: Rank Order of Animals by Component.

Animal	Component 2	Component 3	Component 4	Component 5
Bear	2	5	15	4
Beaver	13	11	5	14
Deer	1	1	1	1
Duck	12	12	3	13
Fish	14	6	9	11
Groundhog	11	3	8	3
Grouse	15	18	15	12
Muskrat	5	13	15	8
Mussels	9	16	4	10
Opossum	17	15	15	18
Otter	17	17	7	18
Rabbit	8	7	15	9
Raccoon	4	2	2	2
Skunk	17	14	15	15
Snails	3	8	11	16
Squirrel	7	10	6	6
Turkey	6	4	15	5
Turtle	10	9	10	7

Table 5.11: Matrix of Spearman's Rank Order Coefficients Between Predicted and Observed Meat Weights --Small Population Foraging Strategy Models and Site Components.¹

	Energy Pattern	B-vitamin Pattern	Vitamin A Pattern	Calcium Pattern	Vitamin-C Pattern	Comp. 2	Comp. 3	Comp. 4	Comp. 5
Energy Pattern	1.000								
B-vitamin Pattern	0.967	1.000							
Vitamin A Pattern	0.979	0.990	1.000						
Calcium Pattern	0.977	0.979	0.994	1.000					
Vitamin C Pattern	0.959	0.969	0.975	0.977	1.000				
Component 2	0.075	0.158	0.148	0.144	0.131	1.000			
Component 3	0.197	0.286	0.263	0.220	0.240	0.665	1.000		
Component 4	0.343	0.364	0.369	0.311	0.246	0.137	0.445	1.000	
Component 5	0.215	0.326	0.284	0.245	0.264	0.698	0.820	0.292	1.000

¹ Correlations between models and components significant at 0.05 level are underlined.

Table 5.12: Matrix of Spearman's Rank Order Coefficients Between Predicted and Observed Meat Weights -- Large Population Foraging Strategy Models and Site Components.¹

	Energy Pattern	B-vitamin Pattern	Vitamin A Pattern	Calcium Pattern	Vitamin-C Pattern	Comp. 2	Comp. 3	Comp. 4	Comp. 5
Energy Pattern	1.000								
B-vitamin Pattern	<u>0.981</u>	1.000							
Vitamin A Pattern	<u>0.963</u>	<u>0.986</u>	1.000						
Calcium Pattern	<u>0.971</u>	<u>0.981</u>	<u>0.977</u>	1.000					
Vitamin C Pattern	<u>0.959</u>	<u>0.971</u>	<u>0.967</u>	<u>0.977</u>	1.000				
Component 2	<u>0.051</u>	<u>0.119</u>	<u>0.109</u>	<u>0.129</u>	<u>0.096</u>	1.000			
Component 3	<u>0.185</u>	<u>0.245</u>	<u>0.263</u>	<u>0.214</u>	<u>0.207</u>	<u>0.665</u>	1.000		
Component 4	<u>0.343</u>	<u>0.328</u>	<u>0.365</u>	<u>0.311</u>	<u>0.256</u>	<u>0.137</u>	<u>0.445</u>	1.000	
Component 5	<u>0.223</u>	<u>0.283</u>	<u>0.306</u>	<u>0.234</u>	<u>0.251</u>	<u>0.698</u>	<u>0.820</u>	<u>0.292</u>	1.000

¹ Correlations between models and components significant at 0.05 level are underlined.

Table 5.13: Matrix of Spearman's Rank Order Coefficients Between Predicted and Observed Meat Weights -- Small Population Early Agricultural Strategy Models and Site Components.¹

	Energy Pattern	B-vitamin Pattern	Vitamin A Pattern	Calcium Pattern	Vitamin-C Pattern	Comp. 2	Comp. 3	Comp. 4	Comp. 5
Energy Pattern	1.000								
B-vitamin Pattern	0.973	1.000							
Vitamin A Pattern	0.967	0.996	1.000						
Calcium Pattern	0.971	0.983	0.988	1.000					
Vitamin C Pattern	0.975	0.986	0.986	0.998	1.000				
Component 2	0.080	0.183	0.181	0.166	0.189	1.000			
Component 3	0.193	0.331	0.321	0.245	0.267	0.665	1.000		
Component 4	0.316	0.343	0.362	0.301	0.301	0.137	0.445	1.000	
Component 5	0.211	0.325	0.318	0.265	0.291	0.698	0.820	0.292	1.000

¹ Correlations between models and components significant at 0.05 level are underlined.

Table 5.14: Matrix of Spearman's Rank Order Coefficients Between Predicted and Observed Meat Weights -- Large Population Early Agricultural Strategy Models and Site Components.¹

	Energy Pattern	B-vitamin Pattern	Vitamin A Pattern	Calcium Pattern	Vitamin-C Pattern	Comp. 2	Comp. 3	Comp. 4	Comp. 5
Energy Pattern	<u>1.000</u>								
B-vitamin Pattern	<u>0.975</u>	<u>1.000</u>							
Vitamin A Pattern	<u>0.983</u>	<u>0.986</u>	<u>1.000</u>						
Calcium Pattern	<u>0.909</u>	<u>0.907</u>	<u>0.915</u>	<u>1.000</u>					
Vitamin C Pattern	<u>0.990</u>	<u>0.975</u>	<u>0.986</u>	<u>0.922</u>	<u>1.000</u>				
Component 2	<u>0.109</u>	<u>0.107</u>	<u>0.131</u>	<u>0.222</u>	<u>0.133</u>	<u>1.000</u>			
Component 3	<u>0.226</u>	<u>0.232</u>	<u>0.255</u>	<u>0.156</u>	<u>0.218</u>	<u>0.665</u>	<u>1.000</u>		
Component 4	<u>0.371</u>	<u>0.326</u>	<u>0.353</u>	<u>0.262</u>	<u>0.320</u>	<u>0.137</u>	<u>0.445</u>	<u>1.000</u>	
Component 5	<u>0.279</u>	<u>0.292</u>	<u>0.294</u>	<u>0.192</u>	<u>0.241</u>	<u>0.698</u>	<u>0.820</u>	<u>0.292</u>	<u>1.000</u>

¹ Correlations between models and components significant at 0.05 level are underlined.

Table 5.15: Matrix of Spearman's Rank Order Coefficients Between Predicted and Observed Meat Weights -- Small Population Late Agricultural Strategy Models and Site Components.¹

	Energy Pattern	B-vitamin Pattern	Vitamin A Pattern	Calcium Pattern	Vitamin-C Pattern	Comp. 2	Comp. 3	Comp. 4	Comp. 5
Energy Pattern	1.000								
B-vitamin Pattern	0.944	1.000							
Vitamin A Pattern	0.936	0.996	1.000						
Calcium Pattern	0.938	0.973	0.979	1.000					
Vitamin C Pattern	0.946	0.971	0.977	0.996	1.000				
Component 2	0.036	0.138	0.185	0.169	0.216	1.000			
Component 3	0.179	0.294	0.325	0.230	0.259	0.665	1.000		
Component 4	0.343	0.376	0.384	0.313	0.297	0.137	0.445	1.000	
Component 5	0.213	0.304	0.322	0.250	0.295	0.698	0.820	0.292	1.000

¹ Correlations between models and components significant at 0.05 level are underlined.

Table 5.16: Matrix of Spearman's Rank Order Coefficients Between Predicted and Observed Meat Weights -- Large Population Late Agricultural Strategy Models and Site Components.¹

	Energy Pattern	B-vitamin Pattern	Vitamin A Pattern	Calcium Pattern	Vitamin-C Pattern	Comp. 2	Comp. 3	Comp. 4	Comp. 5
Energy Pattern	1.000								
B-vitamin Pattern	0.920	1.000							
Vitamin A Pattern	0.920	1.000	1.000						
Calcium Pattern	0.940	0.959	0.959	1.000					
Vitamin C Pattern	0.948	0.955	0.955	0.996	1.000				
Component 2	0.036	0.171	0.171	0.173	0.220	1.000			
Component 3	0.179	0.319	0.319	0.255	0.284	0.665	1.000		
Component 4	0.343	<u>0.423</u>	<u>0.423</u>	0.338	0.322	0.137	0.445	1.000	
Component 5	0.213	0.351	0.351	0.248	0.293	0.698	0.820	0.292	1.000

¹ Correlations between models and components significant at 0.05 level are underlined.

Unfortunately Spearman's rank order test is less valid when there are a large number of ties in the rank orders, and component 4 has a particularly large number of ties. Seven of the 18 animals tie for last place, as they were all absent from the component. In particular, bear and turkey, two species generally discounted by the models but well represented in the other components are absent from component 4. This contributes to the higher correlation of component 4.

Clearly it can be concluded that the models do a poor job of accounting for animal procurement practices at Daugherty's Cave. Contrarily it can be seen that the correlation coefficients among the various models all exceed this value and most are very high indeed. This indicates that adding additional nutrient constraints and varying the population sizes of the models made little difference in the final average annual rank orders of the animals.

Problems with the Animal Food Models

An important problem with the models is the overemphasis given to aquatic resources particularly beaver, fish and mussels. In truth Daugherty's Cave does not seem well located to exploit aquatic resources, especially when compared to the floodplain of the Clinch River located about two miles away. Although nearby Big Cedar Creek would have made some aquatic resources available to the occupants of Daugherty's Cave, it may well have been too small to support populations of these animals large enough to allow a sustainable yield of them. Thus even if the cave inhabitants desired to exploit them, they may have been available only sporadically. In addition the cost estimates of these resources are particularly suspect. Mussel exploitation is characterized by great variability in collection rates (Parmalee, cited in Reidhead 1976:129), and the cost estimation of fish was nearly a frank guess. The low cost assigned to beaver reflects its apparent susceptibility to trapping (Mason et al. 1983). Trapping may have been a less attractive option before metal traps were

available, since aboriginal traps presumably would require more time to manufacture and maintain.

Another discrepancy between the models and the animals exploited at Daugherty's Cave is that the relatively important game species, raccoon, bear and turkey, are assigned quite low values by the models.

This is likely a result of an inadequate estimate of cost. The cost of acquiring raccoon, in particular, was based on scant data. The sensitivity analyses of cost provided by linear programming indicated that raccoon was most nearly an optimal resource in the spring large population early agricultural diet. In this model raccoon would have entered the diet if its cost were reduced to 27 hrs from 59 hrs. Since a reduction of 56% in the cost measure is necessary to move raccoon into the optimal diet, perhaps some confidence in the estimation can be gained. Still, the likelihood of significant overestimation is probably high.

I originally thought that the "nonoptimality" of bear might be traced to an overly simple measure of search cost. In the models search cost was calculated as the reciprocal of the animals average density. This is a common practice in optimal foraging modeling (Stephens and Krebs 1986). However, since bear are at present rare in the eastern forest, the time estimated to locate one, 68 hours, is quite high. The sensitivity analysis of cost indicated that (excluding the suspect vitamin C constraint models) bears are most nearly an optimal resource in the winter large population late agricultural model with B-vitamin constraints. In this model, bears would enter the diet if their cost were reduced to 122 hrs from 242 hrs. A cost reduction of this magnitude would result if the population density of bear were raised to $1/0.14 \text{ km}^2$ from the measured $1/3.4 \text{ km}^2$ (Pelton and Marcum 1975). This is a 2400% greater abundance of bears. This seems unrealistic since the modern population density was taken from good habitat in a remote part of a natural park (Pelton and Marcum 1975).

Turkeys most nearly enter the optimal diet in the summer large population model with all nutrient constraints. In this model turkey would enter the optimal diet if its cost were reduced to 9.2 hrs from 14.4 hrs. That the cost of turkey acquisition may have overestimated by 37% seems quite possible. However, the cost estimation for turkey did use generous estimations of population density ($24/\text{km}^2$) and hunting success rate (50%).

It is possible that the bear, as well as turkey, do not enter the optimal diets because the estimation of their costs did not adequately take in to account behavioral characteristics which seem to have rendered them especially vulnerable to hunting. Bears center their activities around particular den sites and return to the sites on a frequent basis (Pelton 1984). Once a favorable den site was located by a hunter, it could be routinely checked for signs of bear. Similarly if bear sign were observed by hunters, they seem to have been able to track the bear back to its den where it would be vulnerable once smoked or panicked from hiding (Swanton 1946). Turkeys are reported to have congregated in large flocks in the fall to feed on mast, which would have made them easier to locate. Furthermore it is reported that Native Americans were able to flush the turkeys into trees where they were apt to remain perched until shot at close range (Swanton 1946).

COMPARISON OF PREDICTED AND OBSERVED PLANT FOODS

Table 5.17 presents the amounts of plant foods predicted by the models to have been eaten. Tables 5.18 -5.23 present the average acceptable percentage of cost and the rank orders of the plant foods as generated by the optimal diet models. Table 5.24 presents an abbreviated version of the results of the analysis of the food plant remains recovered from the Daugherty's Cave excavations.

Table 5.17: Amounts of Plants (kg) Predicted by the Models to be Consumed Annually (page 1).

	Diet Pattern				
	Energy	B-vit	Vit-A	Cal	Vit-C
Small Population Models					
Foraging Strategy					
Blackberry					105
Chenopod		19	19	1490	1490
Grape					572
Greens			84	292	301
Hickory	2887	2548	2548	1734	1103
Early Agricultural Strategy					
Blackberry					
Chenopod		19	19	1322	1322
Grape					129
Greens			292	570	570
Hickory	2157	1903	1903	1168	1158
Maygrass	1331	1322	1315	1315	1315
Squash					542
Sumpweed				55	55
Late Agricultural Strategy					
Blackberry					
Chenopod					
Dry corn	5660	5092	5102	4700	4737
Grape					
Greens			80	747	880
Hickory					
Maygrass					
Squash					599
Sumpweed				313	313

Table 5.17: Amounts of Plants (kg) Predicted by the Models to be Consumed Annually (page 2).

	Diet Pattern				
	Energy	B-vit	Vit-A	Cal	Vit-C
Large Population Models					
Foraging Strategy					
Blackberry					1144
Chenopod	7218	4388	2958	14836	14836
Grape					572
Greens			2366	3071	3009
Hickory	24800	26069	24426	17509	11095
Early Agricultural Strategy					
Blackberry					8157
Chenopod	1852	2126	234	8157	8157
Grape					129
Greens			7252	9207	9279
Hickory	24800	24800	24800	20689	20681
Maygrass	970	636	2615	427	451
Squash					5882
Sumpweed				807	807
Late Agricultural Strategy					
Blackberry					
Chenopod					
Dry corn	56620	52338	52304	47319	47425
Grape					
Greens			8779	8279	8800
Hickory					
Maygrass					
Squash					5985
Sumpweed				3130	3130

**Table 5.18: Acceptable Percentage of Cost and Rank Order of Plants --
Small Population Foraging Strategy Models (page 1).**

Energy Pattern			B-Vitamin Pattern			Vitamin A Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Hickory	100	1	Hickory	100	1	Hickory	100	1
Chenopod	69	2	Chenopod	100	2	Chenopod	100	2
Grape	56	3	Grape	63	3	Grape	61	3
Blackberry	47	4	Acorn	47	4	Blackberry	58	4
Acorn	44	5	Blackberry	32	5	Acorn	47	5
Walnut	28	6	Walnut	28	6	Walnut	28	6
Maypops	14	7	Butternut	11	7	Maypops	13	7
Butternut	11	8	Maypops	4	8	Butternut	11	8

**Table 5.18: Acceptable Percentage of Cost and Rank Order of Plants --
Small Population Foraging Strategy Models (page 2).**

Calcium Pattern			Vitamin C Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Hickory	100	1	Chenopod	100	1
Chenopod	100	2	Hickory	100	2
Grape	66	3	Grape	100	3
Blackberry	53	4	Blackberry	100	4
Acorn	48	5	Acorn	39	5
Walnut	28	6	Maypops	21	6
Butternut	11	7	Walnut	21	7
Maypops	9	8	Butternut	8	8

**Table 5.19: Acceptable Percentage of Cost and Rank Order of Plants --
Small Population Early Agricultural Strategy Models (page 1).**

Energy Pattern			B-Vitamin Pattern			Vitamin A Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Hickory	100	1	Hickory	100	1	Hickory	100	1
Maygrass	100	2	Maygrass	100	2	Maygrass	100	2
Chenopod	64	3	Chenopod	100	3	Chenopod	100	3
Sunflower	52	4	Sumpweed	65	4	Sumpweed	63	4
Grape	52	5	Grape	55	5	Grape	56	5
Sumpweed	49	6	Sunflower	53	6	Sunflower	54	6
Acorn	41	7	Acorn	41	7	Acorn	42	7
Blackberry	33	8	Blackberry	36	8	Blackberry	38	8
Walnut	26	9	Walnut	26	9	Walnut	26	9
Butternut	10	10	Squash	25	10	Squash	24	10
Squash	8	11	Butternut	10	11	Butternut	10	11
Maypops	5	12	Maypops	5	12	Maypops	5	11

Table 5.19: Acceptable Percentage of Cost and Rank Order of Plants --
 Small Population Early Agricultural Strategy Models (page 2).

Calcium Pattern			Vitamin C Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Chenopod	100	1	Chenopod	100	1
Maygrass	100	2	Maygrass	100	2
Hickory	100	3	Squash	100	3
Sumpweed	100	4	Hickory	100	4
Grape	62	5	Grape	100	5
Sunflower	60	6	Sumpweed	100	6
Acorn	44	7	Sunflower	60	7
Blackberry	38	8	Acorn	44	8
Walnut	26	9	Blackberry	38	9
Squash	25	10	Walnut	26	10
Butternut	10	11	Butternut	10	11
Maypops	5	12	Maypops	5	12

Table 5.20: Acceptable Percentage of Cost and Rank Order of Plants --
Small Population Late Agricultural Strategy Models (page 1).

Energy Pattern			B-Vitamin Pattern			Vitamin A Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Drycorn	100	1	Drycorn	100	1	Drycorn	100	1
Hickory	82	2	Hickory	79	2	Hickory	79	2
Maygrass	51	3	Maygrass	57	3	Maygrass	56	3
Grape	45	4	Chenopod	55	4	Chenopod	53	4
Chenopod	44	5	Sumpweed	50	5	Grape	49	5
Blackberry	38	6	Grape	50	6	Sumpweed	47	6
Acorn	36	7	Green corn	45	7	Green corn	46	7
Sumpweed	35	8	Blackberry	38	8	Blackberry	42	8
Sunflower	35	9	Acorn	38	9	Acorn	37	9
Green corn	32	10	Sunflower	35	10	Sunflower	35	10
Dry beans	29	11	Dry beans	33	11	Dry beans	33	11
Walnut	23	12	Squash	29	12	Squash	27	12
Butternut	9	13	Walnut	22	13	Walnut	22	13
Squash	7	14	Green beans	14	14	Green beans	16	14
Green beans	6	15	Butternut	9	15	Butternut	9	15
Maypops	5	16	Maypops	5	16	Maypops	6	16

Table 5.20: Acceptable Percentage of Cost and Rank Order of Plants --
Small Population Late Agricultural Strategy Models (page 2).

Calcium Pattern			Vitamin C Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Drycorn	100	1	Drycorn	100	1
Sumpweed	100	2	Squash	100	2
Hickory	74	3	Sumpweed	100	3
Chenopod	58	4	Blackberry	97	4
Maygrass	57	5	Hickory	74	5
Grape	56	6	Grape	70	6
Dry beans	42	7	Chenopod	60	7
Blackberry	41	8	Maygrass	59	8
Sunflower	41	9	Green corn	56	9
Acorn	37	10	Dry beans	42	10
Green corn	33	11	Sunflower	41	11
Squash	28	12	Acorn	38	12
Walnut	21	13	Green beans	34	13
Green beans	18	14	Walnut	21	14
Butternut	8	15	Maypops	13	15
Maypops	6	16	Butternut	8	16

Table 5.21: Acceptable Percentage of Cost and Rank Order of Plants --
Large Population Foraging Strategy Models (page 1).

Energy Pattern			B-Vitamin Pattern			Vitamin A Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Hickory	100	1	Hickory	100	1	Hickory	100	1
Chenopod	100	2	Chenopod	100	2	Chenopod	100	2
Grape	80	3	Greens	88	3	Greens	100	3
Blackberry	68	4	Grape	64	4	Grape	63	4
Acorn	63	5	Acorn	50	5	Blackberry	52	5
Walnut	41	6	Blackberry	35	6	Acorn	49	6
Butternut	16	7	Walnut	27	7	Walnut	27	7
Greens	15	8	Butternut	10	8	Maypops	12	8
Maypops	10	9	Maypops	6	9	Butternut	11	9

**Table 5.21: Acceptable Percentage of Cost and Rank Order of Plants --
 Large Population Foraging Strategy Models (page 2).**

Calcium Pattern			Vitamin C Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Hickory	100	1	Chenopod	100	1
Chenopod	100	2	Hickory	100	2
Greens	100	3	Greens	100	3
Grape	68	4	Blackberry	100	4
Blackberry	59	5	Grape	100	5
Acorn	51	6	Acorn	41	6
Walnut	28	7	Maypops	22	7
Maypops	15	8	Walnut	20	8
Butternut	11	9	Butternut	8	9

Table 5.22: Acceptable Percentage of Cost and Rank Order of Plants --
Large Population Early Agricultural Strategy Models (page 1).

Energy Pattern			B-Vitamin Pattern			Vitamin A Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Hickory	100	1	Hickory	100	1	Hickory	100	1
Chenopod	100	2	Greens	100	2	Greens	100	2
Maygrass	100	3	Chenopod	100	3	Maygrass	100	3
Grape	87	4	Maygrass	100	4	Chenopod	100	4
Acorn	75	5	Grape	71	5	Grape	72	5
Blackberry	74	6	Sumpweed	68	6	Sumpweed	69	6
Sunflower	72	7	Acorn	53	7	Acorn	54	7
Sumpweed	69	8	Sunflower	50	8	Sunflower	51	8
Walnut	48	9	Squash	45	9	Blackberry	49	9
Butternut	19	10	Blackberry	41	10	Squash	43	10
Greens	18	11	Walnut	30	11	Walnut	31	11
Squash	15	12	Butternut	12	12	Butternut	12	12
Maypops	11	13	Maypops	4	13	Maypops	5	13

Table 5.22: Acceptable Percentage of Cost and Rank Order of Plants --
Large Population Early Agricultural Strategy Models (page 2).

Calcium Pattern			Vitamin C Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Hickory	100	1	Hickory	100	1
Greens	100	2	Greens	100	2
Chenopod	100	3	Chenopod	100	3
Sumpweed	100	4	Squash	100	4
Maygrass	100	5	Sumpweed	100	5
Grape	74	6	Maygrass	100	6
Sunflower	57	7	Grape	100	7
Acorn	52	8	Sunflower	57	8
Squash	44	9	Acorn	52	9
Blackberry	39	10	Blackberry	49	10
Walnut	27	11	Walnut	27	11
Butternut	11	12	Butternut	11	12
Maypops	7	13	Maypops	8	13

Table 5.23: Acceptable Percentage of Cost and Rank Order of Plants --
Large Population Late Agricultural Strategy Models (page 1).

Energy Pattern			B-Vitamin Pattern			Vitamin A Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Dry corn	100	1	Dry corn	100	1	Dry corn	100	1
Hickory	82	2	Greens	100	2	Greens	100	2
Maygrass	51	3	Hickory	78	3	Hickory	78	3
Grape	45	4	Chenopod	63	4	Chenopod	63	4
Chenopod	44	5	Green corn	61	5	Green corn	61	5
Blackberry	38	6	Maygrass	59	6	Maygrass	59	6
Acorn	36	7	Sumpweed	56	7	Sumpweed	56	7
Sunflower	35	8	Grape	53	8	Grape	53	8
Sumpweed	33	9	Squash	45	9	Squash	45	9
Green corn	32	10	Acorn	39	10	Acorn	39	10
Dry beans	29	11	Dry beans	35	11	Dry beans	35	11
Walnut	23	12	Sunflower	35	12	Sunflower	35	12
Butternut	9	13	Green beans	25	13	Green beans	25	13
Greens	8	14	Walnuts	21	14	Walnuts	21	14
Squash	7	15	Blackberry	19	15	Blackberry	19	15
Green beans	6	16	Butternut	8	16	Butternut	8	16
Maypops	5	17	Maypops	1	17	Maypops	1	17

Table 5.23: Acceptable Percentage of Cost and Rank Order of Plants --
Large Population Late Agricultural Strategy Models (page 2).

Calcium Pattern			Vitamin C Pattern		
Food	Average Percent Cost	Rank	Food	Average Percent Cost	Rank
Dry corn	100	1	Dry corn	100	1
Greens	100	2	Greens	100	2
Sumpweed	100	3	Squash	100	3
Hickory	72	4	Sumpweed	100	4
Chenopod	62	5	Blackberry	97	5
Maygrass	60	6	Grape	73	6
Grape	59	7	Hickory	72	7
Dry beans	45	8	Chenopod	64	8
Sunflower	43	9	Maygrass	61	9
Blackberry	42	10	Green corn	56	10
Acorn	38	11	Dry beans	46	11
Green corn	35	12	Sunflower	45	12
Squash	35	13	Acorn	38	13
Walnut	20	14	Green beans	34	14
Green beans	19	15	Walnut	20	15
Butternut	8	16	Maypops	13	16
Maypops	6	17	Butternut	8	17

Table 5.24: Plant Food Remains from Daugherty's Cave. Normed to 100 l fill.

Component	Nutshell (g)					Cultigens (g)	
	Hickory	Walnut	Butter-nut	Acorn	Hazel	Corn cupule	Squash rind
1. Historic	4.5	1.1	0.0	0.13			
2. Mississippian	110.2	43.6	19.9	1.47		1.988	
3. Middle Woodland	123.0	20.9	4.0	0.37	0.04	0.007	0.060
4. Early Woodland	169.8	26.2	3.3	0.14	0.02		0.036
5. Late Archaic	87.7	11.0	3.9	0.01			0.001

Component	Cultigens (seed counts)					Fleshy Fruits (seed counts)			
	corn	bean	sump-weed	chen-opod	may-grass	grape	bramble	ground cherry	hack-berry
1. Historic	7								
2. Mississippian	32	5				4			
3. Middle Woodland			3	99	11	16	11	3	
4. Early Woodland				6	131	3			
5. Late Archaic									1

Nuts

The rank orders of the nuts are completely consistent from one model to another. The models invariably rank the nuts in descending order of value as hickory - acorn - walnut - butternut. Likewise the plant remains samples are completely consistent in the rank order evaluation of the nut remains recovered from the components. In each component by descending weight of nutshell the rank order is hickory - walnut - butternut - acorn. One does not need a statistical test to recognize that there is a major discrepancy between the observed and the predicted importance of acorn at the site. (However, Spearman's r_s is 0.400, far below the critical value of 1.000 for a 0.05% significance level and a sample size of four.)

Even though it is misleading to compare directly the nutshell weights of thin-shelled acorns with that of the thicker shelled Juglandaceae, the problem is not merely that acorns have more meat relative to shell than do the other nuts. Although on a per gram (uncarbonized) basis, acorn shell represents three times more nutmeat than hickory shell, six times more nutmeat than walnut shell, and 10 times more nutmeat than butternut shell (based on figures in USDA 1984), this is insufficient to change the rank orders of the nuts. It has also been suggested that thin, fragile acorn shell is less likely than other nut shell to be preserved archaeologically, and that for this reason acorns are perhaps vastly underrepresented in the archaeological record (Lopinot 1983:94). However, for acorn to become the second most favored nut as the model predicts, the abundance of acorns needs to be increased by about a factor of 100. It seems easier to conclude that problems of preservation and recovery notwithstanding, the models have done a poor job of accounting for nut usage at Daugherty's Cave.

Seeds

The food plant remains from Daugherty's Cave other than nutshell were compared to the model outcomes in two separate tests. The Mississippian Period Component 2 remains were compared to the Late Agricultural Strategy Models, as these alone deal with corn and beans, staples of the Mississippian period. The Component 3 and 4 remains were compared to the Early Agricultural Strategy Models, as these deal with the native cultigens that occur in these components. Unfortunately the Foraging Strategy Models cannot be compared to any component. The Late Archaic Component 5 was expected to allow a test of this component, but it proved to yield no food plant remains other than nuts and squash.

Results of Testing the Late Agricultural Models. Tables 5.25 and 5.26 show the results of the Spearman's rank-order correlation test of the Mississippian period Component 2 and the Small and Large Population Late Agricultural Strategy Model outcomes. The critical value of r_s for a sample size of 10 and a significance value of 0.05 is 0.516 (Thomas 1986:510). The correlations between the observed and predicted non-nut plant foods do not reach this level, again indicating that the models do a poor job for accounting for the observed subsistence patterns. The correlations among the various model outcomes, however, are significant at the 0.05 level with the exception of the Vitamin C models. Again this suggests that the more complex models have little greater predictive value than the simpler versions.

The weak correlations between the observed and predicted seed remains results largely from two causes. First, beans occur in Component 2, whereas the model ranks them quite low. Secondly, the model suggests the native cultigens to be of relatively high value, and in the models including calcium and vitamin C constraints they actually enter the optimal diet. They are, however, absent from the Component 2 strata.

Table 5.25: Matrix of Spearman's Rank Order Coefficients Between Predicted and Observed Plant Food Weights -- Small Population Late Agricultural Strategy Models and Site Component.¹

	Energy Pattern	B-vitamin Pattern	Vitamin A Pattern	Calcium Pattern	Vitamin-C Pattern	Component 2
Energy Pattern	1.000					
B-vitamin Pattern	0.939	1.000				
Vitamin A Pattern	0.976	0.988	1.000			
Calcium Pattern	0.794	0.915	0.879	1.000		
Vitamin C Pattern	0.418	0.442	0.418	0.503	1.000	
Component 2	0.440	0.291	0.365	0.410	0.291	1.000

¹ Correlations between models and components significant at 0.05 level are underlined.

Table 5.26: Matrix of Spearman's Rank Order Coefficients Between Predicted and Observed Plant Food Weights -- Large Population Late Agricultural Strategy Models and Site Component.¹

	Energy Pattern	B-vitamin Pattern	Vitamin A Pattern	Calcium Pattern	Vitamin-C Pattern	Component 2
Energy Pattern	1.000					
B-vitamin Pattern	0.709	1.000				
Vitamin A Pattern	0.733	0.988	1.000			
Calcium Pattern	0.709	0.891	0.879	1.000		
Vitamin C Pattern	0.345	0.539	0.527	0.442	1.000	
Component 2	0.440	0.350	0.291	0.410	0.291	1.000

¹ Correlations between models and components significant at 0.05 level are underlined.

Actually it seems as if the Late Agricultural Strategy Models' singular success is in correctly predicting that maize should be the most desirable plant food.

Results of Testing the Early Agricultural Models. The results of the Spearman's rank-order test between the Small and Large Population Early Agricultural Strategy Models and Components 3 and 4 of Daugherty's Cave are presented in tables 5.27 and 5.28. For a test involving eight plants and a 0.05 significance level the critical value of r_s is 0.643 (Thomas 1976:510). Thirteen of 20 tests are significant at the 0.05 level. The relative success of the Early Agriculture Models is largely due to the high value they assign to the native cultigens, chenopod and maygrass, which dominate the two archaeological components. The poor showing of the models including calcium and vitamin C constraints results from the low ranking they assign to maygrass due to its low calcium content. The failure of the models with only an energy constraint to account for the component 3 seed data is largely caused by the low ranking assigned to sumpweed, which is present in the component.

SUMMARY

To establish the extent to which the linear programming diets incorporate the essential features of Eastern Woodlands subsistence strategies, the rank orders of the resources as indicated by the models were compared to the rank orders of the resources as represented in the archaeological record of the Daugherty's Cave site (44Ru14) using Spearman's rank-order correlation tests. Overall, the tests indicate the models to be poor ordinal predictors of prehistoric resource selection as reflected by the archaeological record. When tested against the faunal remains from Daugherty's Cave, the only significant correlation was between the Large Population, Late Agricultural Strategy model and the faunal remains from component 4. It is thought that even this agreement is primarily an artifact of the small size of the component 4 faunal sample. The failure of the models to accurately predict the fauna represented at the site is

Table 5.27: Matrix of Spearman's Rank Order Coefficients Between Predicted and Observed Plant Food Weights -- Small Population Early Agricultural Strategy Models and Site Components.¹

	Energy Pattern	B-vitamin Pattern	Vitamin A Pattern	Calcium Pattern	Vitamin-C Pattern	Component 3	Component 4
Energy Pattern	1.000						
B-vitamin Pattern	0.881	1.000					
Vitamin A Pattern	0.881	1.000	1.000				
Calcium Pattern	0.905	0.976	0.976	1.000			
Vitamin C Pattern	0.690	0.714	0.714	0.738	1.000		
Component 3	0.638	<u>0.675</u>	<u>0.675</u>	<u>0.737</u>	0.552	1.000	
Component 4	<u>0.764</u>	<u>0.791</u>	<u>0.791</u>	<u>0.764</u>	<u>0.764</u>	0.745	1.000

¹ Correlations between models and components significant at 0.05 level are underlined.

**Table 5.28: Matrix of Spearman's Rank Order Coefficients Between Predicted and Observed Plant Food Weights
-- Large Population Early Agricultural Strategy Models and Site Components.¹**

	Energy Pattern	B-vitamin Pattern	Vitamin A Pattern	Calcium Pattern	Vitamin-C Pattern	Component 3	Component 4
Energy Pattern	1.000						
B-vitamin Pattern	0.881	1.000					
Vitamin A Pattern	0.905	0.976	1.000				
Calcium Pattern	0.810	0.905	0.857	1.000			
Vitamin C Pattern	0.476	0.548	0.500	0.762	1.000		
Component 3	0.638	<u>0.675</u>	<u>0.749</u>	0.614	0.356	1.000	
Component 4	<u>0.764</u>	<u>0.791</u>	<u>0.873</u>	0.627	0.409	0.745	1.000

¹ Correlations between models and components significant at 0.05 level are underlined.

thought to result primarily from two causes. First, aquatic resources are overemphasized by the models, when, in fact, Daugherty's Cave is poorly located for the exploitation of aquatic animals. Second, the cost measure used by the models does not account for behavioral characteristics of prey, especially bear and turkey, which render them more susceptible to human predation.

The models likewise fail to account for nut usage at Daugherty's Cave, as they consistently rank acorns as more desirable than walnuts and butternuts. This is contrary to the minute amount of acorn recovered from the site. The models do agree with the archaeological record in indicating hickory nuts to be the most desirable of the nuts.

When compared to the Mississippian period Component 2 seed remains, the late agricultural strategy models achieve no significant rank order correlations. This is largely due to the high ranks assigned to native cultigens, which are absent from the Mississippian period strata. The models do correctly recognize maize as the most important crop plant. When compared to the Early and Middle Woodland period seed remains from Daugherty's Cave, the Early Agricultural Strategy models achieve rank-order correlations significant at the 0.05 level in 13 of 20 cases. The success of the Early Agricultural Strategy models is due largely to the high values they assign to native cultigens, which dominate components 3 and 4 of Daugherty's Cave.

Finally the rank order tests indicate generally high correlations among the rank orders of the resources as assigned by the various models. This indicates that increasing the complexity of the models by adding additional nutrient constraints and by varying population size has little effect on the value of the resources at an ordinal level of measurement. This suggests that nutritional constraints may have had a limited influence on prehistoric diet selection.

CHAPTER VI DISCUSSION OF PREHISTORIC DIETS

For anthropology, the greatest benefits of linear programming modeling are the heuristic insights it can provide about complex phenomena such as economic optimization (Reidhead 1979). In this chapter the deceptively precise quantitative aspects of the models' results are discounted and the results interpreted qualitatively. By de-emphasizing precision and maintaining a degree of generality more in keeping with the reliability of the models, it is possible to draw attention to four key issues. These include: (1) the role of nutrient constraints in shaping prehistoric Eastern Woodland diets, (2) the possible influence of population pressure and coevolutionary human-plant relationships in promoting subsistence change, (3) the role of particular resources in prehistoric Eastern Woodlands subsistence strategies, and (4) the role of storage versus mobility in subsistence strategies.

THE ROLE OF NUTRIENT CONSTRAINTS

The importance of nutrient constraints in shaping prehistoric Eastern Woodlands diets remains uncertain in this study. With increasing numbers of nutrient constraints added to the models, the optimal diets are considerably broader than the energy-only models. The broader diets are more costly to obtain but fulfill greater numbers of nutritional needs. The energy-only diets focus on only one or two resources and are clearly too narrow to sustain human health for long. Linear programming thus would seem to indicate that a forager ignoring nutritional needs in order to optimize energetic efficiency would not select an appropriate diet. This suggests that nutrient constraints

and should be by considered by any proposed explanation of prehistoric subsistence choice.

On the other hand, although the nutritionally constrained linear programming models produce broader diets, they are in fact no more realistic than the narrow energy-only models. In fact, the optimal diets generated by the most comprehensive models, those including all nine nutrients, are among the least successful in matching the subsistence remains from Daugherty's Cave. This suggests that the essential features of the Daugherty's Cave subsistence strategy are not incorporated in the more nutritionally comprehensive models. Hence nutritional requirements may not have been necessary considerations governing prehistoric subsistence choice in the Eastern Woodlands.

An unexpected result of the Spearman Rank-Order tests performed in the previous chapter was the indication that the six different versions of the optimal diet models used in this study are very highly correlated with each other. This is particularly true of the animal foods, which tend to be very similar in nutrient composition (Smith 1983), but is true of the plant foods as well. This correlation among the various models indicates that the rank orders of desirability of the resources are quite robust regardless of which nutrient constraints are considered. This suggests that judgements about the desirability of a food need not vary greatly over a range of nutritional constraints.

A number of reasons can be suggested for the similarities in the rank orders of the resources in the models. In general animal foods tend to be highly similar nutritionally (Smith 1983), so the particularly high correlations among the animal rankings are not too surprising. Plants tend to vary in their nutrient composition more than animals, but in this study only 12 plants are considered and these are mostly nuts and seeds with a few fruits. The plants within each category are expected to be

nutritionally similar. Hence it seems that the degree to which the resources vary nutritionally is overshadowed by the degree to which they vary in terms of their costs of procurement. I would suggest that subsequent models of Eastern Woodlands diet choice might justifiably disregard micronutrients and attempt to capture more essential differences in the resources. In particular it may be possible to capture the essential nutritional differences in resources by considering only the macronutrients, protein, carbohydrates and fats.

Another reason that the food rankings remain similar from the simplest to most comprehensive models is that energy remains a binding constraint in all but the highly suspect fall vitamin C models. This indicates that in the prehistoric Eastern Woodlands, regardless of what other nutrients were also needed, much of the choices about subsistence would be shaped by concerns for energy acquisition. This seems to support the contentions of most optimal diet modelers that simple energy-based models are sufficient approximations of the food quest (Winterhalder 1981; Smith 1983; Hill et al. 1987).

One reason simple energy-based foraging models work well is that they allow for encounter-contingent foraging. In these models foraging serves to fulfill energy requirements, but decisions to exploit a resource are made only after the resource is encountered (Winterhalder 1981; Smith 1983; Stephens and Krebs 1986). If the forager selects from a varied resource set and encounters are somewhat stochastic, a varied diet should result. Since varied diets are generally more nutritionally complete than narrow ones (Passmore and Eastwood 1986), encounter contingent models may predict nutritionally adequate diets fortuitously. Unfortunately linear programming cannot deal with encounter-contingency, since it must use linear relationships and constant costs. Furthermore, since linear programming selects a diet by comparing predetermined average costs (Reidhead 1979), it tends to focus on a very limited

number of cheap resources. Hence linear programming is prone to generate quite narrow diets.

The population densities incorporated into the models have also influenced the rankings of the foods by the various models. Even in the large population models, population density is modeled at a rather low 0.8 persons/km². A population at this density is able to fulfill much of its energy and basic nutritional needs by focusing on a few relatively abundant, high quality foods such as meat. A population subsisting on such a high quality diet would fulfill many of its dietary needs without seeking special sources of nutrients. The models suggest that prehistoric Native Americans at low population densities may have commonly obtained many nutrients in surplus.

Nutrient Surpluses in the Modeled Diets

Table 6.1 shows the percentage of the 120 different model runs in which each nutrient was obtained in surplus. This is a general measure of how constraining each nutrient may have been to prehistoric subsistence choice. It must be admitted, however, that some of the surpluses indicated by table 6.1 may be more apparent than real. Protein, for example, always is shown to have been obtained in surplus. Since most of the optimal diets include game, shellfish or a mix of vegetable foods, this is probably a true reflection of protein's relative abundance in the diets of low density populations in the Eastern Woodlands. However, in the late agricultural strategy models, protein was also indicated to have been in surplus even when the diet consisted solely of dried corn. Although gross protein was in excess, it is well known that maize alone is not an adequate protein source. Its content of the essential amino acids lysine and tryptophan are insufficient to maintain health (Katz et al. 1974).

A similar problem surrounds the apparent abundance of iron in some of the diets produced by the models. All-cereal diets (such as some of the late agricultural strategy

Table 6.1: Percentage Occurrence of Nutrient Surpluses in the Optimal Diet Models

Nutrient	Small Pop. Foraging	Small Pop. Early Agr.	Small Pop. Late Agr.	Large Pop. Foraging	Large Pop. Early Agr.	Large Pop. Late Agr.	Total
Protein	100	100	100	100	100	100	100
Thiamine	100	100	100	100	100	100	100
Iron	68	74	100	100	100	100	90
Niacin	47	74	100	32	58	100	68
Vitamin A	42	32	37	16	47	58	39
Riboflavin	42	42	32	32	37	26	35
Calcium	26	16	21	26	37	32	26
Vitamin C	11	26	11	16	26	37	21
Energy	5	0	0	5	0	0	2

diets) can produce iron deficiencies, since their iron, although abundant, is present in a form poorly assimilated by humans (Passmore and Eastwood 1986). When foods with bound iron are eaten with meat, fresh vegetables or fruit, the iron becomes available (Passmore and Eastwood 1986). Unfortunately, linear programming cannot deal with a situation in which the value of a resource varies according to the availability of other resources. Since most of the diets predicted by the model contain mixtures of foods, the differential availability of iron is probably not a serious problem. Of more concern is the fact that the iron requirement of women of reproductive age is particularly high (BNS 1983). Since the model uses an average RNA for the entire population, the overall surplus indicated for the population may have been of little import if the distribution of foods within the population slighted this particularly vulnerable segment of the population. It is noteworthy that in studies of prehistoric Eastern Woodlands burial populations, iron deficiency anemia is the only nutritional deficiency disorder inferred with any regularity (Powell et al. 1991). Significantly it is more common among late maize-dependent populations than among earlier ones. The linear programming late agricultural models correctly point to the potential for a perhaps overly narrow maize-based diet, although for the reasons discussed above, they do not indicate iron to be limiting.

Of the B-vitamins, thiamine seems to have been easily obtainable; every model produces a surplus of it. As thiamine is widely distributed in most foods (Passmore and Eastwood 1986), this is not an unexpected result. Niacin is less frequently produced in surplus by the modeled diets. This is in large part because hickory nuts, the staple food of most of the models, is not a particularly good niacin source. Somewhat ironically given the historical linkage of corn and pellagra, the maize-centered late agricultural strategy diets produce niacin in surplus (Roe 1973). This is because corn contains a more than adequate supply of niacin, but in a form unavailable to humans unless the corn is processed with alkali (Katz et al. 1974). As the models

assume alkali processing in the Eastern Woodlands (Katz et al. 1974), niacin is abundantly available.

The third B-vitamin, riboflavin, is produced in surplus in about one-third of the models. Riboflavin is not particularly widely distributed in foods, and plants except for green leafy vegetables are usually poor sources (Passmore and Eastwood 1986). In this study riboflavin was frequently a binding constraint and was largely responsible for the expansion of the modeled diets away from cheap plant foods to encompass more expensive game.

Vitamin A proved to be obtained in surplus more frequently than did riboflavin. This is an unexpected result, since in the modern world vitamin A deficiency is second only to energy-protein malnutrition in its incidence of occurrence (Passmore and Eastwood 1986). This is because vitamin A has few good sources other than organ meats and fresh vegetables. Although these foods are commonly too expensive for many in the modern world, they are rather cheap in the models of prehistoric Eastern Woodlands subsistence. Potherbs in particular are indicated as a potentially significant source of inexpensive vitamin A during the seasons in which they could be gathered.

Prior studies (Reidhead 1980; Keene 1981) have indicated that calcium might have been relatively difficult to obtain in the Eastern Woodlands. The present study confirms this, in that only about a quarter of the models produced it in surplus. Surpluses of calcium were obtained most readily in the summer when both potherbs and mussels were available. Both are good calcium sources, and they are abundant and cheaply available in the models. Probably the most interesting aspect of the investigation of role of calcium in the prehistoric diet is the prominent role played by stored chenopod as source of calcium in the winter and spring. I do not propose that chenopod was stored - much less domesticated - by prehistoric people solely because it was a source of calcium, but it seems reasonable that stored chenopod may have served

the latent function of maintaining seasonal calcium balance in populations that favored its utilization.

Unfortunately any debate about the possible role of calcium as a critical nutrient must be tempered by two caveats. First, calcium has a highly suspect RNA (Passmore and Eastwood 1986). It has even been suggested that an RNA for calcium serves no useful purpose, as primary calcium deficiency has rarely been observed in humans (BNS 1983:110). Hence any relative scarcity of calcium in the models of Eastern Woodland diet may be a reflection of our inability to assess human calcium needs properly. The second caveat concerning calcium is that the skeleton provides a calcium reserve that can be called upon in times of dietary stress (Passmore and Eastwood 1986). Although drawing upon skeletal calcium would have deleterious effects over the longterm, it is not clear that a seasonal shortfall would cause any significant health problems.

Like calcium, vitamin C has a controversial RNA (Passmore and Eastwood 1986), so any generalizations from the models must be tempered with particular caution. In earlier linear programming models (Keene 1981; Reidhead 1980), vitamin C played a particularly important role in shaping prehistoric Eastern Woodlands diet choice. In the present study, vitamin C is the nutrient other than energy most rarely produced in surplus. It is obtained in surplus in only about one-fifth of the models. This is because for the most part, the optimal diets focus on nuts, cereals and meats, and these are poor sources of vitamin C. The models suggest that except when considerable quantities of potherbs or squash are eaten as a vitamin A source, vitamin C intakes would be insufficient unless particular attention was paid to seeking foods rich in vitamin C. Although this seems to suggest that vitamin C might have played a crucial role in shaping prehistoric Eastern Woodlands diet choices, there are several reasons for skepticism.

It is certain that the models do not contain the full range of vitamin C sources available to prehistoric Eastern Woodlands populations. A number of fresh fruits known to have been utilized in the Eastern Woodlands were not included due to the lack of data on nutritional composition, yield, and cost of collecting. These include pawpaw persimmons, huckleberries, blueberries, serviceberries, gooseberries, wild strawberries, wild plums and wild cherries (Yarnell 1964; Swanton 1946). Given the nutritional similarities among fresh fruits and the vagaries surrounding the grape and blackberry cost and yield estimations, it is perhaps best to consider the occurrence of "grape" or "blackberry" in the modeled diets to actually signify almost any fresh fruit.

In addition a number of roots and tubers were used by Native Americans in the Eastern Woodlands (Yarnell 1964; Swanton 1946). Although the quantitative data necessary to include them in the models are lacking, roots and tubers often contain significant quantities of vitamin C (Watt and Merrill 1965). Hence, these may have been important vitamin C sources, especially during the cold seasons when fresh fruits and vegetables would have been unavailable.

Native Americans also dried fruits, and vegetables for cold season consumption (Swanton 1946), and these may have provided some vitamin C when fresh plants were scarce. Since the vitamin C content of foods is diminished by exposure to heat and air, the dried foods would contain considerably less vitamin C than their fresh counterparts (Passmore and Eastwood 1986). Nonetheless, they may have been of some importance in mitigating vitamin C deficiencies.

A final potential vitamin C source not considered in the models are infusions made from conifers, which are reportedly rich in vitamin C (Wing and Brown 1980). An infusion made from the bark of arborvitae (*Thuja occidentalis*) obtained from the Huron is reported to have cured Jacque Cartier's crew of scurvy during the winter of 1535-36 in only a matter of days (Carpenter 1986). In addition the Micmac are reported to use white pine as well as white spruce as a scurvy treatment (Moerman

1986:348,338). If the common pines are indeed a significant vitamin C source, and the use of pine infusions was a widespread practice in the Eastern Woodlands, then prehistoric vitamin C deficiency may have been of little threat. It should be remembered, however, that a vitamin C deprivation of several months is required to produce clinical signs of scurvy (Carpenter 1986). Hence, it may be that only in the northern reaches of the Eastern Woodlands would winters be sufficiently lengthy to make scurvy a danger. It is interesting in this regard that the Huron and the Micmac, the two societies with reported scurvy cures (Carpenter 1986; Moerman 1986), are both from southern Canada. For much of the Eastern Woodlands, the relatively short winters may have mitigated the threat of scurvy and the need to seek out foods rich in vitamin C.

The Costs of Nutrient Acquisition

Another way of assessing the potential influence of nutrient needs on prehistoric Eastern Woodlands diets is by examining the increased costs necessitated by expanding the diet to meet nutrient as well as energy needs. Figure 6.1 shows for each of the six sets of models how adding nutritional constraints increases the annual cost of subsistence. It can be seen that adding protein, iron, and B-vitamins (the B-vitamin constraint pattern) causes only about a 10% increase in foraging effort. The addition of vitamin A causes a negligible increase in cost over this. The addition of calcium causes the cost of subsistence to rise to over 20% of the basic costs. Finally the addition of vitamin C causes a dramatic change. In the foraging models the costs of obtaining the diet are two-thirds again as expensive as obtaining energy only. In the agricultural models this impact is mitigated by the presence of a relatively cheap vitamin C source in the form of cultigen squash. But still, it is evident that calcium and vitamin C, the two nutrients with the most suspect RNA,s are indicated to have the greatest potential effects on subsistence choices.

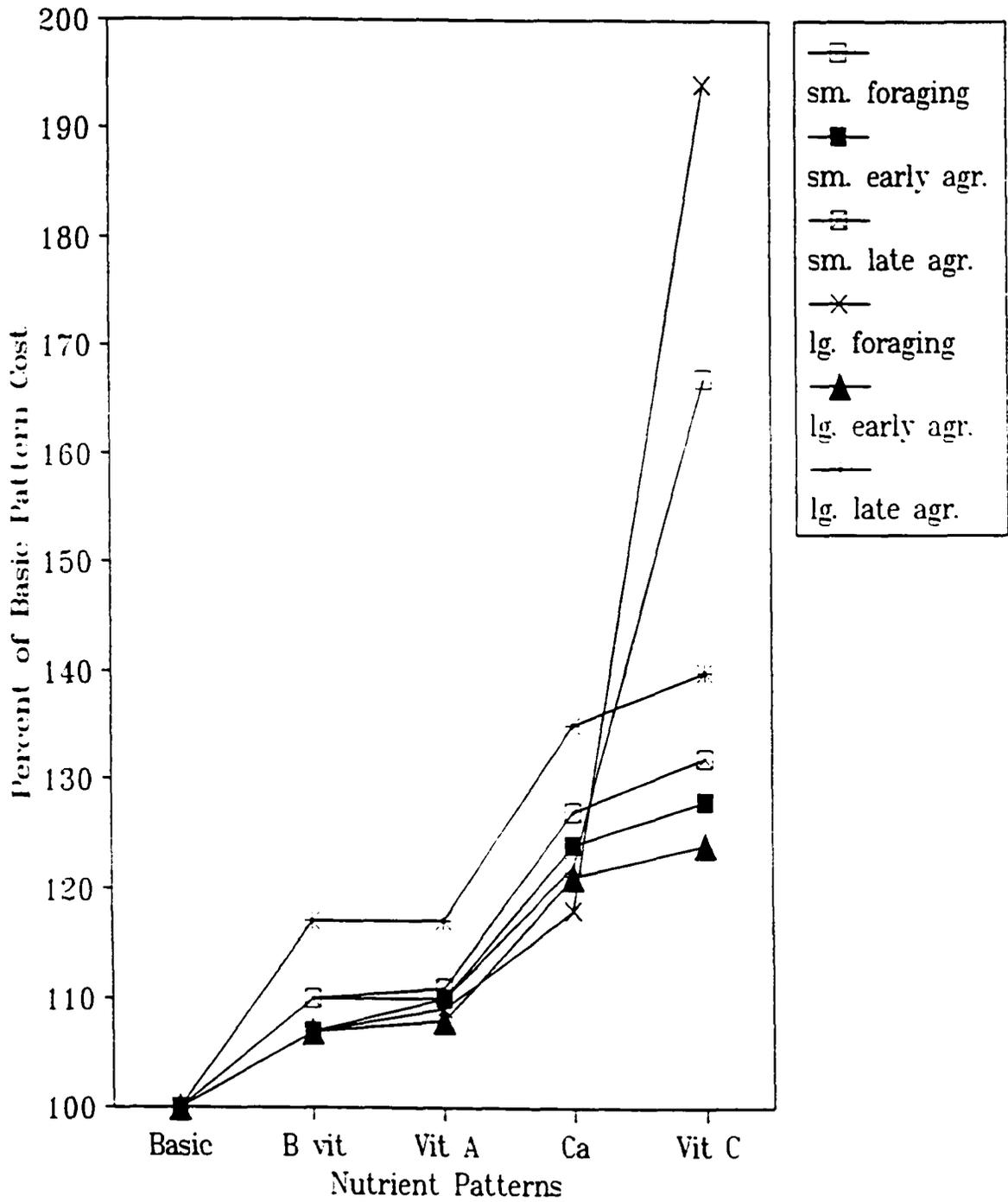


FIGURE 6.1: Percentage Increase in Annual Cost Caused by Adding Nutrient Constraints

This result leads to the conclusion that the nutritional implications of prehistoric foraging are obscured by our currently imperfect knowledge of human nutritional requirements. Nonetheless, the linear programming models do suggest that a complex set of nutritional factors seem to have been of limited importance in structuring prehistoric subsistence adaptations in the Eastern Woodlands. This is a finding of some practical importance in that the next generation of models can thus be made simpler and more tractable. It is this sort of heuristic insight into complex problems which linear programming is most useful in providing.

Admittedly the influence of calcium and vitamin C requirements in shaping Eastern Woodlands subsistence strategies remains unclear. However, it is interesting that the two nutrients which the linear programming models indicate to be relatively scarce and expensive even in an environment as generally "permissive" as the temperate forest prove to have controversial RNA's. The RNA's are controversial largely because human populations are observed to remain in calcium and vitamin C balance over a large range of nutrient intakes (Passmore and Eastwood 1986). I would suggest that over the course of human evolutionary history, the physiological ability to adapt to a range calcium and vitamin C intakes may have been shaped by natural selection. Hence the absence of any dramatic cultural adaptations (i.e. diet choices) to calcium and vitamin C shortfalls may in fact reflect an underlying physiological adaptation.

THE ROLE OF POPULATION PRESSURE AND COEVOLUTION

Population pressure has frequently been cited as a cause of subsistence change (Binford 1968, 1983; Flannery 1973; Cohen 1977; Earle 1980; Christensen 1987). The expected pattern of subsistence change in the face of increased population pressure is that, first, the exploitation of the highest ranked resources increases. Second, as a result of the diminishing returns from exploiting the highest ranked resources, the diet

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expands to include additional, formerly ignored, resources. Finally, if population pressure is unabated, subsistence effort must be refocused to only those resources with the highest yields, regardless of their costs of production. Agriculture is frequently considered an example of this final stage of subsistence modification (Earle 1980).

The first two stages of the above sequence can be inferred from a comparison of the small and large population models. Certainly increased amounts of the highest ranked resources are taken. In the large population models, beaver were exploited to the limits of availability, as were the deer in the closest catchment zone. This did not happen in the small population models. Likewise, the large population models do display an expansion of diet breadth. The average number of optimal and secondary resources in the small population models is 4.7, while that of the large population models is 5.9.

However, the models cannot be used to argue that population pressure in an of itself stimulated food production in the Eastern Woodlands. With the exception of sunflower, all the native annuals eventually domesticated in the Eastern Woodlands entered the optimal diets of one or more Small Population Early Agricultural Strategy models. Although the native annuals were incorporated into these models with costs that did not reflect agricultural production, all had acceptable cost figures that would allow at least some management effort. Corn, also, cannot be inferred to have entered the optimal diets as a result of demographic stress. Rather corn enters both the small population and large population models as a least-effort solution to the food quest. Likewise, the displacement of native cultigens by corn in the optimal diets of the large population models is also a cost minimization strategy and does not reflect the necessity of focusing all subsistence effort on the highest yielding resource. In short the models offer no support for population pressure as the cause of subsistence intensification and plant husbandry in the Eastern Woodlands.

In contrast to population pressure models, coevolutionary models do not view agriculture as the result of efforts to cope with exogenous stress (Rindos 1984; Smith 1987b). Rather they posit that plant management and eventual cultivation were opportunistic responses by humans to the availability of productive seed-bearing plants that occupied the disturbed environs of their settlements. The exploitation and management of plants would have advantages for both people and plants and would create a mutually reinforcing relationship. Through time, domesticated plants and agricultural economies would develop as the mutually fitness-enhancing relationships between people and plants became increasingly obligate (Rindos 1984).

The linear programming models do offer some support for coevolutionary scenarios (Rindos 1984; Smith 1987b). In particular the Small Population Early Agricultural Strategy model suggests that weedy annuals might be a part of a forager's optimal diet, provided they could be obtained without undue effort. These plants might well have been readily available to human foragers, since as weedy natives they would likely favor the anthropogenically disturbed environs of the human habitations. This propinquity would allow them to be exploited quite readily during otherwise nonproductive times (e.g. late twilight), or by otherwise nonproductive members of the group (e.g. children, child-tending women). Their exploitation would thus have -- in the jargon of economists -- low "opportunity costs", as it would not entail the sacrifice of an opportunity to engage in a more "optimal" pursuit (Winterhalder 1983). In addition they would provide an additional source of energy and nutrients (especially calcium) and would be easily storable. Therefore their exploitation might improve the general nutritional status of the population and could buffer seasonal or stochastic shortfalls in nutrient intake. Presumably these benefits of exploiting native weeds would enhance the fitness of the population and lead to eventual longterm population increase. As population grew, more anthropogenic habitats favoring weeds would be created, while firstline foods such as nuts and large game would come under increasing

stress. These factors would favor the increased exploitation and management of the weedy annuals. It is thus easy to imagine the establishment of a self-reinforcing system could transform the incidental exploitation of weedy annuals into agricultural food production without the involvement of human intentionality. Of course it is not necessary to preclude human intentionality or goal-directed behavior. Likewise, although population pressure does not function as a prime mover in this scenario, it is difficult to account for such longterm change in subsistence adaptations without some unidirectional selective pressure. Population growth would not only seem a likely source of such selective pressure, but it also seems a likely product of an effective subsistence adaptation.

THE ROLE OF PARTICULAR RESOURCES

The linear programming models also provide some insight concerning the potential roles of the various resources available in the Eastern Woodlands. In general the diets generated by the linear programming models are considerably narrower than those reconstructed from the archaeological record. Only 14 of the 35 resources included in the models were ever selected as part of an optimal diet, and only half of these were taken with any regularity. Table 6.2 lists the percentage of models in which an available resource was selected. This can be considered a measure of the importance of the resource under varying constraints.

Maize

For maize, at least, the models have produced an intuitively satisfying result. Maize is selected as the staple food in every model in which it is available. This is in accord with the well-established role of maize as the staple of native North American agriculture (Yarnell 1979) and with its place as one of the world's most important crop

Table 6.2: Percentage of Models in Which an Available Resource was Selected

Nutrient	Small Pop. Foraging	Small Pop. Early Agr.	Small Pop. Late Agr.	Large Pop. Foraging	Large Pop. Early Agr.	Large Pop. Late Agr.	Avg.
Beaver	13	7	10	10	10	10	60
Deer	9	5	6	15	14	7	56
Mussels ^a	5	3	8	7	10	8	41
Chenopod	6	5		10	4		25
Grape ^a	1	1		1	1		4
Greens ^b	5	5	4	6	7	8	35
Hickory	18	14		18	19		69
Squash ^c		1	1		1	1	4
Maygrass ^d		5			5	1	11
Fish ^a	1			1			2
Berry ^a	1			1			2
Sumpweed ^e		2	1		2		5
Drycorn ^f			19			19	38
Groundhog ^g				2			2

- ^a available summer and fall only - 60 models
- ^b available spring and summer only - 60 models
- ^c available summer and fall, agricultural models only - 40 models
- ^d available summer, agricultural models only - 20 models
- ^e available agricultural models only - 76 models
- ^f available late agricultural models only - 38 models
- ^g available spring, summer, fall only - 90 models

plants. Maize enters the optimal diet of the small population models as well as the large population ones. This finding suggests that the adoption of maize agriculture might be a least-effort solution to the food quest rather than a labor-intensive response to demographic pressure. Earlier linear programming models of Eastern Woodlands subsistence likewise suggested maize agriculture might be a least-effort strategy (Reidhead 1980). However, in Reidhead's study (1980) maize was available only in models that also incorporated an increased population size, as well as technological and environmental changes. This simultaneous inclusion of multiple changes made it difficult to isolate the factors promoting the exploitation of maize. In the present study, the inclusion of maize in the small population optimal diets cannot be ascribed to pressure on other foods. Clearly maize is included in the small population diets because of its superior cost-benefit ratio.

This conclusion must be tempered, however, by the inevitable vagaries of the modeling endeavor. The models include estimations on the cost of maize production based on modern Central American studies. The extension of these data to the prehistoric Eastern Woodlands is suspect, albeit necessary. Furthermore, the yield figures for maize used in the study are based on Historic Period races of maize. It seems likely that these races, having benefited from over a millennium of husbandry in the Eastern Woodlands, were more productive than their initial Eastern Woodlands progenitors. The models do seem to indicate, however, that if a highly productive race of maize were to have become available in the Eastern Woodlands, its adoption and intensive production might have been seen as a highly attractive option.

Such a scenario may account for the pattern of maize adoption in a portion of the Eastern Woodlands. In the central Ohio River valley region during the Mississippian period (A.D. 950 - A.D. 1650), the Fort Ancient people invested little effort in previously important native crops but became focal consumers and producers of Eastern Eight Row variety maize (Wagner 1986). The archaeological remains of

Fort Ancient maize are sufficiently uniform to suggest a "single, general introduction of seed to the area" (Wagner 1986:128). Thus, the pattern of Fort Ancient maize production is congruent with the models prediction of an abandonment of native crops in favor of a cost-effective productive strain of maize. Unfortunately it is also congruent with a demographic stress model in which the yields of most productive crop must be maximized regardless of labor costs (Earle 1980).

In other areas of the Eastern Woodlands, the pathway by which maize came to dominate Native American crop systems is more unclear, as both the timing of the maize ascendancy and the nature of antecedent subsistence systems are poorly known (Fritz 1990). It is clear, though, that maize varieties other than Eastern Eight-Row were grown by most fully Mississippian cultures, so a simple diffusion of the highly productive Eastern Eight-Row maize variety is an inadequate explanation (Fritz 1990).

Based on current evidence, I would speculate that sometime prior to the late Middle Woodland period (Yarnell 1986:51) maize from the Southwest was incorporated into Eastern Woodlands gardens in much the same fashion as cowpeas or watermelons were incorporated following European Contact (Gremillion 1991). Once maize was established in the gardens, coevolutionary change between it and Eastern Woodlands societies began. Presumably as a result of the coevolutionary process, the cost effectiveness of maize production eventually surpassed that of the native cultigens. At this point, maize production might have spread as a least-effort strategy. It might replace both food production systems based on native cultigens (as in the Fort Ancient area [Wagner 1986]) or foraging systems that had been indifferent to native crops (as in the lower Southeast [Scarry 1988]).

It should be emphasized that in this scenario maize production diffuses as a least-effort strategy, and not as a result of demographic pressure. Hence archaeological evidence of maize agriculture might appear in the absence of evidence of population pressure, as is common in Eastern Woodlands (Fritz 1990). Viewed in this light, the

finding that maize agriculture might be a least-effort subsistence strategy is an interesting, albeit counterintuitive result of the linear programming models.

Mussels

Mussels enter the optimal diet of over two-thirds of the models in which they were available, and would have been taken in many of the spring and summer models had they not been modeled as seasonally unavailable. Mussels are not selected as an energy source, but play an important role in providing calcium and B-vitamins, especially riboflavin. This is in agreement with previous arguments that mussels were more likely a source of nutrients than calories in the prehistoric Eastern Woodlands (Parmalee and Klippel 1974).

In the linear programming models, mussels are indicated to have been of particular importance in the summer when game is lean and hunting costs, high. In the fall, however, the sensitivity analyses of costs (Tables 4.2, 4.5, 4.8, 4.11, 4.14, 4.17) show that the place of mussels in the optimal diet is less clearcut. In most cases the acceptable costs of mussels are only slightly greater than that of deer. Given the uncertainties surrounding the estimations of the model's parameters, there can be little confidence that mussel collecting was actually more efficient than deer hunting. Given the overwhelming archaeological and ethnographic evidence for the predominance of deer hunting as the principal cool-season animal procurement activity in the Eastern Woodlands (Smith 1975; Cleland 1976; Swanton 1946), I am skeptical of the models' fall shellfishing season.

It is also questionable to what extent the optimality of mussel collecting can be extended to the Eastern Woodlands in general or to substantial spans of time. Some rivers and streams in the Eastern Woodlands have supported truly phenomenal quantities of mussels. For example in 1965 a 175 mile stretch of the Tennessee River is reported to have supported 26,000 tons of mussels (Ison 1969). It seems hardly

surprising that the Tennessee River also possessed large prehistoric shell middens (Webb and DeJarnette 1942). However, locales which combine the currents, substrata, and water quality favored by mussels while simultaneously allowing easy routine collection by humans are probably rather patchily distributed. Although most pristine streams may have been capable of yielding a few mussels to Native American collectors, few probably produced enough to nourish any sizable number of people for any substantial amount of time (Parmalee and Klippel 1974).

Moreover the efficiency of collecting mussels is highly variable depending on the extent of the mussel bed, the density of the mussels within the bed, and the turbidity and depth of the water (Parmalee, cited in Reidhead 1976:129). Because of these variable factors, estimating an "average" cost for mussel may be particularly misleading. Also, the cost and effectiveness of mussel collecting may have been difficult for prehistoric Native Americans to project as well, since the turbidity and depth of rivers and streams can vary at short frequencies in response to rainfall. Thus the low search cost assigned to mussels by the models could be misleading, for while they may be perfectly predictable spatially, they are likewise variable temporally.

Another uncertainty surrounding mussels is their ability to withstand exploitation. A sizable mortality is predicted for the local mussel fauna even by the small population models. For example in the Small Population, B-Vitamin, Foraging Pattern Model, 572 kg of mussels are predicted to be eaten in the summer. At about 50 g per mussel (Chapter 3 above), this is over 11,000 individual mussels. Although this is only 5 mussels per person per day, it is questionable how long most catchments could support this level of exploitation before the mussel beds would become too depleted to warrant systematic collection.

In summary the models have probably done a credible job overall of reaffirming the widely accepted view that under favorable conditions mussels can constitute an important foodstuff. However, I suspect a patchy distribution of prime habitat and a

questionable ability to withstand exploitation precluded mussels from forming the basis of a human diet for any extended period of time.

Nuts

Hickory nuts. One important impetus for conducting the present study was a prior indication from linear programming modeling that nuts were not part of the optimal diet during the Archaic period in the Saginaw Valley, Michigan in spite of their high visibility in the archaeological record of the Eastern Woodlands (Keene 1979, 1981, 1982). As discussed in chapter 2, there is reason to suspect that the eclectic measure of cost devised by Keene is responsible for the absence of nuts from the optimal diets of his models. By use of a simpler, more direct measure of cost, the present study indicates that hickory nuts were indeed a optimal resource under most sets of model constraints. In models in which maize is unavailable, hickory nuts are the most common staple food. To my mind the archaeobotanical record of the Eastern Woodlands also suggests that hickory nuts were the most important plant food prior to the wholesale adoption of maize agriculture, but the interpretation of that record is somewhat controversial (Yarnell and Black 1985:98).

Acorn. Hickory's rival claimant as the most important plant food in the pre-Mississippian Eastern Woodlands is acorn (Yarnell and Black 1985). Although the models rank acorn as the second most desirable nut, it is not included in any optimal diet, and it is a secondary resource in only the winter Large Population Early Agricultural Model. The reasons for its omission are twofold. First, acorn has a particularly high processing cost (Petruso and Wickens 1984); whereas hickory nuts have the lowest processing costs of any of the nuts considered in the models. Secondly, a comparison of the nutrient composition of acorn and hickory nuts (Table 3.5) shows that insofar as the nutrients considered in this study are concerned, hickory nuts are decidedly more nutritious (USDA 1984). Given this set of circumstances,

acorns would never enter a linear programming optimal diet until all hickory nuts were expended. This rarely happened in the models, since hickory nuts are so abundant relative to population needs. In the single model (Large Population, Basic Pattern, Foraging Strategy) in which all available hickories were exploited, other resources that ranked higher than acorn were sufficient to fulfill the remaining dietary needs.

Considering hickory's lower cost of processing (Talalay et al. 1984), its superior nutrient composition (USDA 1984) and its overwhelming domination of the pre-Mississippian Eastern Woodlands archaeobotanical record (Yarnell and Black 1985), I see no compelling reason to doubt its place as the principal non-maize plant food. Admittedly the large, dense shell of hickory nuts is more prone to archaeological recovery than is the thinner shell of acorn, and on a per gram basis, a given amount of acorn shell represents more food than does a similar amount of hickory shell. In particular, hickory nuts are 65% refuse; whereas acorns are 35% refuse (USDA 1984). Thus one gram of uncarbonized hickory nutshell represents 0.54 g of hickory nutmeat, while one gram of uncarbonized acorn shell represents 1.63 gram of acorn meat. A direct gram to gram of comparison of nutshell would thus underestimate the contribution of acorn by at least a factor of three.

It has been suggested as well that the thinner, more fragile acorn shell is less likely to be preserved or recovered archaeologically, or, due to its greater tendency to minute fragmentation, to be recognized in paleoethnobotanical analyses (Lopinot 1984). However, in preparation for consumption, hickory nuts seem to have been usually crushed and boiled, while acorns were shelled then leached and cooked (Swanton 1946:346-365). The dry shell of acorn would seem more likely than the sodden shell of hickory to be disposed of in a fire. Of course, hickory nuts could be dried, then burned, if fuel were at a premium. Nonetheless, I would argue that the difference in the processing of hickory nuts and acorns probably mitigates the skewing effects of hickory's greater likelihood of postdepositional preservation and recovery. I am not

prepared, however, to assign a numerical coefficient to this likelihood so as to be able to estimate a correction factor for comparing acorn shell to hickory nutshell in archaeobotanical samples. However, given the nutritional superiority of hickory nuts and their apparently less costly processing, I would caution against the easy acceptance of any correction factor which serves to lessen the apparent role of hickory nuts vis a vis acorns.

Walnut and Butternut. In the case of acorn, I could, at least, argue that its scant occurrence at Daugherty's Cave is qualitative support of its low value in the models. This is not the case with walnuts and butternuts. Both are considered by the models to be even less desirable than acorns, and both occur at the site in considerable quantity. Likewise, both are well-represented in Eastern Woodlands archaeological sites in general (Yarnell and Black 1985). Since it is a given of this study that prehistoric Native Americans were rational decision makers (see Plattner 1990 and chapter 1 above), it follows that some essential property of walnuts and butternuts has escaped these models.

In the past I have suggested that walnuts and butternuts entered the prehistoric Eastern Woodlands diet not because they were a targeted resource, but because they were incidentally collected when they were encountered during hickory nut collecting ventures (Gardner 1985). The linear programming suggests this is not an adequate explanation. In constructing the linear programming models, the search costs of nuts was set at zero, since it was considered that nut trees being common and sessile would require no search costs beyond walking to them. Thus the exclusion of walnuts and butternuts from the models cannot be a result of their more sparse distribution. Rather it reflects their high processing costs (Talalay et al. 1984). The models suggest that walnuts and butternuts should have been ignored no matter how routinely they were encountered, since the cheaper-to-process and nutritionally similar hickory nuts should have been available in abundance.

Obviously, however, walnuts and butternuts were not ignored by Native Americans. Not only are they common at Daugherty's Cave, but they are routinely recovered from archaeological sites in the Eastern Woodlands (Yarnell and Black 1985). A "least-effort" explanation of this seemingly nonoptimal usage is difficult to develop, although three commonsensical reasons for their use can be suggested.

First, the husks of walnuts and butternuts were used by Native Americans as dyestuffs (Yarnell 1964; Swanton 1946). However, as the archaeologically recovered remains of walnuts and butternuts are usually identical to that of hickory nuts, that is, small fragments of shell devoid of meat, it seems that walnuts and butternuts were also being used as a source of food even if they provided dyes as well.

A second reason for the use of walnuts and butternuts might be that although they have low value in average years when hickory nuts are abundant, they might be of considerable importance as easily storable, nutritious foods during years of poor hickory production. As hickory nuts produce poor crops every few years (Fowells 1965), this might well account for the routine recovery of relatively small amounts of walnuts and butternuts from archaeological sites.

Finally, like the exploitation of weedy annual plants, the use of butternuts and walnuts might have low "opportunity costs" if properly scheduled. Not only could walnuts and butternuts have been gathered cheaply, either from trees located in the immediate environs of the cave or while systematically pursuing other resources, but it is a task that could be performed by otherwise nonproductive members of the group, such as small children. It is also possible that the nuts may have been cracked and eaten during nonproductive periods spent at the cave, e.g. night time, or during spells of bad weather. In this scenario the relatively high costs of walnuts and butternuts are acceptable since there is no competing economic use of the time. Basically this scenario describes a use of butternuts and walnuts that is more of a leisure activity

rather than a economic one. The desirable taste of walnuts and butternuts would make them likely subjects of such activities.

Greens

Greens play a important role in the optimal diets. Greens are considered an optimal resource in 58% of the models in which they are available (Table 6.2). In the models greens play particularly important roles in providing calcium, vitamin A and B-vitamins. Their high status is largely a function of their high nutrient densities combined with relatively low production costs.

Greens themselves are, of course, archaeologically invisible, but numerous weedy forbs are represented in the archaeological record of the Eastern Woodlands by their seeds (Yarnell 1986). Historically potherbs seem to have been of considerable seasonal importance among some groups in the northern parts of the Eastern Woodlands (Yarnell 1964) but do not figure in southeastern food lists (Swanton 1946).

The models may over-emphasize the importance of greens in Eastern Woodlands subsistence strategy. The cost estimation of greens production is based on three short-term experiments, and the search costs are highly artificial. In general they are modeled as abundant and easily obtainable. It is perhaps more likely that edible greens were patchily distributed in scattered disturbed habitats in the forest and that considerable travel time would have been required to obtain them in quantity. The exploitation of greens from the anthropogenically disturbed environs of the human habitations, or from gardens and fields would seem a particularly attractive option, however. The opportunity costs of exploiting nearby greens would seem particularly low.

It is not clear over how long a period edible wild greens would have been available for harvest. Cultigen greens such as spinach tend to become bitter and

unpalatable as the growing season progresses. Modeling greens as available over a six month period may have been overly generous.

The linear programming models do draw attention, however, to the potential nutritional importance of greens to the Eastern Woodlands diet. It is noteworthy that greens were also included within the optimal diets of previous models of prehistoric Eastern Woodlands subsistence (Reidhead 1976; Keene 1982), even though the earlier models were constructed with markedly different estimations and parameters than my own. Thus the exploitation of greens is a rather robust result of the optimal diet models, but unfortunately one that seems largely impervious to archaeological test.

Native Annuals

Included in this category are maygrass, utilized in 55% of the models in which it was available; chenopod, utilized in 22%; squash, utilized in 10%; sumpweed, utilized in 7%; and sunflower, which never entered an optimal diet. All except sunflower (Heiser 1978) and possibly squash (Decker 1988) are natives of the Eastern Woodlands. Apparently all were domesticated there in prehistoric times (Smith 1987b; Watson 1989; Fritz 1990). The linear programming has provided some interesting insights into their possible roles in prehistoric Eastern Woodlands subsistence. Many ambiguities and uncertainties remain, however, especially given the gross estimations of many of the variables categorizing the costs and yields of these plants.

Of these plants, squash has the clearest role in the models. When available it always enters the optimal diet of the fall season to provide vitamin C. It is never selected to provide energy or other micronutrients, and it is never selected in seasons when the more cheaply gathered greens are available. Had it been modeled as available in the winter, it would have entered as a vitamin C source. Including it in the winter models may have been appropriate, as squash was sometimes dried in the Eastern Woodlands (Swanton 1946), and there a varieties of winter squash which can be stored

for months under cool, dry conditions. (Winter squash (*Cucurbita moschata*) does not seem to have been present in the prehistoric Eastern Woodlands (Cutler and Whittaker 1961) and is excluded from the models for that reason). Were squash available in the winter models, the optimal diet solution, rather than being mathematically infeasible, would have been essentially the same as that of the fall (game, squash, and hickory or corn). Mitigating a winter time vitamin C scarcity could well have improved the health of the population and might help explain why the practice of drying a fruit which is over 90% water (Watt and Merrill 1965) could become established as a regular cultural practice.

The other native annuals play a more varied role in the models. In the small population models, in which the first-line foods hickory and game are abundant relative to population requirements, the native annuals seldom enter the optimal diet. A dramatic exception is maygrass, which totally dominates the summer diet when it is available at a cost reflecting gathering. As mentioned in chapter 4 this clearly seems to be a bogus result stemming from the use of a cost measure based on gathering wild wheat. When a higher cost reflecting food production is used, maygrass remains part of the summer optimal diet but in much reduced amounts.

A more interesting exception to the general non-utilization of the native annuals in the small population models can be found in some of the spring season models. In the spring, with game relatively expensive to acquire, chenopod and sumpweed are selected as sources of B-vitamins and calcium. It is interesting that the native seeds are more valuable as a stored commodity than as fresh foods. This is also a robust result of linear programming modeling in that Reidhead (1976) also found stored "weed seeds" (his composite of chenopod, maygrass and sumpweed) to be part of the optimal diets in winter and spring.

A final inference from the small population models is that even as sources of micronutrients in the spring, the native annuals do not compete favorably with corn. The late agricultural models focus on dried corn augmented by fresh greens.

In the large population models, manipulation of the models' components allows additional insights into the potential roles of the native annuals. When the seasonal consumption of hickory nuts is limited in the foraging strategy model, chenopod is valued not only as a springtime nutrient source but becomes the secondmost source of calories. An examination of the sensitivity analysis of cost (Table 4.11), however, tempers this conclusion. If the cost of storing chenopod were to exceed about 5% of its fresh cost, additional hunting and fishing would become rival strategies for energy acquisition. Nonetheless, even if a general broadening of the diet were to occur as nut exploitation reached its limits of expansion, the models indicate that increased use of native seed plants would likely be an effective part of the strategy.

The native annuals play a more modest role in the diets when their costs are raised in the Early Agricultural Strategy models to reflect the higher costs of gardening. Chenopod is no longer selected as a source of calories except in the spring, and maygrass becomes less important than hickory nuts and mussels in the summer. The sensitivity analysis of acceptable costs (Table 4.14), however, shows that all of the native annuals except squash are secondary sources of energy in one or more seasons. Chenopod and sumpweed are selected as calcium sources in the winter and spring respectively, and the sensitivity analysis indicates that they could have been possible secondary sources of B-vitamins and calcium during the winter to summer seasons.

To generalize I think two patterns emerge from the role of native annuals in the linear programming optimal models. First, the plants are generally nutritious, especially as a source of B-vitamins and calcium. If they could have been collected or produced at reasonable costs, then their addition to the diet could well have improved the health of the population. Hence, small scale, low cost utilization of and

experimentation with these plants may have had longterm fitness-enhancing effects for the populations exploiting them. This would tend to reinforce the exploitation of these plants and would perhaps accelerate their movement towards domestication (see Rindos 1984). In addition native annuals would have provided an additional set of resources that might have served to buffer the impact of stochastic shortfalls in the availability of game and nuts.

The second generalization is that the native annuals do not compete well with animal foods. In the fall and summer, when game or shellfish is inexpensive and abundant, the models tend to relegate the native annuals to secondary roles. This suggests, first, that the native annuals may have been more important as storable commodities than as fresh foods. Hence they may not have been particularly attractive resources to highly mobile populations. Secondly it suggests that were meat to become scarce relative to population needs - and concomitantly more expensive to acquire - then the increased utilization of the native annuals would become an increasingly attractive strategy. Thus under conditions of increasing demographic stress, it would be expected that prehistoric Native Americans would expand their diets to include increasing amounts of the native annuals.

Basically this is the pattern that Eastern Woodlands archaeology reveals. In the Early and Middle Archaic, populations seem to have been sufficiently small to allow a mobile, hunting-focused subsistence (Stoltman and Baerreis 1983). Hickory nuts seem to have been the only staple plant food (Asch et al. 1972). As populations grew, mobility was constrained, hunting became more unreliable and more costly to pursue, and the diet expanded to include increased amounts of the native annuals (Phillips and Brown 1983; Asch and Asch 1985). Through time utilization and management of these plants increased and eventually led to their domestication (Smith 1987b).

Game

The models have done a poor job of accounting for prehistoric animal procurement. Only three game animals are selected as part of the modeled optimal diets. Fifty-five percent of the optimal diets include beaver, 49% include deer and 2% include groundhog. Deer, of course, is an expected part of the prehistoric Eastern Woodlands optimal diet, but neither beaver or groundhog seems to have been of particular importance.

Beaver in particular seems to play a much more important role in the models than archaeology (Cleland 1966; Smith 1975) or ethnographic accounts (Swanton 1946) would suggest was actually the case. Three reasons account for this. First, beaver is an unusually fatty game animal, so it is a relatively good source of calories (Medical Services Branch 1985). This raises its status in the models. Second, the effectiveness of beaver trapping was based on a single modern study (Mason et al. 1983) and may be an overestimation of actual rates, especially for prehistoric trapping dependent on deadfalls or babiche snares. Third, the model assumes that the prehistoric foragers limited their harvest of beaver to a sustainable yield. In fact, had the models not incorporated an availability constraint limiting beaver predation to 20% of the standing stock, the "optimal" beaver harvest from the first catchment zone would have been over 200 beaver even in the simplest small population models. This suggests that beaver populations in the vicinity of forager encampments would be in grave danger of extirpation. Although foragers moving into a previously unexploited territory might indulge in an initial orgy of exploiting these fatty, easily located animals, the vulnerability of beavers to rapid overexploitation probably precludes their forming the basis of the human diet for any protracted period of time. Smith (1975:137) has likewise argued that the inability to sustain exploitation limited the role of beaver in the prehistoric Eastern Woodlands diet.

In general the models have successfully accounted for the role of deer as the principal game animal in the aboriginal Eastern Woodlands. Although beaver occurs in the optimal diets of a few more models than does deer, deer provides a greater proportion of the diet. The models also point to fall and winter as the primary seasons for deer hunting. A pattern confirmed by ethnographic descriptions (Swanton 1946).

However, deer are not as prominent in the models as I would have expected. However, An examination of the sensitivity analysis of costs (Tables 4.2, 4.5, 4.8, 4.11, 4.14, 4.17) indicates that deer would constitute a larger part of the optimal diets were it not for the premium placed on beaver and mussels. As already suggested, the availability of beaver and mussels was probably more limited than the models indicate.

Somewhat unexpectedly, deer enter the nutrient-constrained models more frequently than the energy-only ones. This fact suggests that deer might have been more important as a source of vitamins and minerals than as a source of calories alone. This is because relatively cheap and abundant nuts and seeds suffice to meet caloric needs but are deficient in micronutrients, especially riboflavin and vitamin A. Deer play an important role in providing these nutrients.

More specifically it is the organ meats of deer which provide substantial amounts of riboflavin and vitamin A (Table 3.6). This raises an important question about the allocation and consumption of deer organs within the society. Whereas women and growing children have the greatest need for regular supplies of nutrients (Passmore and Eastwood 1986), it is the adult men who hunt that have first access to fresh game. If hunters in the field eat the more perishable organ meats and return only dressed carcasses to camp for allocation to others, then the adult male segment of the population may receive a disproportionate share of important nutrients. The likelihood that hunters would not return entire carcasses to the settlement would seem to increase with the distance they were forced to travel to find game. Since game is depleted from the near environs of human settlements through time (Hames and Vickers 1982), sex-

and age-dependent riboflavin and vitamin A deficiencies might be one of the first stresses experienced by a sedentary population attempting to meet its nutritional needs through long-distance hunting. Unfortunately, riboflavin and vitamin A deficiencies are not recognizable from skeletal remains (Wing and Brown 1979), so it is not possible to test the hypothesis with prehistoric Eastern Woodlands data. Furthermore, as children and women have more stringent nutritional requirements than do adult males (Passmore and Eastwood 1986), it will most always be the case that they will be the first to experience nutritional stresses. Hence, it will be difficult to differentiate empirically between nutritional deficiencies generated by age-and-gender-specific differences in the allocation of particularly critical foods from those reflecting a general inadequacy of diet.

Groundhog is the only small game animal other than beaver to enter the models, and its inclusion is highly artificial. It is taken in the summertime large population foraging models under vitamin A and vitamin C constraints. In both cases sufficient deer are available to fulfill the population's vitamin A and C requirements, but so much iron has been consumed from use of mussels that the iron-rich resources must be avoided. With faultless mathematical logic, the linear programming solves the dilemma by selecting groundhogs on the basis of their low iron to vitamin ratio. This is not the sort of criterion one expects to have guided human foraging decisions. In reality iron overload almost never results from dietary sources (Passmore and Eastwood 1986). The maximal iron constraint serves in the models as an effective and reasonably nonarbitrary means of limiting grossly excessive mussel consumption. Ironically the inclusion of small game within the optimal diet seems quite reasonable, but in this case must be considered a result of an unrealistic modeling procedure. Reasons for the absence of small game from the models will be discussed in the final chapter.

Fleshy Fruits

Fruits are not much esteemed by the models. Grape is selected in seven percent of the models in which it is available and blackberry in three percent. In all cases fruits are selected to fulfill the vitamin C constraint. Grape is also a secondary calorie source in the Large Population Early Agricultural Models. Not surprisingly fresh fruits are more important in the Foraging Strategy models than in those in which squash is available as a vitamin C source. Blackberry is selected only in the Foraging Strategy models. In the fall Early Agricultural Strategy models, grape continues to be part of the optimal diet under vitamin C constraints but unexpectedly is dropped from the optimal diet when corn becomes available. Apparently when corn production provides such a cheap source of calories, it is more efficient to focus on the production of energy-poor but vitamin C rich squash than to continue foraging for the more caloric but more costly grapes.

Fish

In only the suspect models of fall season foraging under vitamin C constraints do fish enter the optimal diets. Although fish is rarely part of the predicted optimal diet, it is frequently a secondary resource. Its greatest demand is in the winter and spring when alternative sources of vitamins and calcium are either unavailable or more expensive to procure. More interestingly, in the Large Population Foraging Strategy models, fish is a secondary resource even as an energy source, and in summer it is a secondary resource under all sets of nutritional constraints. Interpreting the models qualitatively, I would suggest that fish has a considerable potential as a nutritious food, provided it could be acquired in large numbers and at relatively low costs. Fish from the swift running rivers and streams of southwestern Virginia would not meet these

criteria, and the Appalachian highlands in general are not an area where fishing was of much aboriginal importance (Rostlund 1952).

The quite limited role fish play in the present optimal diet models is in marked contrast to previous linear programming models of Eastern Woodlands subsistence. Fishing was indicated by Keene's linear programming to be the optimal subsistence strategy of Archaic period foragers in the Saginaw Valley, Michigan during the Spring (1982). According to linear programming models, fish should have been the most highly valued resource in southeastern Indiana in both the Late Woodland and Fort Ancient periods (Reidhead 1980). The archaeological test of Reidhead's models indicated no support for such a prominent role for fish, a discrepancy which Reidhead was at a loss to explain (1980). More recently (Yerkes xxxx) it has been pointed out that the experiments Reidhead performed to estimate prehistoric fishing costs (Reidhead and Limp 1974) yielded mostly non-native fish. Hence the harvest rates they indicate cannot be extrapolated to prehistoric times. This highlights one of the disadvantages of complex models such as linear programming. As the number of estimations and calculations increases, so does the likelihood that a frank error of model construction will occur (Starfield and Blalock 1986). While the ability to deal simultaneously with a multitude of variables is linear programming's principal strength, it also makes it particularly prone to such error.

THE ROLE OF STORAGE AND INTENSIVE COLLECTING

The linear programming optimal diets indicate that plant foods, particularly hickory nuts and cultigen seed crops should form the basis of the diet in every season of the year. This intensive utilization of plants implies a substantial reliance on food storage. The model does not treat plant storage in a realistic fashion, however. First, no additional cost is attached to stored foods to reflect the time that would be required to prepare them for storage or to produce and maintain storage facilities. Since the

acceptable additional costs of hickory nuts usually range from 10% to 30% (Tables 3.1-3.11), the need to dig large storage pits or construct substantial cribs may have made stored hickory nuts unattractively expensive. Second, the models always assume a constant production of resources. No allowance is made for bad years in which no storable surplus would be available. Since mast crops, in particular, are subject to periodic failures every two to five years (Fowells 1965), investing in storage facilities may have seemed an even less attractive option. Of course, the same variability in annual yields might make storage more attractive, provided it was possible to store a nut surplus from one year to the next. However, the limited period of time available to gather the nut harvest would hamper efforts to collect a multi-year windfall.

An intensive reliance on food storage does not seem to characterize the Eastern Woodlands before the emergence of food production. Rather it has long been accepted that Eastern Woodlands foragers of the Archaic period were highly mobile and practiced a seasonal round of residential moves that allowed them to strategically fit their residence location to seasonally available resources (Caldwell 1957; Brown and Price 1985).

To determine if the removal of stored foods would create a more balanced reliance on seasonally available foods, the Small Population, Vitamin C Pattern Foraging Strategy model was rerun with hickory nuts and chenopod removed from the available spring resources. The new optimal diet was composed of 5 deer, 14 beaver, 544 kg of greens and 1181 kg of acorns. Although hunting was of increased importance, a stored plant food was still the staple commodity. Re-running the model with acorn removed produced an optimal diet of 1 deer, 14 beaver, 987 kg of greens and 701 kg of walnuts. Again a stored plant food was of key importance. Finally with walnut removed, rerunning the model produced a diet composed entirely of fresh foods: 14 beaver, 110 deer and 463 kg of greens. The fresh foods diet is about 5 times more time-consuming than is the original hickory nut based diet. Furthermore, the

level of deer harvest - more than eight deer per week - would seem difficult to sustain during a season in which deer become increasingly solitary and less mobile (Scanlon et al. 1983).

In light of the difficulty encountered removing stored nuts and chenopod from the optimal diet, and the suspect hunting strategy that replaces storage, it seems difficult to discount the role of stored plant foods during the spring season. In retrospect, it appears that a single subsistence strategy emphasizing deer hunting and stored plant foods would be optimal during the period of time from the late fall deer-rut and mast-harvest until deer-fawning and the greening of the leaves made hunting less fruitful in late spring.

There is some support that such a strategy was in fact followed by Eastern Woodlands foragers, although surprisingly few reconstructions of the seasonal round have been proposed for the Eastern Woodlands. For the Late Archaic period middle Tennessee River region, it has been proposed (Jenkins 1974) that May to October was spent at riverine shell midden locales where mussels, fish, and riverine animals and plants were exploited, while November to December was spent in upland settlements for the exploitation of fresh and stored nuts and game. Jenkins model seems reasonable for the Tennessee river, or for any region where substantial mussel shoals are available. The shell mounds of the Green River, Kentucky also seem to have been inhabited from late spring to late fall (Marquardt and Watson 1983).

The bipartite cool season - warm season pattern receives some support for later periods as well. For the Woodland period (300 B.C. - A.D 1000) in the upper Mississippi River region, Theler (1987) argues from faunal remains data that the spring and summer were spent at shell middens exploiting fish and mussels, while the fall and winter was spent in the uplands hunting deer intensively and small game such as beaver and raccoon opportunistically. Plant foods were not considered in Theler's (1987) study.

Even after sedentary communities and food production were established in the Eastern Woodlands, a cool season - warm season shift in foraging strategies seems evident. For the early Late Woodland period lower Illinois River region, the warm season strategy emphasized fish and mussels, and the cool season deer hunting and nut collecting (Styles 1981). For the Mississippian period, Smith (1975) found that faunal exploitation in the Middle Mississippi region emphasized fish, turtles and rabbits in the warm seasons and deer, migratory waterfowl, and small game in the cool seasons.

In the above reconstructions the warm seasons are indicated to have been spent exploiting aquatic resources, particularly mussels and fish. Notably all of the reconstructions deal with locales such as the Tennessee or upper Mississippi Rivers which have prominent mussel shoals, or with locales such as the lower Illinois River Valley or the Middle Mississippi region which are characterized by highly productive mature river systems with numerous oxbow lakes and sloughs. Southwestern Virginia, however, does not have such productive aquatic environments, so aquatic resources are likely to have been less abundant.

Nonetheless, the linear programming suggests that mussel collecting in southwestern Virginia would be a key source of nutrients in the summer. However, the models also suggest that collecting mussels would be "subsidized" with cheap energy from stored plant foods. The absence of shell middens from southwestern Virginia suggests that the models have not portrayed correctly the role of mussels in southwestern Virginian prehistoric diets. To investigate the possibility that the unrealistic treatment of storage creates this discrepancy, the Small Population Foraging Strategy Vitamin C Pattern model for summer was re-run with hickory nuts removed. The optimal diet of this modified model was 51 kg of mussels, 271 kg of greens and 1208 kg of chenopod. Although mussel consumption is cut to 10% of its former level (confirming the suspicion that cheap hickory nut calories complement mussels) the inclusion of stored chenopod renders the new diet equally unrealistic. Removing

chenopod as well as hickory produces an optimal diet composed of 2295 kg of fish, 181 kg of blackberries, and 474 kg of mussels. The new diet is about 60% more costly than the original hickory-focused one, but still requires only about 2.4 hrs per producer per day. Quite interestingly the all-fresh-food optimal diet is even more riverine focused than the original one. Hence, a seasonal round in which the summer is spent exploiting aquatic resources receives some support from the models. However, this is tempered by the fact that the new optimal diet for 25 people requires about 25 kg (55 lbs) of fish per day. A broader diet would seem more reasonable.

The seasonal subsistence pattern suggested by the models is supported in part by the sole study of aboriginal Virginian seasonal rounds. From a Late Woodland period site in the Virginia piedmont, Waselkov (1977) argued for a seasonal round which emphasized fall nut-gathering and small game hunting, and winter deer hunting and the use of stored food. During the spring, small game was the focus of subsistence, and during the summer, fish, turtles and fresh plant foods were emphasized (Waselkov 1977). This varies from the models' predictions in the emphasis placed on small game in the spring and in the range of resources taken in the summer. The revised model which removes stored plant foods from the summer larder more closely approximates Waselkov's (1977) empirically determined summer diet.

SUMMARY

As heuristic tools for exploring prehistoric Eastern Woodlands subsistence strategies, the linear programming optimal diet models have been useful in illuminating: (1) the potential importance of nutrient constraints in shaping prehistoric diets, (2) the relative strengths of population pressure and coevolutionary explanations of Eastern Woodlands subsistence change, (3) the roles of particular resources in the diet, and (4) the potential importance of storage versus intensive collecting in prehistoric Eastern Woodlands subsistence economies.

The linear programming models indicate that energy requirements would have the most influence on shaping diet choice. However, a least-cost diet aimed only at meeting caloric needs would focus too narrowly on nuts or maize and leave other nutrient requirements unfulfilled. The requirements for B-vitamins, especially riboflavin, were important for broadening the diet to include game and shellfish. Protein was always obtained in excess, but this result may be misleading in that the models considered only gross protein and not necessary amino acids. Iron was also usually obtained in abundance, but some optimal diets consisted entirely of plant foods, which may not have yielded iron in a usable form. Vitamin A was most cheaply obtained by the consumption of fresh potherbs, but meat, particularly organ meats, was also an important source. Calcium needs were fairly influential in shaping optimal diets. Potherbs and shellfish were particularly important sources. Vitamin C was second only to energy in its influence on the optimal diets, but some significant sources -- such as conifer infusions -- may have been overlooked, or Native Americans may have coped with shortterm, season vitamin C deficiencies.

The relative importance of calcium and vitamin C in shaping the optimal diets is a robust finding of this and earlier linear programming studies of Eastern Woodlands subsistence (Reidhead 1980; Keene 1991). It is intriguing that the two nutrients indicated to be most costly even in a permissive temperate forest environment are also the nutrients for which humans successfully adapt to a wide range of intakes (Passmore and Eastwood 1986). This suggests perhaps that a physiological adaptation to low calcium and vitamin C intakes may have mitigated the need to structure diets to insure their abundant supply. Certainly, the optimal diets focusing on calcium and vitamin C are not well supported by empirical evidence, nor do calcium or vitamin C deficiencies seem to have been of much importance in the Eastern Woodlands.

The linear programming models also indicated that at an ordinal level of measurement, the relative cost-effectiveness of the resources did not vary greatly under

differing nutrient constraints. This suggests that nutritional requirements might have had little influence on decisions about whether or not to exploit a resource.

Furthermore, if exploitation of resources were encounter-contingent, then the diets that resulted would be broader than the usually narrow linear programming ones, and hence, more likely to be nutritionally adequate. This suggests that complex linear programming models involving nutrient constraints may have few advantages over simpler, encounter-contingent models dealing with energy alone.

Increasing the population size to 250 from 25 in the linear programming models caused a slight widening of diet breadth and increased the level of exploitation of the highest ranked resources. More interestingly, the eventually domesticated native annuals, chenopod, maygrass, sumpweed and squash, entered an least one optimal diet in the small population models as a wild food. In addition corn agriculture was a least-effort strategy in the small population models. Since the population density in these models was less than 0.1 person/mi^2 , this indicates that population pressure is not necessary to compel the exploitation of small seeds or the adoption of agriculture. A coevolutionary explanation of agricultural origins (Smith 1987b) is better supported by the models results.

Only 14 of the 35 resources included in the models entered an optimal diet. The models correctly capture the importance of the Eastern Woodlands staples corn, deer and hickory nuts. Their selection of mussels, greens, grape, blackberry, and fish is intuitively satisfying, although perhaps mussels are overemphasized and fruits and fish underemphasized in the optimal diets. Maygrass, chenopod and sumpweed are all indicated to be of possible importance as sources of calories for foragers, particularly if hickory nut consumption were constrained. Interestingly, chenopod and sumpweed are indicated to be potentially most important as stored foods that could supply b-vitamins and calcium in the winter and spring. Squash is indicated to be an important source of vitamin C. It would be particularly valuable as a stored commodity in winter when

good sources of vitamin C are few. And indeed some Native Americans did dry squash for storage (Wilson 1917).

The linear programming optimal diets omitted some important foods. No important Eastern Woodlands game animal, except for deer, entered an optimal diet. Wild turkey, raccoon, and bear were all ignored in favor of beaver or more rarely groundhog. The discrepancies are most likely the result of faulty cost estimations, the absence of encounter-contingent foraging, and an assumption that only sustainable yields of highly valued game would be harvested. Acorns, walnuts and butternuts were ignored by the models, yet all seem to have been exploited widely in the Eastern Woodlands. The reasons for the discrepancies may be faulty cost estimations, an unreasonably generous allotment of hickory nuts which mitigated the demand for the other nuts, or the inability of the models to account for exploitation of less cost-effective resources when their opportunity costs were low.

A somewhat unexpected result of the linear programming was the importance attached to stored nuts and seeds as staple foods for foragers. A reliance on food storage does not seem characteristic of Eastern Woodlands subsistence prior to food production. The discrepancies are probably the result of failure to account for the costs of building and maintaining storage facilities, overly high estimations of animal procurement costs in the spring and summer which lessen the demand for fresh foods, and perhaps the assumption of game harvests limited to sustainable yields. The need to relocate settlements following localized game depletion may have outweighed the advantages to be gained from sedentism and food storage.

CHAPTER VII LIMITATIONS OF LINEAR PROGRAMMING DIET SELECTION MODELS

The present study of prehistoric diet selection has produced mixed results. Some parts of the modeled optimal diets are congruent with the archaeological record while others are not. In particular, the models failed to replicate the breadth of resources that were exploited in the prehistoric Eastern Woodlands, although they did incorporate the staple foods, maize, hickory and deer. A mixed result is not necessarily a bad thing, since the purpose of a model is to provide insight into complex systems, not merely to mimic reality (Foley 1985). Because of their heuristic value, a model's inaccuracies are often more interesting than its successful predictions.

However, not every failure of a model need illuminate some deficiency in our understanding of the real world. All analytic methods have limitations, and certainly linear programming modeling is no exception. I wish to address in this chapter some factors inherent to linear programming optimization models which may limit their ability to predict human diets accurately.

THE PROBLEM OF PERFECT INTELLIGENCE

Although in reality all people make decisions based on imperfect information, linear programming models contain an assumption that decision-makers possess perfect knowledge of all factors that should influence their decisions. This assumption plays a critical role in determining what diets should be optimal, particularly for foragers.

It seems the rule that foragers search for multiple resources simultaneously and then decide upon encountering a particular resource whether to pursue it or to continue searching for more desirable resources (Winterhalder 1981; Smith 1983). Thus

whether or not a particular resource enters the forager's diet is contingent on the probability of encountering that resource vis a vis more highly ranked resources (Winterhalder 1981; Smith 1983). Linear programming, however, does not allow for this sort of encounter-contingent decision-making. Rather linear programming models of subsistence choice treat the actor's environment as if it were a very familiar supermarket in which the location, abundance, cost, and benefit of each resource is perfectly known before foraging begins. Armed with this sort of information, a forager could always take only the best of everything. Thus linear programming optimal diets are generally quite narrow. While they are useful as ideal templates against which real diets can be judged (cf. Foley 1985), they are often poor reflections of reality.

The skewing influence of perfect intelligence on linear programming's optimal diets can be lessened by forcing the model to expand the diet. This can be done in two ways. First, the availability of the highest ranked resources can be artificially limited. This is the tack taken by Reidhead (1976), who models only the resources available within 3.5 km (2.2 mi) of the Leonard Haag site. Not surprisingly, availability constraints play an important role in determining diet breadth in Reidhead's models (Jochim 1983). Although limiting the availability of the high ranked resources is an effective means of creating more realistic diets, it does force the modeler to predetermine diet breadth to some extent. Unfortunately diet breadth is one of the factors that the models are supposed to illuminate, so its predetermination compromises the modeling endeavor.

The second means of broadening linear programming optimal diets is to introduce additional constraints which might favor otherwise lowly ranked resources. For example, in the present study, the maximal iron constraint precluded the consumption of astronomical amounts of mussels. Adding constraints, however, makes the model more complex. Increased complexity increases the probability that erroneous or unreasonable features will be introduced into the model (Starfield and Blalock 1986).

In the present study the maximal iron constraint can be criticized as unrealistic, as iron overload is rarely a danger from dietary sources (Passmore and Eastwood 1986). Increased complexity also decreases the interpretability of the model (Boyd and Richardson 1987). For example, in the present study groundhog sometimes enters the optimal diet during seasons of potential iron overload. Although exploiting groundhogs is an intuitively reasonable summertime pursuit, I am skeptical that it resulted from their relative iron content.

Rather than adding constraints to the models, it has been suggested that modifying the cost measure might enable linear programming to predict broader diets. In particular, it has been suggested that an assumption of simultaneous searching might be incorporated into linear programming formulations by averaging the costs of taking a resource over all types of forays in which it might be taken (Durham 1981:221). Unfortunately this will not work. The model would merely relate the benefits of the resources to their new averaged costs and select the resource with the best ratio. The optimal diet would remain unreasonably narrow.

Since linear programming must use invariant, predetermined costs, the assumption of perfect intelligence is inherent in the method. Thus it is limited as a tool for predicting forager diets, since these seem to be structured by encounter-contingent decision making (Winterhalder 1981). Whereas, foragers in the real world pursue resources that are less than ideal when they recognize that the immediate probability of doing better is low, linear programming never allows for probability. Since linear programming cannot allow for probabilistic outcomes, it cannot encompass the entire complexity of human diet choice.

Recognizing linear programming's inability to deal with encounter-contingent foraging does not imply that this study has been a fool's errand. On the contrary, the consistent failure of linear programming to predict reasonable diets has drawn attention to the critical importance of encounter-contingency as a factor in determining diet

breadth. This is a heuristic insight of considerable importance for understanding human subsistence. The importance of encounter-contingency relative to other factors such as nutritional requirements was not apparent prior to systematic modeling.

THE PROBLEM OF NUTRIENT CONSTRAINTS

Humans cannot live by energy alone but must continually provision themselves with a suite of vitamins, minerals and amino acids. Investigating how this need for micronutrients might constrain diet choice is a complex problem. In fact, it is the interest in nutrient constraints that mandates the use of linear programming, since linear programming is designed to solve complex problems with multiple constraints. Nonetheless incorporating nutritional constraints into diet selection models creates a number of practical and conceptual problems.

The practical difficulties of modeling diet choice with nutritional constraints are considerable. First, there remain uncertainties about basic aspects of nutrition. There is considerable debate about the level of necessary intake for many nutrients, and it is generally unclear for what period of time a nutritional shortfall can be maintained before fitness is reduced (BNS 1983). In addition, modeling traditional diets is hampered by the limited data on the nutrient composition of "bush" foods. As a result of these facts, creation of a model of diet choice with nutrient constraints will inevitably force the modeler to make numerous extrapolations, estimations and judgement calls. These uncertainties, combined with the overall increased complexity of the nutritional constraint models, increase the likelihood that errors will be introduced into the models (Starfield and Blalock 1986).

Ironically in spite of the great complexity of models of diet selection with nutrient constraints, they remain incomplete (Hill et al. 1987; Hill 1988). At present there are over 40 substances which have been determined to be necessary for the maintenance of human health (Pellett 1987) Most of these seem to be of no practical

importance for human diets, since they are so widely distributed in foods or needed in such minute amounts (Passmore and Eastwood 1986). Nonetheless there is always a possibility that some nutrient not included in the models might play a significant role in human subsistence. Recently the need for lipids (dietary fats) has been suggested as a factor in promoting energetically suboptimal hunting by South American foragers (Hill 1988) and in selecting against the consumption of lean meat by late prehistoric - early historic period bison hunters on the southern plains (Speth and Spielmann 1983). The inclusion of lipids in future models of prehistoric subsistence would seem to be a promising avenue of study. However, it is presently hampered by the lack of data on the essential fatty acid content of "bush" foods and by uncertainties concerning the RNA of the essential fatty acids (Speth and Spielmann 1988; Medical Services Branch 1985; Watt and Merrill 1963).

Adding nutritional constraints to optimal diet models creates a theoretical problem in that it presupposes that humans are able to make nutritionally optimal choices. Nutritional optimization would require that people be able to monitor their own nutritional status in order to assess what nutrients were needed. Furthermore, since food-sharing is characteristic of humans, nutritional optimization would also require an ability to assess the nutritional needs of dependents. Of course, such considerations might not necessarily reach the level of human consciousness. If during the evolutionary past, nutritional optimization were of critical survival value, natural selection might perhaps have engendered some predisposition to fulfill nutritional requirements.

However, it is much more difficult to imagine how natural selection could engender the ability to fulfill nutritional needs with only optimal resources. To select an optimal resource mix, people would require not only the inclination to partake of different nutrients, but also the ability to judge the relative merits of acquiring different combinations of nutrients (Smith 1981). For example a person might need to choose

between either a fruit with 20 mg of riboflavin and 4 mg calcium or a tuber with 30 mg iron and 6 mg vitamin C. Is it reasonable to expect such a detailed and knowledge-laden calculus? Finally, since the body maintains stores of most nutrients (Passmore and Eastwood 1986), it would be cost-effective to accept short-term deficits in some nutrient intakes in order to lower the immediate costs of obtaining others. However, to do this in an optimal manner, people would need to be able to predict future availabilities and abundances of resources with great accuracy (Smith 1983).

Overall, I think that compared to energetic efficiency, the optimization of nutrient intakes is an unlikely outcome of most subsistence adaptations. Because of their physiological ability to maintain nutrient homeostasis under a wide range of conditions (Passmore and Eastwood 1986), humans in most environments may not require complex cultural adaptations (i.e. diet optimization) to insure that nutritional needs are met. Whereas humans require an intake of energy on nearly a daily basis, most nutrient shortfalls can be weathered for weeks to months (Passmore and Eastwood 1986). Thus it seems that the selective pressure for optimizing nutrient intakes might not be as frequent or as consistent as those for energetically-efficient diet selection.

As a rule of thumb, a varied diet is most likely to meet nutritional needs, and as omnivores, humans are presumably predisposed to eat a variety of foods. Food sharing, especially if combined with a sexual division of labor, would help to broaden human diets. In addition, choosing foods in an encounter-contingent manner should also serve to broaden the diet. Hence, foragers in a resource-varied environment may have satisfied their nutritional requirements as an incidental product of energetically efficient foraging. Hence, regions such as the temperate forest may not have required special dietary adaptations aimed at providing necessary nutrients. However, nutrient constraints may have played a larger role in diet choice in more extreme or highly seasonal environments that limit dietary variety (Casimir 1981; Speth and Spielman 1983).

So far, the linear programming models of prehistoric subsistence with nutrient constraints (Reidhead 1976; Keene 1979; and this volume) have failed to demonstrate convincingly that nutrient constraints structured resource selection in the prehistoric Eastern Woodlands. Certainly the results do not seem to warrant abandoning simpler models using energy or energy and macronutrient constraints in favor of more complex models incorporating micronutrients.

THE UTILITY OF PRECISE MODELS FOR ARCHAEOLOGY

Linear programming models produce highly precise outputs. However, the usefulness for archaeologists of linear programming's precision is limited by the coarse resolution of the archaeological record. Whereas linear programming optimal diet models specify exact counts of the optimal resources, zooarchaeological and paleoethnobotanical analyses only allow rank-order measurement of subsistence remains. Thus the high precision of linear programming is of little practical use for archaeological research. Since all models are a compromise of precision, realism and generality (Levins 1966), archaeologists would seem better advised to explore more thoroughly the less precise, more general graphical models used in optimal foraging studies (Winterhalder 1981; Yesner 1981).

I do not wish to imply that archaeologists should abandon modeling altogether. Rather there should be a creative interplay between model construction and archaeological empiricism. Even if as some archaeologists have suggested, the absence of critical data concerning past subsistence practices limits diet selection models to serving as rough analogies (Bettinger 1981), this alone is useful. Testing the implications of a model developed a priori from diet selection theory would at least be an advance over the all-too-common practice of explaining archaeological patterns by matching them post hoc to ethnographic analogies or to commonsense notions about human behavior.

However, I confess to some disenchantment with linear programming as tool for studying Eastern Woodlands subsistence. This is because the construction and testing of the linear programming models has indicated that the contingencies of prey encounter are an important factor in structuring prehistoric diet selection. Models such as linear programming that cannot account for encounter-contingency may be too unrealistic to be of much utility. Future modeling efforts would seem better spent in exploring more realistic models that can deal with encounter-contingency.

Developing encounter-contingent models for prehistoric subsistence will require information on prehistoric subsistence tactics and their costs and on the abundance and distribution of prehistoric resources. Proxy measures of prehistoric subsistence costs can be generated by ethnographic studies of modern peoples (Hill et al. 1987) and by experimental replication of subsistence tasks (Munson 1984). Understanding the abundance and distribution of prehistoric resources can be illuminated by modern ecological (McCullough 1979) and wildlife management sources (Goodrum et al. 1971). However, the nature of the catchments that surrounded prehistoric settlements will always remain a critical variable in structuring the subsistence strategies practiced there. Archaeologists studying prehistoric subsistence might do well to emphasize reconstruction of prehistoric environments (Thompson and Hattori 1983) and on relating archaeological subsistence remains to local catchments (Styles 1984). In addition, the recovery and quantification of archaeological subsistence remains will remain the primary window into prehistoric subsistence. Modeling, regardless of its sophistication, cannot replace the empirical study of the archaeological record. It can, however, augment empiricism by generating ideas and hypotheses and guiding the search for data. A mix of modeling and fieldwork seems the optimal choice for improving both our data and our understanding.

APPENDIX A EXCAVATION OF THE DAUGHERTY'S CAVE SITE -- 1982-83

The Daugherty's Cave site (44Ru14) is located in Russell County in southwestern Virginia (Figure A.1). Daugherty's Cave is a moderate sized cavern with a depth of about 300 feet, but only the rockshelter portion lying immediately outside the cave proper shows evidence of human occupation. The site is located at the head of a small cove about 100 ft west of, and about 80 ft above, Big Cedar Creek. Near the cave Big Cedar Creek is about 30 ft wide and varies in depth from about two to probably about six ft. It joins the Clinch River about 4.5 miles downstream from the site.

Southwestern Virginia lies within of the Ridge and Valley physiographic province of North America (Fenneman 1938). The region is characterized by alternating southwestern - northeastern ridges and valleys and by karstic terrain. Caves and sinkholes are common, and chert suitable for stone tool manufacture occurs abundantly (Woodward 1938; McIlheny 1983).

The climate of Russell county is mild. Average annual temperature is 54^o F. and the annual average rainfall is 49 in (Woodward 1938). The frost-free period extends usually from about April 20 to October 30, and the growing season is about 180 days long (Woodward 1938). As in any mountainous region, however, there is local variation in climate due to the effects of altitude and topography. Elevations in Russell county range from about 1350 ft to 4700 ft AMSL (Woodward 1938) with Daugherty's Cave situated at 1880 ft AMSL.

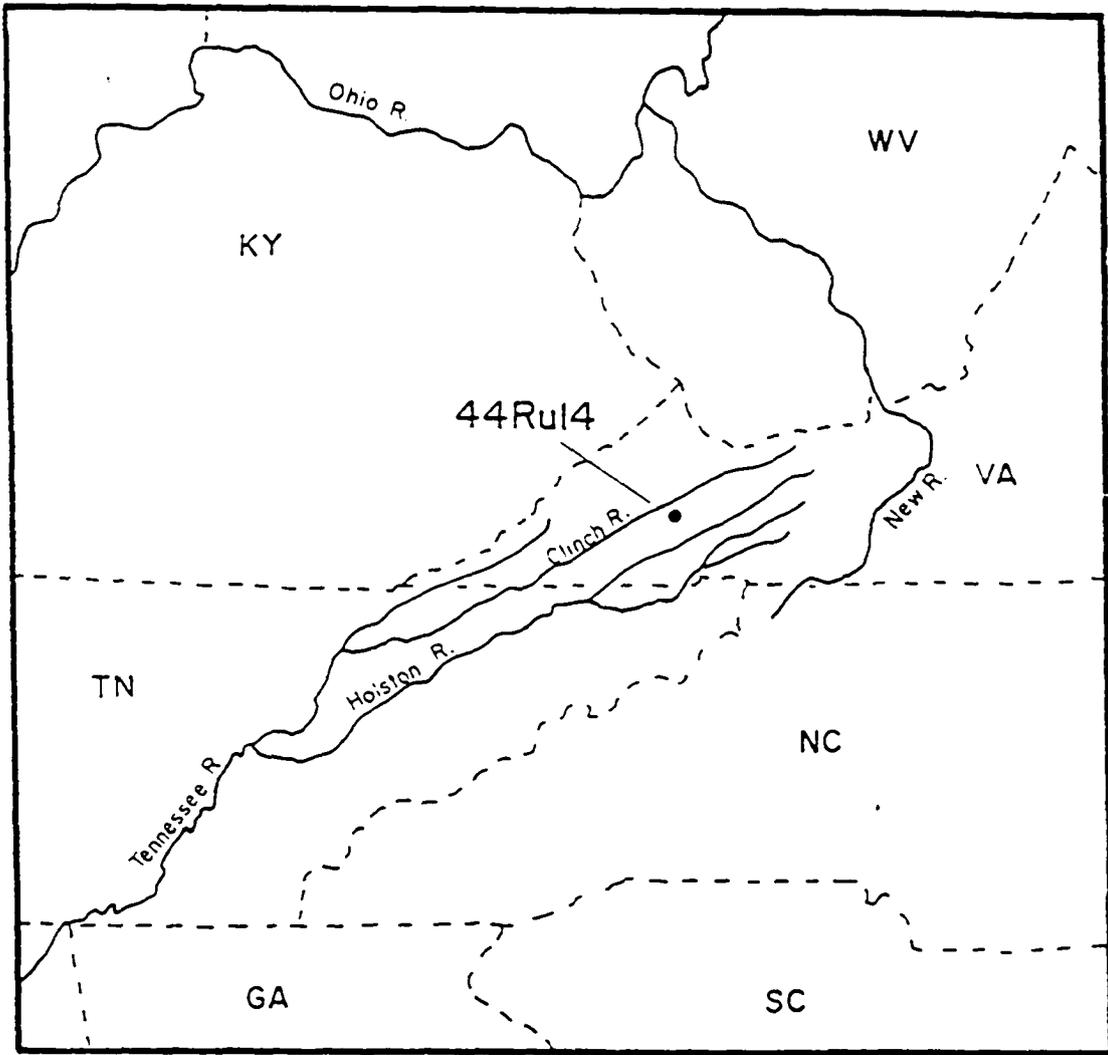


Figure A.1: Location Map of the Daugherty's Cave Site

PRIOR EXCAVATIONS

From May to August 1967 Joseph Benthall, then of the Virginia State Library, excavated at Daugherty's Cave with a crew composed of members of the Archaeological Society of Virginia and other nonprofessional volunteers (1969, 1975). Benthall excavated a trench 30 ft by 10 ft by 10 ft deep in the southern end of rockshelter. The excavation was by natural strata subdivided into 4 in levels. Trowels were used to remove the fill, and the wet soils of the site precluded dry-screening. Although Benthall reports that the fill from the site was carried to Big Cedar Creek and washed (1975:11), this apparently refers to washing the recovered trowel-sorted material and not to waterscreening the soil matrix (Benthall, personal communication 1983).

Benthall recognized 10 natural strata and seven cultural zones. The material recovered included ceramics, lithic and bone tools, faunal remains and a small amount of carbonized plant remains. Temporally the site was seen to span the period from the Mississippian New River phase (ca. A.D. 1200 - A.D. 1600) to the Early Archaic Kirk (ca. 8000 B.C. - 6500 B.C.) phase with only the Middle Archaic period (ca. 6000 B.C. - 3000 B.C.) not being represented by an occupational strata.

Three radiocarbon dates were obtained. A pit feature in the lowest level of Zone A produced a date of A.D. 322 \pm 70 associated with Wright Check-Stamped, Candy Creek Cordmarked and Long Branch Fabric-Imprinted pottery and mica fragments. This same level yielded a carbonized corn cob, the only cultigen remain recovered by Benthall. A rock hearth in Zone F. produced a date of 3740 B.C. \pm 260. No diagnostic artifacts were associated with the hearth, but Zone F. is considered an early Late Archaic period zone. It yields small stemmed projectile points classified by Benthall as Cedar Creek points (1975) and is stratigraphically below a zone yielding Savannah River projectile points. Finally Zone J, the lowermost strata producing

cultural material, yielded a date of 7840 B.C. \pm 400. The only diagnostic artifact from this zone is a single Kirk corner-notched projectile point (Benthall 1969, 1975).

Benthall's work was aimed at providing a chronological framework for southwestern Virginia based on a stratigraphic sequence of material cultural. Benthall's excavation accordingly emphasized the recovery of diagnostic artifacts with only ancillary attention paid to obtaining subsistence remains. Hence I anticipated that a further excavation of site emphasizing the systematic recovery of faunal and botanical remains would complement the previous work and provide direct evidence of subsistence change in this little investigated section of the Eastern Woodlands.

THE 1982-83 EXCAVATIONS

From August 4 to September 29, 1982 the author and Nick Coleman began a second excavation of the Daugherty's Cave site. Excavation began by mapping the rockshelter portion of the cave, then re-exposing the south and east profiles of the eastern portion of Benthall's 1967 trench. The south profile of Benthall's unit was designated the 0N line and the east profile the 10.5E line. Two 1.5 m squares designated from their SE corners as 1.5N12E and 0N12E were laid out along the east edge of Benthall's trench, and squares 1.5S10.5E and 1.5S9E were laid out along the eastern portion of Benthall's south profile (Figure A.2). A permanent datum was established by chiseling an "X" onto the corner of a large breakdown boulder near the rear of the shelter.

The excavation plan was to dig by natural strata subdivided into 10 cm levels if the thickness of the strata so warranted. Twenty liters of soil from each level were to be waterscreened and twenty liters floated. The remainder was to be screened through 0.25 in mesh. Features, postmolds and intrusions would, of course, be isolated and excavated separately.

While this plan was adhered to during the 1982 field season, several factors combined to reduce its effectiveness and to slow progress. First, the late summer of 1982 was one of southwestern Virginia's wettest. Water dripped from the roof of the shelter nearly continually and turned the site matrix into gummy mud. This was time-consuming to dry-screen. Further the wet soils tended to be somewhat unstable making the profiles along Benthall's trench prone to collapse. Had Daugherty's Cave been an open site rather than a rockshelter, it would have been deemed too wet to work. A second difficulty soon encountered was that the thick, relatively level soil strata described by Benthall (1975, and personal communication 1981) were not in evidence. Rather the upper zones were composed of many thin, superimposed lenses, and soil coloration changed dramatically over short distances horizontally as well as vertically. Attempting to tease apart the thin lenses in order to follow natural strata proved time consuming and frustrating. The final difficulty was that the rockshelter opening faced north; hence the excavations never received direct sunlight. As a result the north and east profiles of the squares were in perpetual shadow rendering them of little use as guides to excavation. Initially Coleman lanterns were employed to illuminate the profiles, but the harsh white light they produced washed out soil color differences completely. Hence the lanterns were soon abandoned and excavation guided largely by the naturally illuminated south and west profiles alone.

When the 1982 excavations were closed after eight weeks, square 1.5N12E had been excavated to a depth of about 60 cm, square 1.5S9E to a depth of about 65 cm, and square 1.5S10.5E to a depth of about 75 cm. Square 0N12E was not excavated in 1982.

In the summer of 1983 the author resumed excavation at Daugherty's Cave assisted by Stan Bukowski. The excavation procedures were modified in the following ways. First, dry-screening of soil was abandoned. All matrix not floated or

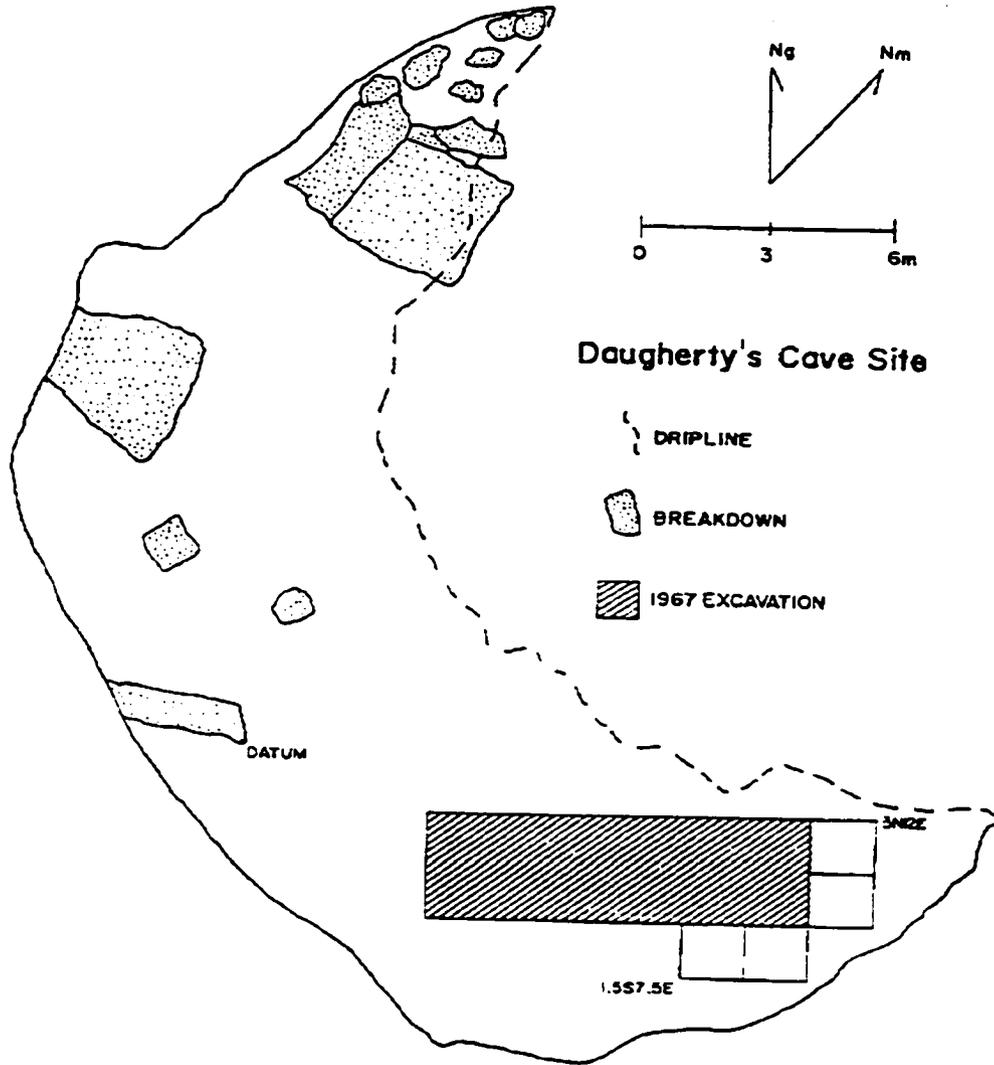


Figure A.2: Site Plan of the Daugherty's Cave Site

waterscreened through window screen was carried to the creek and washed through 0.25 in mesh. Second, the vertical unit of excavation was shifted from levels-within-zones to zones-within-levels. That is, squares were dug in 10 cm arbitrary levels with different zones within a level kept separate. Although this does not free the archaeologist from the complexities of separating thin soil lens, it is much easier conceptually to deal with strata in 10 cm slices rather than trying to follow their natural dips, pitches and variations in their entirety. A final modification of the research plan was to abandon excavation of squares 1.5N12E and 1.5S9E. Excavation of square 1.5N12E was abandoned because its location in the northeast corner of the excavation block left it with only poorly lit north and east profiles. Excavation of square 1.5S9E was abandoned in order to maintain a west profile for 1.5S10.5E.

At the end of the 9.5 week field season square 1.5S10.5E was excavated to a depth of 165 cm and square 0N12E was excavated to a depth of 140 cm. In all about 10 m³ (358 ft³) were excavated. All diagnostic artifacts were piece-plotted.

Table A.1 lists the components recognized during the 1982-83 excavations, their cultural historical affiliations, and the zones and levels comprising them. Table A.2 lists the radiocarbon dates acquired during the 1982-83 excavations. Figure A.3 displays the site profile along the 0N12E to 0N9E line.

STRATIFICATION, FEATURES, AND RADIOCARBON DATES

Component 1: Historically Disturbed

The uppermost component of Daugherty's Cave represents strata disturbed during modern times. The soil of the disturbed zones is a dark grey to brown loam, the upper portions of which contain a large amount of organic matter introduced by cattle and sheep, which use the shelter as a refuge from heat and inclement weather. In addition the first 10-20 cm of soil are highly churned by the feet of the livestock.

Table A.1: Components Recognized at the Daugherty's Cave Site (page 1).

Component Number and Temporal Period	Square and Levels
1. Historically Disturbed	1.5N12E Zone 1
	0N12E 0 - 30 cm Fea. 107
	1.5S10.5E Zone 1 - 2
	1.5S9E Zone 1 - 2
2. Mississippian	1.5N12E Zone 2-4, level 1
	0N12E 30 - 50 cm
	1.5S10.5E Zone 3 Fea. 102
3. Middle Woodland	1.5N12E Zone 4, levels 2 - 4 Fea. 103, 104, 105
	0N12E 50 - 90 cm
	1.5S10.5E Zone 4 to 85 cm Fea. 108
	1.5S9E Zone 3 to 65 cm Fea. 106

Table A.1: Components Recognized at the Daugherty's Cave Site (page 2).

Component Number and Temporal Period	Square and Levels
4. Early Woodland	1.5N12E Top of 1983 excavation to 70 cm 0N12E 90 - 110 cm 1.5S10.5E 85 - 105 cm 1.5S9E 65 - 75 cm Fea. 101
5. Late Archaic	0N12E 110 - 140 cm 1.5S10.5E 105 - 165 cm

Table A.2: Radiocarbon Dates from the Daugherty's Cave Site
1982-83 Field Season

Lab No.	Level (cm)	C-14 Age B.P.	Uncalibrated "date"
Square 0N12E			
Beta-19269	30-40	480 \pm 60	A.D. 1470 \pm 60
Beta-19270	45-50	1050 \pm 60	A.D. 900 \pm 60
Beta-19271	50-60	1580 \pm 70	A.D. 370 \pm 70
Beta-19272	60-70	1570 \pm 70	A.D. 380 \pm 70
Beta-19274	80-90	1370 \pm 80	A.D. 580 \pm 80
Beta-19276	100-110	2520 \pm 80	570 B.C. \pm 80
Beta-19278	120-130	3600 \pm 70	1650 B.C. \pm 70
Beta-19279	130-140	3800 \pm 70	1850 B.C. \pm 70
Square 1.5S10.5E			
Beta-19268	Zone 3	470 \pm 70	A.D. 1480 \pm 70
Beta-19273	65-75	1370 \pm 60	A.D. 580 \pm 60
Beta-19275	85-95	2090 \pm 80	140 B.C. \pm 80
Beta-19277	115-125	3580 \pm 70	1630 B.C. \pm 70
Beta-19280	135-145	4300 \pm 80	2350 B.C. \pm 80
Beta-19281	155-165	4690 \pm 70	2740 B.C. \pm 70

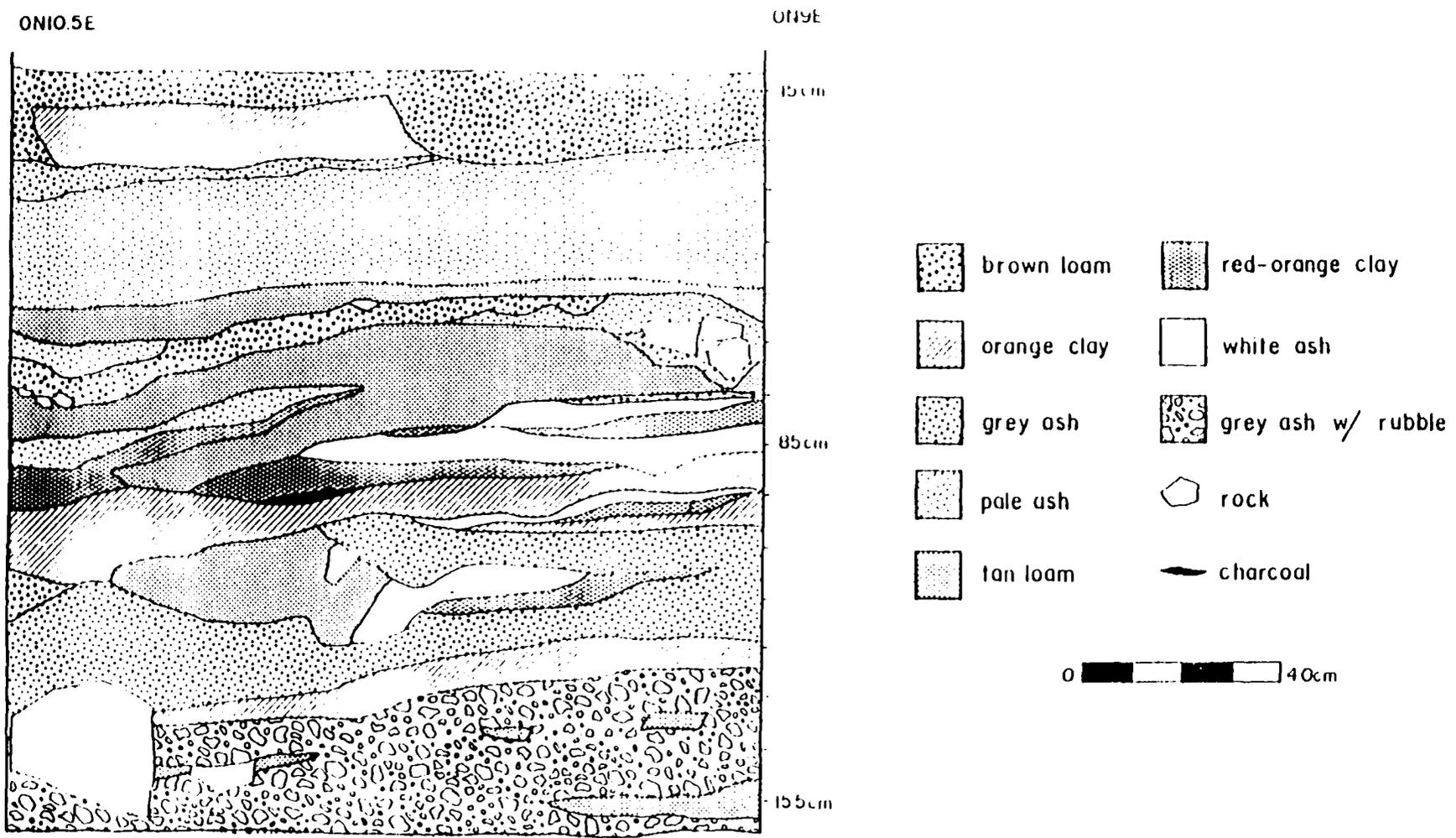


Figure A.3: Profile from ON12E to ON9E.

Extending 20 - 40 cm below this "cow zone", the loam is more consolidated but shovel-disturbed and contains a mixture of cinders, metal fragments, Euroamerican artifacts and mostly late prehistoric materials. It is assumed the digging has been done by fishermen seeking worms for bait, since Daugherty's Cave has escaped the attentions of pothunters due to the vigilance and stewardship of the landowner. Also helpful in this regard is that neither the surface of the shelter nor of the talus slope produce artifacts.

Feature 107, an animal burrow, had its point of origin in the historically disturbed zone of square 0N12E. The portion exposed by the excavation measured 25 cm wide by 120 cm long by 20 cm deep. It contained a single shell-tempered cordmarked sherd, debitage, bone, charcoal and a cinder.

Component 2: Mississippian Period

In squares 1.5N12E, 0N12E and 1.5S10.5E, the soil strata laid down during the Mississippian period are zones of grey ashy loam and yellow ash that extent about 20-30 cm beneath the historically disturbed soil. In square 1.5S9E the Mississippian period strata have been completely destroyed by later disturbances.

In square 0N12E a prominent lens of aquatic snail shells was observed in this zone, but no features were encountered.

In square 1.5S10.5E, an area approximately 75 cm in diameter and 10 cm deep of grey ashy loam with much charcoal was removed as Feature 102. This seems not to have been a prepared basin, but rather a low area (slump) in which soils and artifacts accumulated.

Three radiocarbon dates were acquired from this component: 470 \pm 70 BP (Beta-19268), 480 \pm 60 BP (Beta-19269) and 1050 \pm 60 BP (Beta-19270).

Component 3: Middle Woodland Period

The Middle Woodland strata are comprised of generally thin lenses of ashy soil usually grey, tan or yellow in color. These Middle Woodland lenses extend about 30-40 cm beneath the Mississippian strata and are not sharply differentiated from them in soil texture or color. In square 1.5N12E the grey soils of this component tended to be somewhat more brown and loamy than in the other three squares.

In square 1.5N12E, two contiguous, amorphous areas of darker, looser soil were removed as Feature 103/104. The features were consolidated when it became apparent that no pit edge separated them. This area is a natural slump.

Feature 105 was a small rock hearth comprised of rubble and charcoal spread across the northeastern quadrant of square 1.5N12E at an depth of about 0.5 m beneath the present surface. Associated artifacts were two limestone-tempered cordmarked potsherds, a bone pin and debitage.

In square 1.5S9E a dark grey loam slump area at approximately 60 cm beneath the surface was excavated as Feature 106. Another grey loam slump was removed from 1.5S10.5E as Feature 108. This feature extended across the southern one-third of the square at a level of about 55 cm.

Feature 109, like Feature 105, was a small hearth area comprised of rubble and charcoal located in square 1.5N12E. Feature 109 was about 40 cm in diameter and was found in the southeastern corner of the square at an assumed elevation of 98.26 m. This seems to be a continuation of the "scattered Woodland hearth" recorded by Benthall (1975) in 1967 as Feature 24. No diagnostic artifacts were recovered from this feature in either the 1967 or 1982-83 excavations. Benthall (1975) did obtain a radiocarbon date of A.D. 322 \pm 70 from another feature at the same level as Feature 24, that is his Zone A, level 4.

Four radiocarbon dates were acquired from this component during the 1982-83 excavation: 1580 ± 70 BP (Beta-19271), 1570 ± 70 (Beta-19272), 1370 ± 60 BP (Beta-19273), and 1370 ± 80 BP (Beta-19274). The uncorrected radiocarbon ages for these dates are AD 370 ± 70 , AD 380 ± 70 , AD 580 ± 60 , and AD 580 ± 80 .

Component 4: Early Woodland Period

The Early Woodland period strata are again predominantly grey and white ash lens that are not distinctly different from the overlying Middle Woodland strata. This zone is generally thin, only about 20 cm thick and as a result little cultural material was found from this time period. The only feature recorded in this zone was in square 1.5S10.5E, where a charcoal lens overlying a fired red clay lens was removed as Feature 110. No cultural material was recovered from the feature.

Two radiocarbon dates are available for this component from the 1982-83 excavations: $2090 \pm$ BP (Beta-19275) and 2520 ± 80 (Beta-19276).

Component 5: Late Archaic Period

In squares 1.5S9E and 1.5N12E these strata were not exposed by the 1982-3 excavation due to time constraints and the desire to maintain more adequately lighted profiles for squares 1.5S10.5E and 0N12E. In squares 1.5S10.5E and 0N12E a zone of orangish clay extending approximately 1 to 1.5 m beneath the surface yielded Late Archaic materials. The density of cultural remains within the orange clay strata was generally quite low. At about 1.5 m a zone of grey ashy loam with much rubble was encountered. This correlates with the dark grey ash stratum designated Zone F by Benthall (1975) which produced a radiocarbon date of 3740 B.C. ± 260 .

Only a single Late Archaic feature, a clay-lined pit, was encountered. Feature 111 was located in square 1.5S10.5E about 1.3 m beneath the surface (Assumed elevation 97.8 m). The feature was 25 cm in diameter and 40 cm deep and was lined

with yellow ashy clay 1.5 cm thick. The interior of the pit contained two cobbles within a brown loam matrix. Waterscreening of the brown loam produced no artifacts other than debitage.

Five radiocarbon dates were acquired from the Late Archaic strata in 1982-83: 3580 \pm 70 BP (Beta-19277), 3600 \pm 70 BP (Beta-19278), 3800 \pm 70 BP (Beta-19279), 4300 \pm 80 BP (Beta-19280), and 4690 \pm 70 BP (Beta-19281).

POTTERY ANALYSIS (Figures A.4, - A.7; Tables A.3-A.6)

Mississippian Period Pottery

A total of 558 potsherds greater than one inch in size were recovered from the 1982-83 excavations. For the most part these are assignable to established types and occur in proper stratigraphic sequence. Of the 558 potsherds 35% were recovered from the Mississippian component and another 15% were recovered from the overlying disturbed zone. Most of the sherds from the disturbed zone are assignable to Mississippian period types.

Shell-Tempered Pottery. The shell-tempered potsherds from Daugherty's Cave are the least problematic. These sherds are clearly assignable to the pottery types New River Cordmarked, New River Plain, and New River Knot and Net Roughened (Evans 1955). At Daugherty's Cave shell-tempered sherds are found solely within the disturbed and Mississippian zones, with the exception of a single sherd recovered from near the top of the underlying Middle Woodland zone. This stratigraphic superiority accords well with the well-established post A.D. 900 temporal position of shell-tempering in the Tennessee River drainage (Schroedl et al. 1990). Likewise the Daugherty's Cave radiocarbon dates of AD 1470 \pm 60 and AD 1480 \pm 70 (uncalibrated) seem reasonable for the New River phase occupation of the shelter. The

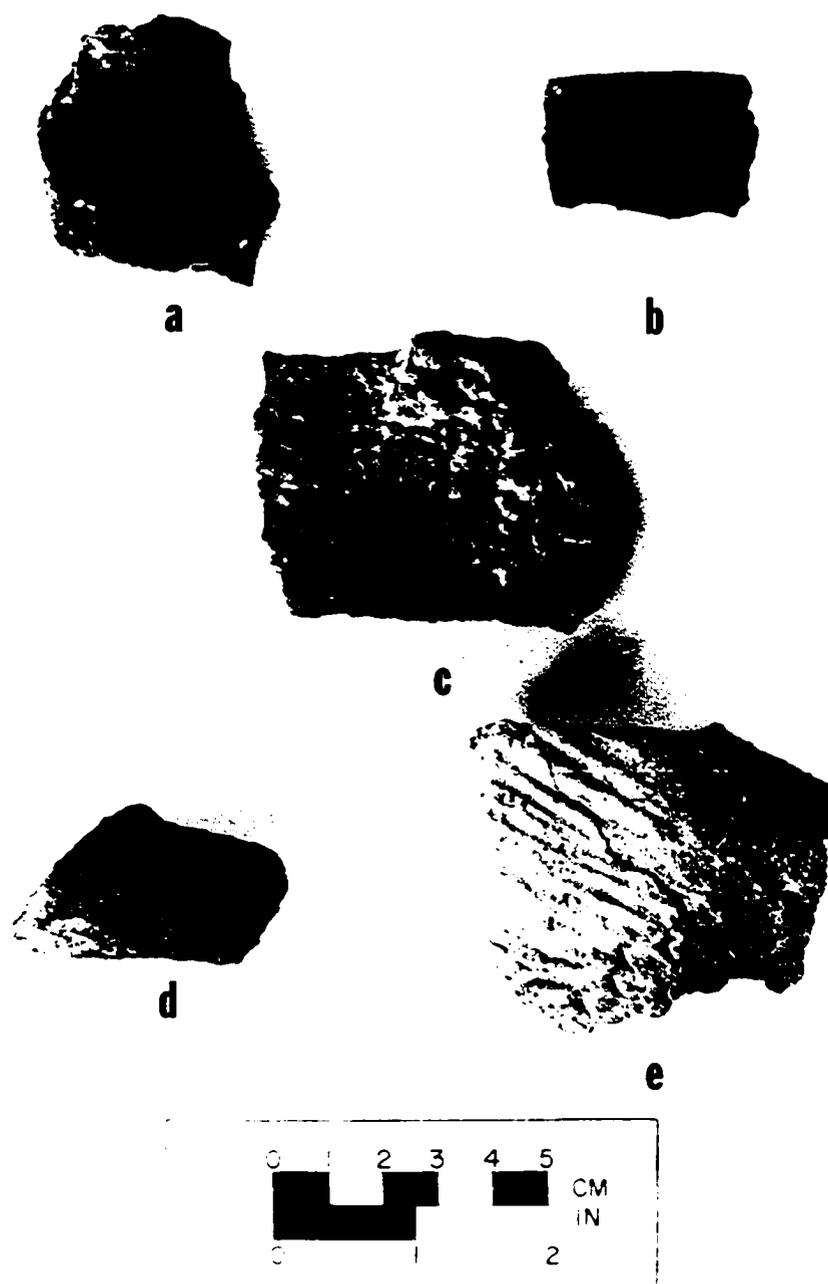


Figure A.4: Potsherds.
 a. Shell-tempered Smoothed; b. Shell-tempered Smoothed with Lug Handle; c. Shell-tempered Roughened; d. Sand-tempered Incised Bowl; e. Sand-tempered Simple-stamped.

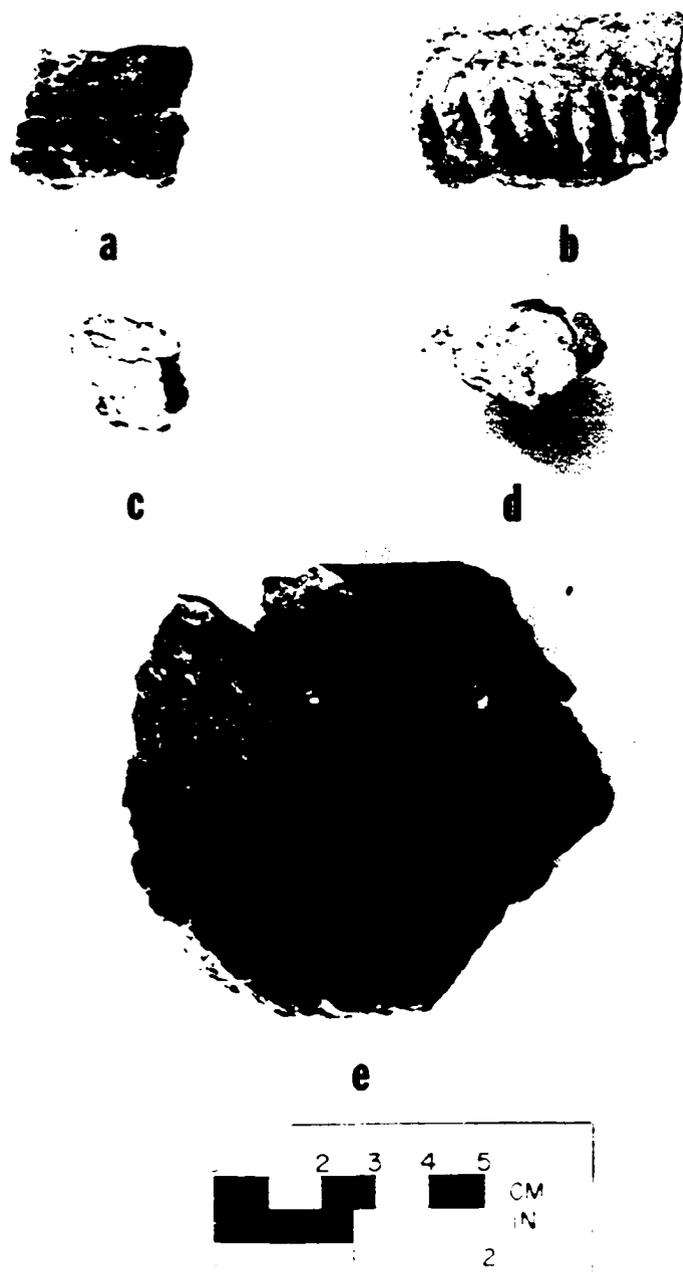


Figure A.5: Limestone-tempered Potsherds.
 a. Smoothed Rim with Notched Fillet-Strip; b. Smoothed Rim with Vertical Punctations; c. d. Smoothed Body Sherds; e. Roughened Rim with Pisgah Herringbone Punctations.

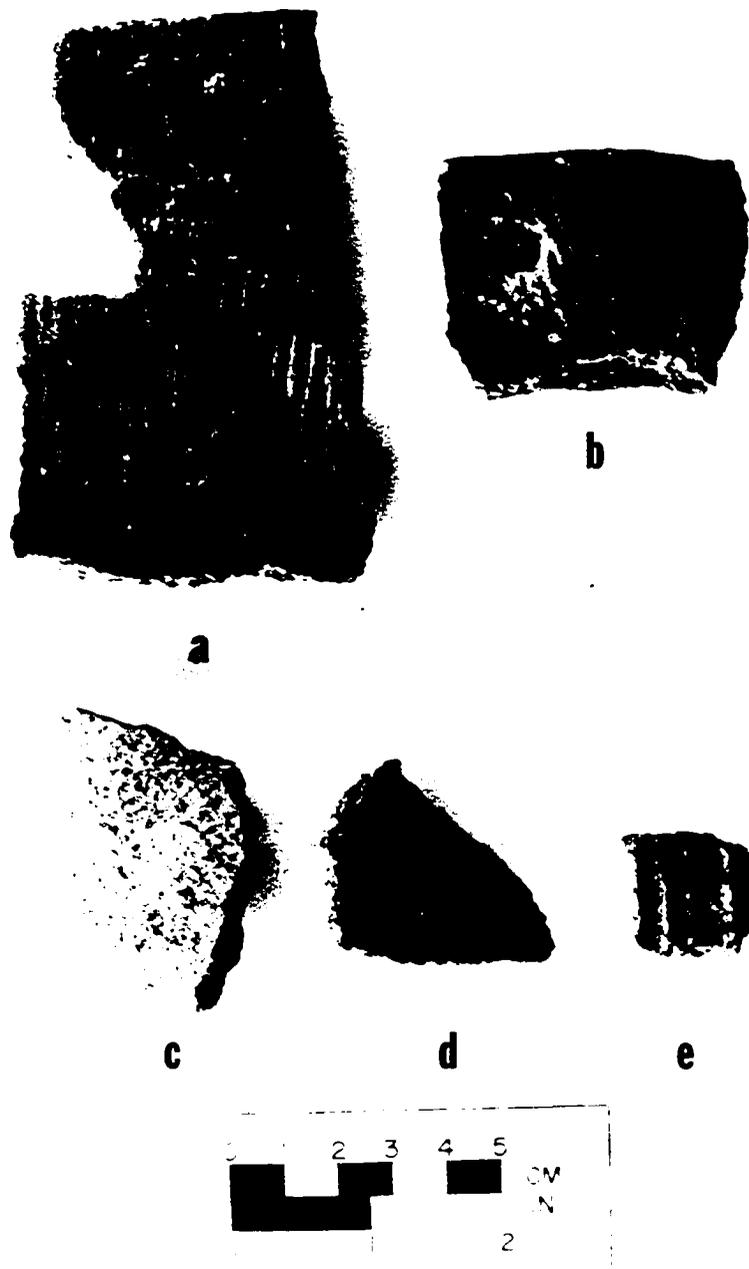


Figure A.6: Limestone-tempered Potsherds.
 a. b. Cordmarked;
 c. Check-stamped; d. e. Simple-stamped.



Figure A.7: Potsherds.
a. Granite-tempered Fine Fabric-impressed; b. Granite-tempered Smoothed;
c. Limestone-tempered Heavy Fabric-impressed;
d. Limestone-tempered Knotted Net-impressed.

Table A.3: Potsherd Counts - Square 0N12E (page 1).

Level (cm) or Feature	Comp	Shell-tempered				Total
		Cord	Smooth	Rough- ened	Unid.	
0 - 30	D		12	1		13
F. 107	D			1		1
30 - 40	MIS	7	9	4	1	21
40 - 50	MIS	2	2	5		9
50 - 60	MW	1				1
60 - 70	MW					
70 - 80	MW					
80 - 90	MW					
90 - 100	EW					
100 - 110	EW					
110 - 120	LA					
Total		10	23	11	1	45

Level (cm) or Feature	Comp	Sand-tempered						Total	
		Cord	Smooth	Simple Stamp	Rough- ened	Fine Fabric	Brush		Unid
0 - 30	D			2					2
F. 107	D								
30 - 40	MIS								
40 - 50	MIS	2	3		1		1	1	8
50 - 60	MW								
60 - 70	MW				1	1			2
70 - 80	MW								
80 - 90	MW								
90 - 100	EW								
100 - 110	EW								
110 - 120	LA								
Total		2	3	2	2	1	1	1	12

Table A.3: Potsherd Counts - Square 0N12E (page 2).

Level (cm) or Feature	Compo- nent	Granite-tempered		
		Fine Fabric	Heavy Fabric	Total
0 - 30	D			
F. 107	D			
30 - 40	MIS	1		1
40 - 50	MIS			
50 - 60	MW	1		1
60 - 70	MW	1	2	3
70 - 80	MW	1		1
80 - 90	MW			
90 - 100	EW			
100 - 110	EW			
110 - 120	LA			
Total		4	2	6

Table A.3: Potsherd Counts - Square 0N12E (page 3).

Level (cm) or Feature	Comp	Limestone-tempered					
		Cord	Smooth	Check Stamp	Simple Stamp	Rect Stamp	Rough- ened
0 - 30	D	1	2				
F. 107	D						
30 - 40	MIS	5					
40 - 50	MIS	9	14			1	5
50 - 60	MW	20	9				1
60 - 70	MW	26	21	18	4		
70 - 80	MW	15	8	1	1		
80 - 90	MW	3	1	1			
90 - 100	EW		1	1			
100 - 110	EW						
110 - 120	LA						
Total		79	56	21	5	1	6

Level (cm) or Feature	Comp	Limestone-tempered					Square Total
		Knotted Net	Fine Fabric	Heavy Fabric	Unid.	Total	
0 - 30	D	1				4	19
F. 107	D						1
30 - 40	MIS	1	1		1	8	38
40 - 50	MIS		1			30	41
50 - 60	MW				2	32	34
60 - 70	MW				2	71	74
70 - 80	MW			1	3	29	30
80 - 90	MW			2		7	7
90 - 100	EW	3		9		14	14
100 - 110	EW	7		1	1	9	9
110 - 120	LA	2				2	2
Total		14	2	13	9	206	269

Table A.4: Potsherd Counts - Square 1.5S10.5E (page 1).

Zone, Level (cm) or Feature	Compo-	Shell-tempered			
		Cord	Smooth	Net	Total
Zone 1	D		2		2
Zone 2	D		8	1	9
Zone 3	MIS	1	2	4	7
F. 102	MIS		1		1
Zone 4	MW				
75 - 85	MW				
F. 108	MW				
85 - 95	EW				
95 - 105	EW				
105 - 115	LA				
115 - 125	LA				
Total		1	13	5	19

Level (cm) or Feature	Comp	Sand-tempered		Granite-tempered	
		Smooth	Total	Fine Fabric	Total
Zone 1	D				
Zone 2	D	3	3		
Zone 3	MIS	1	1		
F. 102	MIS				
Zone 4	MW				
75 - 85	MW				
F. 108	MW			3	3
85 - 95	EW				
95 - 105	EW				
105 - 115	LA				
115 - 125	LA				
Total		4	4	3	3

Table A.4: Potsherd Counts - Square 1.5S10.5E (page 2).

Zone, Level (cm) or Feature	Comp	Limestone-tempered								Square Total	
		Cord	Smooth	Simple Stamp	Rough- ened	Knotted Net	Fine Fabric	Heavy Fabric	Unid		Total
Zone 1	D		1							1	3
Zone 2	D		5		1		1			7	19
Zone 3	MIS	2	3	1			2		3	11	19
F. 102	MIS	1	4			2				7	8
Zone 4	MW							1		1	1
75 - 85	MW	6						1		7	7
F. 108	MW	5	2					1		8	11
85 - 95	EW		1					6		7	7
95 - 105	EW	4	1					1		6	6
105 - 115	LA										
115 - 125	LA	1								1	1
Total		19	17	1	1	2	3	8	5	56	82

Table A.5: Potsherd Counts - Square 1.5S9E (page 1).

Zone, Level (cm) or Feature	Comp	Shell-tempered			Granite-tempered	Calcite-tempered
		Cord	Smooth	Total	Fine Fabric	Cord
Zone 1	D					
Zone 2	D	1	5	6		
Zone 3	MW					
Z.3- 65	MW					1
Fea 106	MW					
65 - 75	EW					
Fea 101	EW				1	
Total		1	5	6	1	1

Table A.5: Potsherd Counts - Square 1.5S9E (page 2).

Zone, Level (cm) or Feature	Comp	Limestone-tempered								Square Total	
		Cord	Smooth	Check Stamp	Rough- ened	Knotted Net	Heavy Fabric	Brushed	Unid		Total
Zone 1	D										
Zone 2	D	7	9	1	5	1		1	2	26	32
Zone 3	MW	1							1	2	2
Z.3- 65	MW	2		1						3	4
Fea 106	MW	4								4	4
65 - 75	EW						4			4	4
Fea 101	EW	1								1	2
Total		15	9	2	5	1	4	1	3	40	48

Table A.6: Potsherd Counts - Square 1.5N12E (page 1).

Zone Level (cm) or Feature	Comp	Shell-tempered				Total
		Cord	Smooth	Rough- ened	Unid.	
Zone 1	D	1	5			6
Zone 2	MIS	1		2		3
Zone 3	MIS	16	7	4	3	30
Zone 4A	MIS			3		3
Zone 4B-C	MW		2			2
F. 103/104	MW					
F. 105	MW					
- 60	EW					
60 - 70	EW					
F. 109	EW					
70 - 80	EW					
Total		18	14	9	3	44
Site Total		30	55	25	4	114

Table A.6: Potsherd Counts - Square 1.5N12E (page 2)

Zone, Level (cm) or Feature	Comp	Sand-tempered							Total	
		Cord	Smooth	Check Stamped	Simple Stamped	Net	Fine Fabric	Brushed		Unid
Zone 1	D	1								1
Zone 2	MIS									
Zone 3	MIS									
Zone 4A	MIS									
Zone 4B-C	MW			2						2
F. 103/104	MW									
F. 105	MW									
- 60	EW									
60 - 70	EW									
F. 109	EW									
70 - 80	EW									
Total		1		2						3
Site Total		3	7	2	2	2	1	1	1	19

Table A.6: Potsherd Counts - Square 1.5N12E (page 3).

Zone, Level (cm) or Feature	Comp	Granite-tempered			Total	Calcite- tempered Cord
		Fine Fabric	Heavy Fabric	Unid.		
Zone 1	D					
Zone 2	MIS					
Zone 3	MIS					
Zone 4A	MIS	1			1	
Zone 4B-C	MW	1		1	2	
F. 103/104	MW					
F. 105	MW					
- 60	EW					
60 - 70	EW					
F. 109	EW					
70 - 80	EW					
Total		2		1	3	
Site Total		10	2	1	13	1

Table A.6: Potsherd Counts - Square 1.5N12E (page 4).

Zone, Level (cm) or Feature	Comp	Limestone-tempered					
		Cord	Smooth	Check Stamped	Simple Rectilinear Stamped	Rough- ened	
Zone 1	D		1			3	
Zone 2	MIS						
Zone 3	MIS	28	6			3	
Zone 4A	MIS	4	5				
Zone 4B-C	MW	15	7			6	
F. 103/104	MW	3	3			1	
F. 105	MW	2					
- 60	EW	1	1				
60 - 70	EW	6	6			1	
F. 109	EW	3					
70 - 80	EW						
Total		62	29			14	
Site Total		175	111	6	6	1	26

Table A.6: Potsherd Counts - Square 1.5N12E (page 5).

Zone, Level (cm) or Feature	Comp	Limestone-tempered					Total	Square Total
		Knotted Net	Fine Fabric	Heavy Fabric	Brushed	Unid.		
Zone 1	D						4	10
Zone 2	MIS							3
Zone 3	MIS	2				2	41	72
Zone 4A	MIS		1			1	11	15
Zone 4B-C	MW	4			1	2	35	41
F. 103/104	MW		1				8	8
F. 105	MW						2	2
- 60	EW						2	2
60 - 70	EW	1		2		2	18	18
F. 109	EW						3	3
70 - 80	EW	2					2	2
Total		9	2	2	1	7	126	176
Site Total		26	7	27	2	24	411	558

date of AD 900 \pm 60 (uncalibrated) was obtained from charcoal near the base of the Mississippian strata. No sherds tempered solely with shell occur in this zone, but two sherds heavily tempered with coarse sand and small amounts of mussel shell were found. A date of circa AD 900 seems reasonable for the introduction of shell-tempering to southwestern Virginia.

Sand-Tempered Pottery. Only 17 sand-tempered potsherds were recovered from the Mississippian and disturbed zones of Daugherty's Cave, so little can be said conclusively about them. In southwestern Virginia, sand-tempered pottery from late contexts is generally assigned to the Wythe series (Holland 1970). However, the Wythe Series is indistinguishable from the Dan River Series originally described from the North Carolina - Virginia piedmont (Coe and Lewis 1952; Gardner 1980; Egloff 1986). The Dan River series name seems preferable for use in western Virginia as well. Although Dan River pottery is now known to occur with some frequency west of the Blue Ridge on the James and Shenandoah Rivers (Whyte 1989), it has never been found in more than trace amounts on the more westerly Clinch and Powell drainages (Egloff 1986).

The sand-tempered cordmarked, smoothed, and net-roughened sherds from Daugherty's Cave are typical of late prehistoric Dan River assemblages (Davis 1987; Whyte and Akers 1989), and presumably represent some interaction between southwestern Virginia and regions further east. The two sand-tempered simple-stamped sherds from the disturbed zone are probably Dan River Ware as well. They are about 8 mm thick and sparsely tempered with coarse quartz sand. They seem too thick to be Middle Woodland Connestee Ware (Keel 1976) and too sparsely tempered to be Pisgah (Dickens 1976). The fabric-impressed sherd from the Mississippian Zone is presumably displaced from some earlier component. It is not a fragment of a saltpan.

Limestone-Tempered Pottery. About 55% of the pottery recovered from the Mississippian strata of Daugherty's Cave is tempered with crushed limestone.

Although typically lumped wholesale into the Late Woodland period Radford series (Evans 1955; Holland 1970) when found in southwestern Virginia, limestone-tempered pottery actually encompasses several temporally significant types (Egloff 1987). These types include Early Woodland period Longbranch fabric-impressed type, and Middle Woodland Mulberry Creek plain, Wright check-stamped, Candy Creek Cordmarked, and Bluff Creek simple-stamped types, as well as the Late Woodland/Mississippian period Radford net-roughened, cordmarked and plain types.

Although limestone-tempering is restricted to the Woodland and early Mississippian periods in Tennessee (Kimball 1985), it appears to have remained in use throughout the Mississippian period in southwestern Virginia. For example, the ceramic assemblage from the fifteenth century Sullins site in the Holston River drainage was 99.9% limestone-tempered, mostly net roughened and cordmarked (MacCord 1981). At the Crab Orchard site (44Tz1) on the upper Clinch River, limestone-tempered sherds made up 83% of the ceramic assemblage. Radiocarbon dates from Crab Orchard are AD 1570 \pm 120 and AD 1610 \pm 55 (uncalibrated) (Egloff 1986). Fifty percent of the limestone pottery was smoothed, 35% cordmarked, 9% corncob-impressed and 6% net-impressed (Egloff 1986). The Daugherty's Cave percentages are similar: cordmarked makes up 45% of the limestone-tempered assemblage, smoothed 30% and net-impressed 12% and minority finishes or earlier sherds, 13%. Corncob-impressing was not recognized at Daugherty's Cave.

The popularity of limestone-tempered cordmarked and smoothed pottery in the Late Woodland and Mississippian periods in southwestern Virginia creates problems for the ceramic analyst. This is because body sherds of the Late Woodland/Mississippian Radford cordmarked and smoothed types cannot be confidently separated from the similarly manufactured Middle Woodland Candy Creek cordmarked and Mulberry Creek plain. However, vessel morphology can be used to separate the earlier from the later wares. The earlier wares are simple open-mouthed vessels with vertical rims;

whereas the Late Woodland/Mississippian period ware possesses constricted necks with recurved rims (Egloff 1986). Some of the cordmarked and smoothed limestone-tempered sherds from the Mississippian component at Daugherty's Cave may be wares displaced from earlier components. This is almost certainly the case with the fabric-impressed sherds and perhaps with the brushed and simple- and checked-stamped sherds as well.

Although no limestone-tempered rim sherds from the Mississippian component at Daugherty's Cave were large enough to reconstruct the vessel profiles, some Mississippian attributes were in evidence. One rim sherd has a notched rim fillet (fig. A.5:a), a trait characteristic of the late Mississippian period (Hally 1986; Kimball 1985:151), and one net-roughened sherd (fig A.5:e) displays the incised herringbone design rim of the Mississippian period Pisgah phase (Dickens 1976). Similar pottery combining Pisgah phase rim motifs with crushed stone temper and textile-impressed surface treatments has also been recovered from the late Mississippian period Ward site in northwestern North Carolina (Purrington 1983:143). In addition one limestone-tempered rectilinear-stamped sherd recovered from Daugherty's Cave may also denote Pisgah influence. This seems the most likely explanation for this sherd, since similar pottery, as well as "classic" (i.e. sand-tempered) Pisgah rectilinear-stamped pottery, has been recovered from other Clinch River sites in southwestern Virginia (Egloff 1986).

The radiocarbon date of AD 900 \pm 60 (uncalibrated) from the 40-50 cm level of ON12E may be somewhat early for the mix of shell-tempered and predominantly smoothed limestone-tempered ceramics recovered from the level. A very similar date of AD 890 \pm 60 (uncorrected) was recovered from the nearby Arrington site on Holston River drainage and was associated with a ceramic assemblage comprised of 89% limestone-tempered cordmarked, 9% limestone-tempered smoothed and 2% sand-tempered plain (Barlett 1980). This latter assemblage is much more Hamilton-like

(Lewis and Kneberg 1946) than is the Daugherty's Cave assemblage and seems more reasonable for this remote area of the southeast at this time period than does the more Mississippian-like Daugherty's Cave material. Overall, I am inclined to think the radiocarbon sample from this level of Daugherty's Cave may have contained some charcoal displaced from an earlier occupation.

Granite-tempered pottery. Two sherds of a granite-tempered fabric-impressed pot were recovered from the Mississippian strata of the site, but are considered to be displaced from the earlier Middle Woodland component. This pottery will be discussed under the Middle Woodland component section.

Middle Woodland Period Pottery

The ceramics from the Middle Woodland period levels of Daugherty's Cave are much less varied in temper than those of the subsequent Mississippian period. Only three shell-tempered sherds were recovered from the Middle Woodland period strata and these are considered intrusive from the Mississippian zone. Two sand-tempered Connestee check-stamped sherds were recovered from the upper part of the Middle Woodland layer, and 10 fabric-impressed sherds tempered with crushed granite were scattered throughout the Middle Woodland levels.

The granite-tempered ware is something of an enigma. The granite inclusions in the Daugherty's Cave material average about 3 mm in size and the paste is quite petrous. The warp elements of the fabric are small, usually less than 5 mm in diameter, and the weft elements are fine and tightly packed. These technological attributes argue against the pottery being an Early Woodland "Watts Bar- or Pigeon-like" ware displaced from an earlier component. Furthermore, it cannot be a local product, since granite is not found in the Ridge and Valley physiographic province. The nearest source of granite would be the Appalachian mountains, but its use as a pottery tempering agent is not reported there (Keel 1976). Furthermore, by the Middle

Woodland period in the southern Appalachians, fabric-impressing seems to have been abandoned (Keel 1976; Chapman and Keel 1979; Kimball 1985). The only granite tempered pottery of which I am familiar are the Hercules fabric-impressed and Hercules cordmarked types defined by Smith (1971) from the Hand site in southeastern Virginia. Hercules ware is considered a late Middle Woodland period ware, circa AD 200 to AD 900, and is distributed in the interior coastal plain and piedmont/coastal plain fall line zone of southern Virginia (Egloff and Potter 1982). Hence, the dating of Hercules ware is congruent with the granite tempered ware from Daugherty's Cave, but its geographic distribution is disjunct. However, since the James River spans Virginia from the Ridge and Valley to the southern coastal plain, some long distance movement along it might be expected. Although I am not prepared to assign the Hercules fabric-impressed type name to the handful of similar sherds recovered from Daugherty's Cave, I do not have a better explanation for its origin.

A single cordmarked sherd tempered with what is apparently calcite is likewise enigmatic. I know of no reported calcite-tempered wares. Since calcite is common in the Ridge and Valley, this sherd may represent an idiosyncratic variant of the local limestone-tempered ware.

Of the 225 sherds recovered from the Middle Woodland component of Daugherty's Cave, 94% of them are limestone tempered. Candy Creek cordmarked makes up 45% of the sherds from this component, Mulberry Creek plain, 23%; Wright check-stamped, 9%; Radford net-roughened, 5%; Bluff Creek simple-stamped, 2%; Longbranch fabric-impressed 2%; and Flint River brushed less than 1%. The Wright check-stamped sherds are mostly smoothed over, but the check-stamping remains discernable.

The predominance of cordmarked, followed by plain, limestone-tempered sherds suggests the Middle Woodland period Hamilton complex of eastern Tennessee (Kneberg 1961). Although no dates are available for the Hamilton complex, it follows

the Candy Creek complex now securely dated to the fifth century AD at the Icehouse Bottom site (Chapman and Keel 1976). Likewise, it is antecedent to the Roane-Rhea complex. Roane-Rhea complex pottery is associated with a date of AD 625 \pm 107 (uncorrected) from the Westmoreland-Barber site (Kimball 1985:133; Faulkner and Graham 1966). The sixth century AD thus seems the proper temporal placement of the Hamilton complex. At first glance the Middle Woodland component dates of AD 580 \pm 60, and AD 580 \pm 80 from Daugherty's Cave would seem to accord nicely with the Tennessee sequence. Unfortunately, the level producing the AD 580 date from 1.5S10.5E is associated with only a single, unidentifiable sherd, while the AD 580 date from 0N12E is stratigraphically reversed beneath two fourth century AD dates. The fourth century AD seems too early for a ceramic assemblage dominated by cordmarked and smoothed sherds. Certainly in eastern Tennessee (Kimball 1985) and northern Alabama (Walthall 1980), a greater percentage of stamped and fabric-impressed sherds would be expected.

Although data are limited, the same sequence of types seems to characterize southwestern Virginia as well. From southwestern Virginia only two sites have radiocarbon-dated Middle Woodland ceramic assemblages. The first is from Feature 19 of Daugherty's Cave, excavated by Benthall in 1967. This feature was radiocarbon dated A.D. 322 \pm 70 (uncorrected) and produced 51 sherds of which 88% were Wright check-stamped, 10% were Longbranch fabric-impressed, and 2% were "Radford" (presumably Candy Creek) cordmarked (Benthall 1975:25). Feature 19 occurred within Benthall's Zone A level 4 which correlates to the 60-70 cm level of 0N12E, radiocarbon dated to AD 380 \pm 70. This would seem to suggest that the fourth century AD dates are appropriate for the Middle Woodland strata of Daugherty's Cave., and that the dearth of stamped pottery from the 1982-3 excavations is a result, perhaps, of sampling error.

The second radiocarbon dated Middle Woodland period ceramic assemblage from southwestern Virginia is from the Fox Meadow Apartments site (44Ru44), located on Big Cedar Creek about two miles upstream from Daugherty's Cave (McIlheny 1983). Here Candy Creek cordmarked made up 43% of the potsherds, Mulberry Creek plain 12%, Bluff Creek simple-stamped 2%, and 32% of the sherds were limestone-tempered with unidentifiable surface treatments. A single Wright check-stamped sherd (smoothed over) was recovered. Sand-tempered Connestee ware made up another 8% of the sherd assemblage. In addition, the site yielded prismatic and crested blades, mica, and a fragment of a two-hole gorget. Three uncorrected radiocarbon dates are available from the site: AD 180 \pm 115, AD 410 \pm 80 (MacIlheny 1983) and 515 BC \pm 560 (C.W. McIlheny, personal communication 1983). The first two dates seem appropriate for the ceramic and lithic material recovered, while the third date seems too early. However its sigma range is very large and at the upper end would be reasonable as well. In fact, averaging the two latter dates from the Fox Meadows Apartments site produces an average radiocarbon age of 1615 BP \pm 66 (AD 345 uncorrected), while averaging all three dates provides an the very similar radiocarbon age of 1627 BP \pm 65 (AD 323 uncorrected) (Stuiver and Pearson 1987). Certainly a fourth century AD radiocarbon age seems reasonable for the Fox Meadows ceramic and lithic assemblages.

Given the similarities between the ceramic assemblages of the Fox Meadow Apartment site and the Middle Woodland component at Daugherty's Cave, as well as the presence of a prismatic and crested blades and mica at both, it seems reasonable to assume contemporaneity between the two sites. Thus the two fourth century AD dates from the Middle Woodland component of Daugherty's Cave seem more likely to be accurate than do the two sixth century AD dates.

Early Woodland Period Pottery

A total of 67 sherds were recovered from the relatively thin Early Woodland layer of Daugherty's Cave. Except for a single granite-tempered fabric-impressed sherd, all are limestone tempered. Longbranch fabric-impressed makes up 34% of the pottery from this level, Candy Creek cordmarked 22% and Mulberry Creek plain 15%. Wright check-stamped and Radford net roughened are represented by one sherd each. The latter is most likely intrusive from a higher level. About 19% of the pottery from this level is comprised of a thick (about 8 mm) ware tempered with abundant quantities of coarse crushed limestone and impressed with a tightly woven knotted net. The net used had knots about 2 mm in diameter and a mesh openings of about 2 mm to 4 mm. The pottery is clearly distinctive from the Radford net-roughened type even on quite small sherds.

Net-impressing is generally considered a Late Woodland period trait in southwestern Virginia (Egloff 1986), but is common in the Early and Middle Woodland periods in the Virginia coastal plain and lower piedmont (Egloff and Potter 198x). Except for its crushed limestone temper, the knotted-net-impressed pottery from Daugherty's Cave does closely resemble the common coastal plain Early Woodland period Popes Creek net-impressed type. Thus the Daugherty's Cave pottery may represent a rare combination of "exotic" surface treatments on typical Ridge and Valley crushed limestone pastes. On the other hand, if sherds with tightly woven net-impressions have been lumped with fabric-impressed sherds within the Longbranch (or Radford) fabric-impressed type, the type may be more common than current studies have indicated. Given the propensity of many southwestern Virginia ceramic analysts to focus on temper as the critical attribute governing typological assignment, this is probably at least partially true.

The earliest radiocarbon date from Daugherty's Cave associated with ceramics is 2520 BP \pm 80 (570 BC uncorrected). This was obtained from the 100 - 110 cm level of ON12E which yielded seven of the limestone-tempered knotted net-impressed sherds along with one Longbranch fabric-impressed sherd. The date seems credible, as Longbranch fabric-impressed pottery is common in upper East Tennessee at this date (Lafferty 1981:500). The latter date of 2090 \pm 80 (140 BC uncorrected) from the upper portion of the Early Woodland levels is also credible. A very similar date of 2100 BP \pm 100 (150 BC uncorrected) was obtained from level D of the Russell Cave site which, like the Early Woodland component of Daugherty's Cave, had a ceramic assemblage dominated by Longbranch Fabric-impressed and Mulberry Creek plain (Griffin 1974).

It is interesting that the earliest ceramics known from the Tennessee River drainage, the sand-tempered Swannanoa series and the quartz-tempered Watts Bar series, are both absent from Daugherty's Cave. Although small amounts of Swannanoa ceramics have been recovered elsewhere in southwestern Virginia (Egloff 1986), apparently Daugherty's Cave was not occupied during the period of earliest use of ceramics, circa 1000 BC to 500 BC (Lafferty 1981).

STONE ARTIFACTS (Figures A.8, A.9; Tables A.7 -A.9)

Projectile Points

Chipped stone projectile points were common in all four components of the Daugherty's Cave site. There were 182 projectile points sufficiently complete to allow assignment to typological categories (Table A.7). Most were found in proper stratigraphic placement, but others were found in problematic contexts and a number of Early Archaic points are clearly out of place.

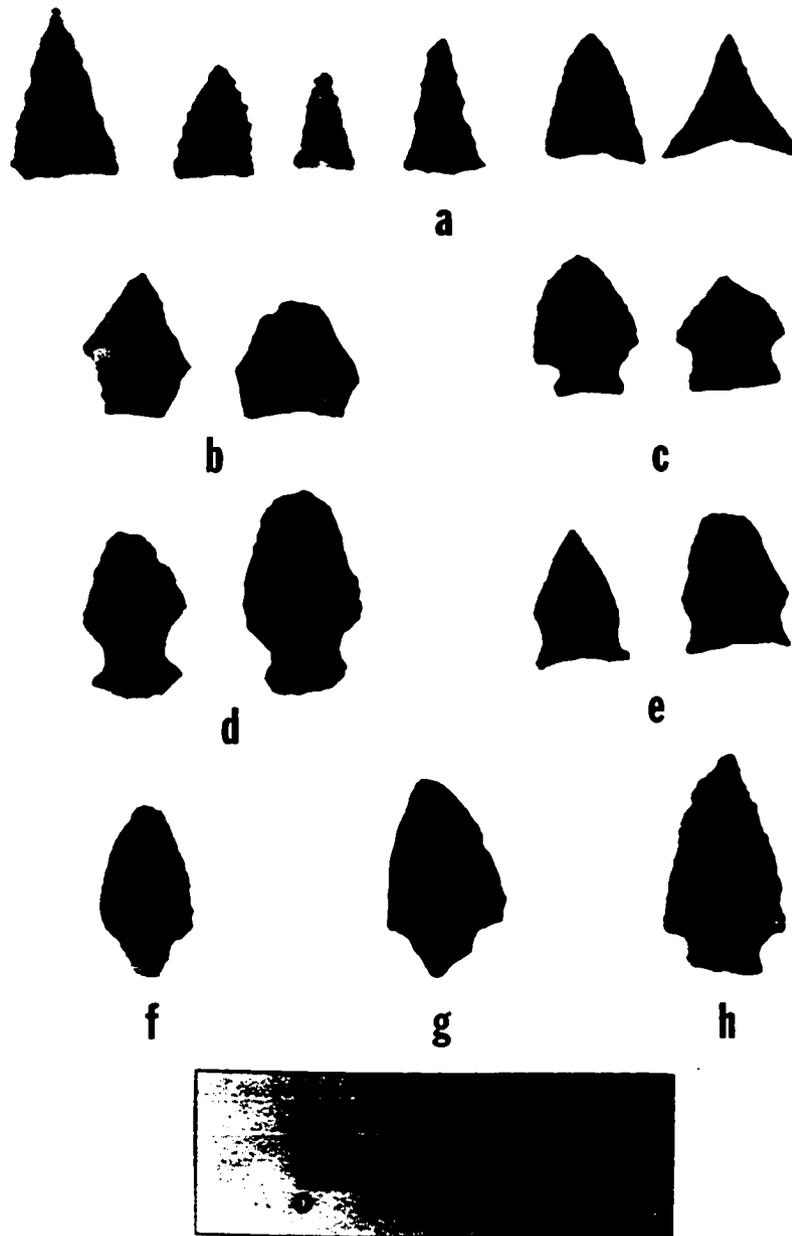


Figure A.8: Projectile Points
 a. Triangular;
 b. Pentagonal; c. Jack's Reef;
 d. Swan Lake; e. Nolichucky;
 f. Swannonoa; g. Gypsy; h. Ottare.

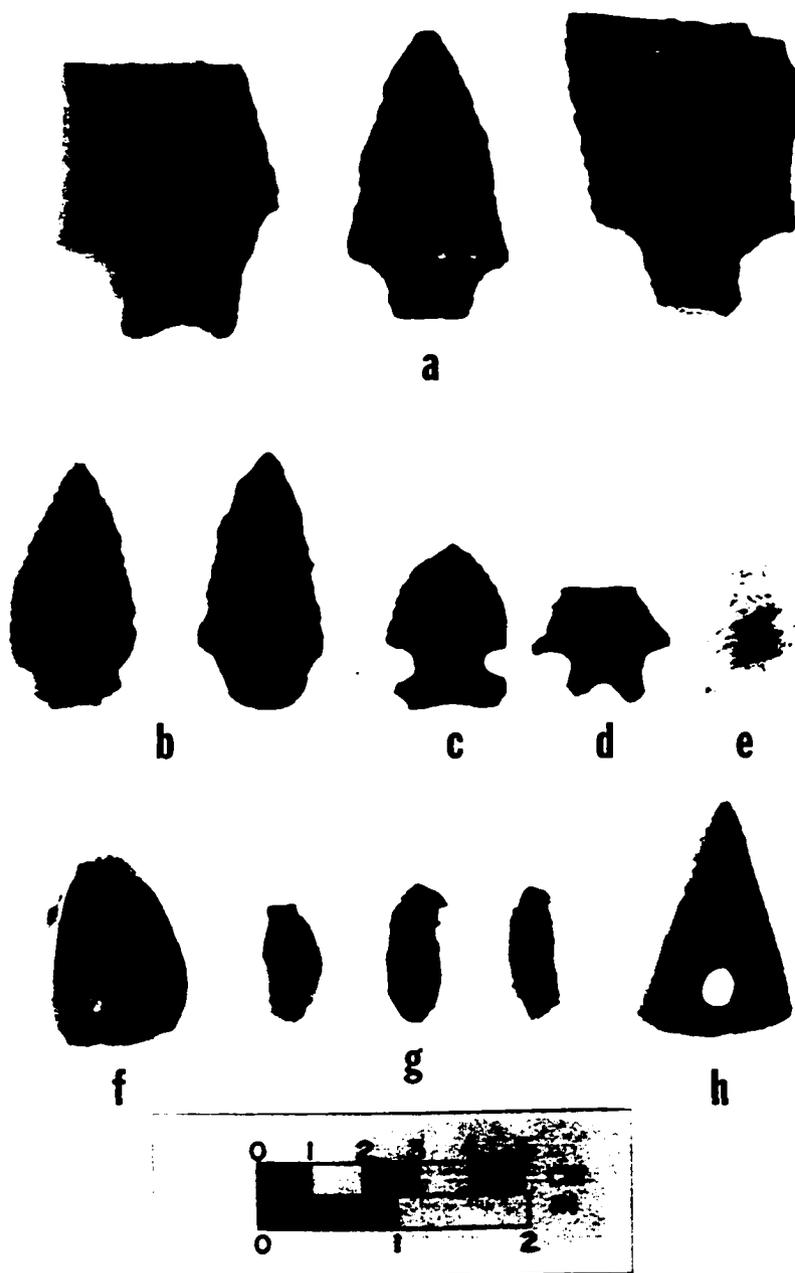


Figure A.9: Projectile Points and Other Lithics
 a. Savannah River;
 b. Archaic Stemmed; c. Big Sandy; d. Bifurcate; e. Palmer;
 f. Chert blade core; g. Chert blades; h. Soapstone pendent.

Table A.7: Distribution of Projectile Points By Component.

Component	Triang-ular	Pentag-onal	Jack's Reef	Swan Lake	Bradley Spike	Noli-chucky	Swan-nanoa	Gypsy
Disturbed	51	2	5		1		4	1
Mississippian	41	3	3			2		
Middle Woodland	23		2	3	2			
Early Woodland	7			3			2	1
Late Archaic								
Total	122	5	10	6	3	2	6	2

Component	Ottare	Savannah River	Lamoka	Archaic Stemmed	Guil-ford?	Big Sandy	Bifur-cates	Palmer	Total
Disturbed								1	65
Mississippian	1	1					1		52
Middle Woodland						1	1	1	33
Early Woodland	2	1							16
Late Archaic	2	10	1	2	1				16
Total	5	12	1	2	1	1	2	2	182

Local Ridge and Valley raw materials were greatly favored by the Daugherty's Cave inhabitants. Of the 182 projectile points, 53% were manufactured of grey Conococheague formation chert, 32% were manufactured of black Chepultepec formation chert and 1% were manufactured of Conococheague formation chalcedony. These raw materials are all locally abundant (C.W. McIlhaney, personal communication 1983). In addition, 2% of the projectile points are manufactured of mottled cherts and 2% are manufactured of jasper. These two raw materials are found elsewhere in the Ridge and Valley physiological province (Kimball 1985) and are presumed to occur in southwestern Virginia as well. A stone identified by Joe Benthall as "silicified limestone" (1975, and personal communication 1983), was used to make 4% of the projectile points. The only raw material utilized that would not be available locally is rhyolite, which was used to fashion eight points, 4% of the total. Except for two triangular points, all of the rhyolite points are of Archaic period date. Rhyolite would be available at a distance of about 40 miles from Daugherty's Cave near the Mount Rodgers area of the Appalachian Mountain physiographic province.

Triangular points. Triangular points make up 67% of the Daugherty's Cave projectile point assemblage. The distribution of the triangular points by component, length, and basal morphology is given in table A.8. As has been noted in previous studies (Coe 1964; Ritchie 1971; Keel 1976), the size of the triangular points decreases through time. At Daugherty's Cave 78% of the large triangular points are recovered from the Early and Middle Woodland components, while 84% of the very small triangular points are recovered from the Mississippian and overlying disturbed components. It can also be seen that incurvate bases dominate the entire triangular point assemblage from Daugherty's Cave but may be less common in the Early Woodland component. However, the particularly small size of the Early Woodland triangular point assemblage (four specimens) makes this inference suspect. Although

**Table A.8: Percentage Distribution of Triangular Projectile Points
by Component, Size and Basal Morphology**

Component	Very Small (< 21 mm)			Small (21 - 29 mm)			Large (> 29 mm)			Total	
	Incur- vate	Straight	Excur- vate	Incur- vate	Straight	Excur- vate	Incur- vate	Straight	Excur- vate	Percent- age	Count
Disturbed	50	5		23	18		5			100	22
Mississippian	32		9	32	9	14	5			100	22
Middle Woodland	31			38	8		15	8		100	13
Early Woodland							25	50	25	100	4
Late Archaic										100	
Total	36	2	3	28	11	5	8	5	2	100	61

the data are not shown, the edge morphology of the Daugherty's Cave triangular points is not temporally patterned - straight edges dominate all components and size classes.

Pentagonal Points. Five pentagonal points were recovered from Daugherty's Cave, all from the Mississippian and disturbed components. Although Keel (1976:157) assigns his South Appalachian pentagonal point to the Middle Woodland Connestee phase, the small Daugherty's Cave sample does not support this. In agreement with the Daugherty's Cave data, a Late Woodland to Mississippian period temporal placement for pentagonal points has been indicated by research in eastern Tennessee (Kimball 1985:60) and the Carolina piedmont (Coe 1952). The pentagonal points from Daugherty's Cave range in length from 22-33 mm, in width from 19-25 mm and in thickness from 4-7 mm. All are made of local grey and black chert. One point has two shallow (ca. 1.5 mm deep) basal notches that weakly define a stem about 11 mm wide.

Jack's Reef. The Jack's Reef projectile point is a late Middle to early Late Woodland period corner-notched point (Ritchie 1971). The distribution of the Daugherty's Cave Jack's Reef points is somewhat troubling in that the popularity of the type increases from the Middle Woodland component 3 to the Historically Disturbed component 1. This is the reverse of the expected temporal pattern. This may reflect nothing more than mixing of the cave strata. On the other hand, similar small, corner-notched projectile points have been reported from Mississippian period contexts in the Tellico River region (Kimball 1985). Thus the Daugherty's Cave sample may contain a mixture of Jack's Reef and latter "Mississippian corner-notched" points. I suspect this is the case. The Daugherty's Cave specimens range in length from 20-37 mm, in width from 17-26 mm and in thickness from 4-7 mm.

Swan Lake. Six side-notched points fitting the definition of Swan Lake points (Cameron and Hulse 1975) were recovered. Swan Lake points were recovered from Layer C of Russell Cave which is radiocarbon dated to AD 450 to AD 800 (Griffin

1974). The recovery of Swan Lake points from the Middle Woodland component of Daugherty's Cave is thus expected, but their presence in the Early Woodland component is somewhat suspect. However, it has been suggested that Swan Lake points occur earlier as well (Cameron and Hulse 1975). The specimens from Daugherty's Cave range from 27-47 mm in length, from 15-22 mm in width, and from 5-10 mm in thickness.

Swan Lakes are somewhat troublesome in that I know of no way to separate them confidently from the Late Archaic period side-notched variant of Lamoka points (Ritchie 1971). The sorting criterion used in this study has been context. The points in Woodland contexts were assigned to Swan Lake, while those in Archaic contexts were assigned to Lamoka. Apparently I am not the only typologist confounded by the similarity between the two types. Keel and Egloff report that Lamoka points are the most common point at the Cane River site in western North Carolina (1984). As they consider the site to date circa AD 650 to AD 800, the Swan Lake type, not Lamoka, is the more likely classification.

Nolichucky. Two points were assigned to the Nolichucky type (Kneberg 1957) based on the presence of broad, shallow side-notches. The single measurable length was 38 mm, and the single measurable width was 21 mm. One specimen was 5 mm thick, the other 18 mm. The thicker specimen could also be considered a Pigeon side-notched point (Keel 1976). Nolichucky points are an Early Woodland type (Kimball 1985), and the Pigeon side-notched type dates to the early Middle Woodland period (Keel 1976; Kimball 1985). Unfortunately both specimens from Daugherty's Cave were recovered from Mississippian contexts. Presumably they have been displaced from earlier levels.

Bradley Spike. The Bradley spike is a Middle Woodland type common in eastern Tennessee (Kimball 1985). Although one specimen from Daugherty's Cave was recovered from the Mississippian strata, the other two were found in the

appropriate Middle Woodland context. All three specimens were manufactured of local grey chert. The one measurable specimen from Daugherty's Cave was 30 mm long X 13 mm wide X 6 mm thick.

Swannanoa stemmed. Swannanoa stemmed points are small, thick stemmed points with poorly defined shoulders that date to the Early Woodland period (Keel 1976). Two of the Daugherty's Cave specimens were found in the expected Early Woodland component, but four specimens were displaced to the uppermost historically disturbed strata. All six specimens were made of local cherts. Length ranged from 33-42 mm, width from 18-25 mm, and thickness from 7-20 mm. Stem lengths were 4-13 mm and widths 12-18 mm.

Gypsy stemmed. The gypsy stemmed point is similar to the Swannanoa stemmed type but has more distinct shoulders (Oliver 1981). Like the Swannanoa stemmed type, Gypsy points are associated with the Early Woodland period in western Carolina (Oliver 1981). One gypsy stemmed point was recovered from the Early Woodland component at Daugherty's Cave. The other was displaced to the historically disturbed zone. The measurable specimens suggest typical sizes of 35 mm length, 18 mm width and 7 mm thickness. Stems are 7-12 mm long by 10-11 mm wide. All Daugherty's Cave specimens were made of local cherts.

Ottare. Ottare points are associated with the terminal Archaic period and are little more than small variants of the familiar Late Archaic period Savannah River point (Keel 1976; Oliver 1981). The Daugherty's Cave specimens are from 32-42 mm in length, 23-25 mm in width and 7-11 mm in thickness with stems from 8-13 mm long and 14-19 mm wide. The two specimens recovered from the Late Archaic levels are in their expected context. The two Early Woodland specimens are probably displaced from the underlying zone. The specimen recovered from the Mississippian period component is undoubtedly displaced. Two of the Daugherty's Cave Ottare points are

made of local grey chert, two are made of nonlocal rhyolite and one is made of a silicified limestone.

Savannah River. Twelve projectile points from Daugherty's Cave could be assigned to the Late Archaic period Savannah River type (Coe 1964). All but two of the Daugherty's Cave specimens were found in the Late Archaic component. The Daugherty's Cave specimens are from 54-57 mm in length, from 30-52 mm in length and from 7-14 mm in thickness with stems 9-18 mm long and 15-28 mm wide. Two of the Daugherty's Cave Savannah River points were made of jasper, three of rhyolite and seven of silicified limestone. The local cherts were not used to fashion Savannah River points, presumably because the nodule size of the chert is too small to allow the manufacture of these large dart points.

Lamoka. One side-notched point recovered from the lowest level (130-140 cm) of 0N12E was assigned to the Lamoka projectile point type (Ritchie 1971). No side-notched points occur in the upper levels of the Late Archaic component, but as mentioned above, six morphologically similar points were recovered from Woodland components and were assigned to the Swan Lake type. The Daugherty's Cave Lamoka point was associated with three Savannah River points and a radiocarbon date of 2350 BC \pm 80 (uncorrected). A date of 2350 BC is early for Savannah River (Kimball 1985:284), but is late for Lamoka (Ritchie 1971). Thus it seems perfectly reasonable for the period in which they co-occur. I see no reason to think the Late Archaic period side-notched point is an intrusive Swan Lake points. The Daugherty's Cave specimen is fragmentary and made of jasper.

Archaic stemmed. Two projectile points, also recovered from the lowest level of 0N12E, do not readily fit into any established type. The first is made of grey chert and is 47 mm long by 24 mm wide by 8 mm thick. It has a short (8 mm) expanding stem that was at least 18 mm wide before breakage. It matches most closely the Middle Archaic period "Category 7 - corner removed, narrow expanding stem"

projectile point described by Chapman (1978:43) from Bacon Farm and Icehouse Bottom. The second point is fashioned of rhyolite and measures 49 mm X 24 mm X 8 mm with a short, broad stem 9 mm and 19 mm wide. The nearest match is with the "Category 11 short-contracting stem" projectile point recovered from Middle Archaic contexts at the Bacon Farm and Icehouse Bottom sites (Chapman 1978:44).

A Middle Archaic date is too early for the level in which the Daugherty's Cave specimens occur. They may be displaced from a lower component, although Benthall (1975) does not report a Middle Archaic component from his more extensive excavations at Daugherty's Cave. Another possibility is that the points are somewhat anomalous Kirk corner-notched and Kirk stemmed points displaced from the Early Archaic component at Daugherty's Cave identified by Benthall (1975).

Displaced Archaics. Six points diagnostic of the Middle and Early Archaic periods were recovered from the 1982-83 excavations at Daugherty's Cave. They are all clearly out of context. A fragment of what appears to be a early Late Archaic period Guilford projectile point (Coe 1964) was recovered from the upper part of the Late Archaic component.

The 70 - 80 cm level of 0N12E produced three Early Archaic projectile points. This first was a black chert Big Sandy point (Cameron and Hulse 1975) measuring 32 mm X 23 mm X 7 mm with a stem 11 mm long by 22 mm wide. Its base is ground. Within a foot of the Big Sandy point was found a St. Albans point (Broyles 1966). This point is missing the distal end but is 22 mm wide by 8 mm thick with a stem 10 mm long by 15 mm wide. The third Early Archaic point from this level was a chalcedony Palmer point (Coe 1964) measuring 30 mm by 17 mm by 7 mm with a stem 9 mm long by 17 mm wide. Its base is also ground. Since all three Early Archaic points were found within a meter of Feature 109, a Middle Woodland period hearth, it is tempting to speculate that the three Early Archaic points might have been introduced into site by some Middle Woodland period antiquarian.

The final Early Archaic period projectile points found in the 1982-83 excavations are a crudely fashioned Lecroy (Broyles 1966) found in the Mississippian component and a Palmer found in the historically disturbed zone. The Lecroy measures 29 mm by 17 mm by 6 mm with a stem 13 mm long by 11 mm wide. The Palmer measures 30 mm by 28 mm by 7 mm with a stem 11 mm long by 28 mm wide. Both are made of local black chert.

Other Stone Tools

Compared to the array of projectile points, the 1982-83 excavations at Daugherty's Cave produced a rather depauperate assemblage of other stone tools. These are tabulated in table A.9.

The biface category is comprised mostly of fragments of bifacially worked stone that are presumed to parts of projectile points but which lack diagnostic attributes. Only two preforms, both small triangular specimens, were recovered. These were found in the Early Woodland component.

Utilized flakes were common in the Woodland and Mississippian period samples but less so in the Archaic strata. Many of the utilized flakes displayed only slight "nibbling" along the edges. This low degree of wear was discernable on chert flakes but may have been so on the less silicious stone favored by the Archaic period inhabitants. Thus the difference in the distribution of utilized flakes among the components may be more apparent than real.

Only three types of formal stone tools other than projectile points were recognized in the Daugherty's Cave samples. Ten chert side-scrapers were recovered, all from the Mississippian and Middle Woodland components. These were rather poorly executed specimens that suggest they may have been expedient rather than formal tools. Four chert flakes with retouching that forms a small projection were classified as graters. Five bifacially worked chert fragments were classified as drills

**Table A.9: Distribution of Stone Tools other than Projectile Points
by Component.**

Component	Biface	Utilized Flake	Scraper	Graver	Drill	Anvil Stone	Hammer- Stone	Ground Stone	Mica	Blade	Blade Core	Total
Disturbed	13	11		1			2	1				28
Mississippian	19	24	6	1	5	1	9			6		71
Middle Woodland	20	19	4	1			7		3	18	1	73
Early Woodland	18	8				2	3		2	7		40
Late Archaic	7	5		1		2	1		1			17
Total	77	67	10	4	5	5	22	1	6	31	1	229

based on their triangular or diamond-shaped cross-sections. No drill hafts were recovered.

Five limestone cobbles with flat faces bearing shallow depressions were classified as anvil stones. These may have been used in processing nuts or in bipolar lithic reduction.

Twenty-two cobbles with battered edges were classified as hammerstones. These may have been used in stone tool manufacture or in food, especially nut, processing.

One specimen of groundstone were recovered, a triangular soapstone pendant measuring 46 mm long by 22 mm wide. The suspension hole is near the base. This object was recovered from the backfill of Benthall's 1967 excavation near the north edge of 1.5S9E.

Six fragments of mica were recovered from Daugherty's Cave, three from the Middle Woodland component, two from the Early Woodland and one from the Late Archaic. Mica has also been recovered from the Middle Woodland period Fox Meadows Apartment site two miles upstream from Daugherty's Cave (McIlhaney 1984). Mica is also known to have been one of the commodities circulating throughout the "Hopewellian Interaction Sphere" (Chapman and Keel 1979). Hence, it seems safe to conclude that the Daugherty's Cave mica belongs to the Middle Woodland period component of the site. Mica is not found in the Ridge and Valley, but is present in southwestern North Carolina. Southwestern Virginia was astride the routes linking southwestern North Carolina and Ohio (Tanner 1990), so the recovery of small amounts of mica is unsurprising.

Also presumed to be a product of participation in the Hopewell Interaction Sphere are 31 crested or prismatic blades and one blade core. The distribution of these centers on the Middle Woodland levels, but some, presumably displaced, are found in the Mississippian and Early Woodland levels as well. All of the Daugherty's Cave

specimens are made of local Chapultepec and Connochochegue chert. Crested and prismatic blades were also recovered from the Middle Woodland period Fox Meadows Apartments site (McIhanev 1984), and more distantly from the Garden Creek site in western North Carolina (Keel 1976) and from the Icehouse Bottom site in eastern Tennessee (Chapman and Keel 1979). Unlike the latter two sites, neither of the southwestern Virginia sites produced blades on Ohioan Flint Ridge chert. This may merely reflect the much smaller size of the southwestern Virginian samples.

FAUNAL REMAINS (Tables A.10 - A.15)

Nearly 55,000 fragments of bone, shell or chitin were recovered from the 1982-83 Daugherty's Cave excavations. The faunal material includes the remains of at least 103 taxa of animals. About 55% of the elements represent aquatic snails and another 1%, freshwater mussels. Excepting 31 fragments of crayfish shell, the remainder of the faunal material is derived from vertebrates. Of the vertebrate material, mammals contribute 83%; birds, 6%; amphibians, 4%; turtles, 3%; snakes, 2%; and fish, 2%. In addition 14 elements derive from Old World domesticates. Except for two intrusive elements found in the immediately underlying Mississippian levels, all of these domesticate remains were recovered from the uppermost historically disturbed level. As the site is presently used as a shelter for farm animals, the presence of the domesticates is expected.

Methods

Identification of the faunal remains from the 1982-83 excavations at Daugherty's Cave were made by zooarchaeologist Gregory Waselkov of the University of South Alabama. Table A.10 shows the distribution of elements among taxa and components at Daugherty's Cave. Although the relative importance of taxa can be

Table A.10: Distribution of Faunal Elements by Component and Taxa (page 1).

Taxon	Comp. 1	Comp. 2	Comp. 3	Comp. 4	Comp.5	Total
Mussels						
Unidentified	51	75	105	109	47	387
<i>Eliptio complanata</i>		5	2	3	1	11
<i>E. crassidens</i>		7	6	3	1	17
<i>Dysnomia</i> sp.	1					1
Aquatic Snails						
<i>Elimia clavaeformis</i>	4610	23762	1420	90	126	30008
<i>Io fluviialis</i>	1	6	3	1	11	22
Crayfish						
Unidentified		9	3	8	11	31
Fish						
Unidentified	30	67	98	35	109	339
Unid. Minnow			2	1		3
Redhorse		2		1		3
Unid. Sucker			8		2	10
Unid. Catfish	1					1
Unid. Black Bass			1			1
Yellow Perch		3	3		1	7
Freshwater Drum	2					2
Amphibians						
Unidentified	29	41	296	19	219	604
Salamanders	41	56	65	34	17	213
American Toad	13	70	77	1	13	174
Frog		5	3			8
Turtles						
Unidentified	1	3	1		4	9
Snapping Turtle	5	3	6	1	1	16
Painted Turtle	18	11	51		30	110
Eastern Box Turtle	159	133	235	49	68	644
Spiny Softshell		1				1
Snakes						
Unidentified	5	28	70	30	13	146
Black Racer	15	10	4	1	7	37
Rat Snake		1	10		3	14
Kingsnake		2	1			3
Northern Water Snake	3	2	8	8		21
Pine Snake			1		5	6
Timber Rattlesnake	47	44	93	58	52	294

Table A.10: Distribution of Faunal Elements by Component and Taxa (page 2).

Taxon	Comp. 1	Comp. 2	Comp. 3	Comp. 4	Comp.5	Total
Birds						
Unidentified	132	292	515	166	300	1405
Pied-billed Grebe	5	4	7	1	1	18
Green Heron		1				1
Unid. Marsh Ducks	1		1	2		4
Mallard		2				2
Blue-winged Teal	1			1		2
Wood Duck		6				6
Hooded Merganser	1					1
Merlin			2			2
Ruffed Grouse	6	8	1		2	17
Bobwhite Quail	1	8	1			10
Wild Turkey	4	14	8		3	29
Unid. Rail	1					1
Passenger Pigeon	5	1	5		1	12
Barred Owl			1			1
Red-bellied Woodpecker		7	6		3	16
Unid. Perching Birds		2	4	1	5	12
American Robin		1				1
Unid. Wood Warblers		2				2
Brown Thrasher			1			1
Eastern Meadowlark			1			1

Table A.10: Distribution of Faunal Elements by Component and Taxa (page 3).

Taxon	Comp. 1	Comp. 2	Comp. 3	Comp. 4	Comp.5	Total
Mammals						
Unidentified	3231	3148	4954	2345	5611	19289
Opossum	1		1			2
Eastern Mole	2		2			4
Short-tailed Shrew				1	1	2
Least Shrew					1	1
Unid. Bats	5	3	10	6	2	26
Hoary Bat	1			1	1	3
Unid. Rabbit	3	8	14		2	27
Groundhog	1	1	6	1	5	14
Unid. Squirrels	2					2
Grey Squirrel	7	10	15	3	4	39
Fox Squirrel		1	1		3	5
Southern Flying Squirrel	3	2	11	5	4	25
Beaver	4	1	4	2	1	12
White-footed Mouse	1					1
Marsh Rice Rat		4				4
Eastern Woodrat	12	2	5	1		20
Muskrat	2	10	2		2	16
Meadow Vole				4		4
Porcupine				1	7	8
Domestic Dog	2		4	1	2	9
Grey Fox	2	2	1		2	7
Black Bear	35	13	5		3	56
Raccoon	18	11	10	9	17	65
Mink	1					1
Striped Skunk			1		1	2
River Otter			1	1		2
Elk	1		4		5	10
White-tailed Deer	188	63	124	36	99	510
Native Species Total	8711	27973	8300	3040	6829	54853
Old World Domesticates						
Domestic Pig	3					3
Domestic Cattle	5					5
Domestic Sheep	4	1				5
Domestic Horse		1				1
Total	8723	27975	8300	3040	6829	4867

Table A.11: Results of Faunal Analysis of Component 1 (page 1).

Taxon	Elements	MNI	Element Weight (g)	Biomass		Extrapolated Biomass		
				Weight (kg)	Per- cent	Weight (kg)	Per- cent	
Mussels								
Unidentified	51		77.3	0.18	0.4			
Dysnomia sp.	1	1	9.5	0.04	0.1	0.2	0.4	
Aquatic Snails								
Elimia clavaeformis	4610	4610	1493.8	1.00	0.0	1.0	1.9	
Io fluvialis	1	1	6.7	0.01	0.0	0.0	0.0	
Fish								
Unidentified	30		2.8	0.07	0.1			
Unid. Catfish	1	1	2.3	0.06	0.1	0.1	0.2	
Freshwater Drum	2	1	0.5	0.02	0.0	0.0	0.1	
Amphibians								
Unidentified	29		4.0	0.06	0.1			
Salamanders	41		13.5	0.19	0.4	0.2		
American Toad	13	2	3.1	0.04	0.1	0.1	0.1	
Turtles								
Unidentified	1		0.2	0.01	0.0			
Snapping Turtle	5	1	8.9	0.14	0.3	0.1	0.3	
Painted Turtle	18	2	61.0	0.50	1.0	0.5	1.0	
Eastern Box Turtle	159	5	154.4	0.93	1.8	0.9	1.8	
Snakes								
Unidentified	5		0.8	0.01	0.0			
Black Racer	15	1	2.6	0.04	0.1	0.0	0.1	
Northern Water Snake	3	1	2.1	0.03	0.1	0.0	0.1	
Timber Rattlesnake	47	3	5.9	0.08	0.2	0.1	0.2	
Birds								
Unidentified	132		43.4	0.63	1.2			
Pied-billed Grebe	5	1	1.4	0.03	0.1	0.1	0.2	
Unid. Marsh Duck	1	1	1.1	0.02	0.0	0.1	0.2	
Blue Winged Teal	1	1	0.4	0.01	0.0	0.0	0.1	
Hooded Merganser	1	1	0.2	0.00	0.0	0.0	0.0	
Ruffed Grouse	6	2	2.5	0.05	0.1	0.2	0.4	
Bobwhite Quail	1	1	0.2	0.00	0.0	0.0	0.0	
Wild Turkey	4	1	3.5	0.06	0.1	0.3	0.5	
Unid. Rail	1	1	0.1	0.00	0.0	0.0	0.0	
Passenger Pigeon	5	1	1.6	0.03	0.1	0.1	0.2	

Table A.11: Results of Faunal Analysis of Component 1 (page 2).

Taxon	Elements	MNI	Element Weight (g)	Biomass		Extrapolated Biomass	
				Weight (kg)	Per- cent	Weight (kg)	Per- cent
Mammals							
Unidentified	3231		3107.5	36.57	70.6		
Opossum	1	1	3.2	0.07	0.1	0.3	0.6
Eastern Mole	2	1	0.3	0.01	0.0	0.0	0.1
Unid. Bat	5		0.6	0.02	0.0	0.1	
Hoary Bat	1	1	0.1	0.00	0.0	0.0	0.0
Unid. Rabbit	3	1	1.6	0.04	0.1	0.2	0.3
Groundhog	1	1	0.6	0.02	0.0	0.1	0.1
Unid. Squirrel	2	1	0.9	0.02	0.0	0.1	0.2
Grey Squirrel	7	1	2.2	0.05	0.1	0.2	0.4
Southern Flying Squirrel	3	1	0.5	0.01	0.0	0.1	0.1
Beaver	4	1	3.3	0.08	0.1	0.3	0.6
White-footed Mouse	1	1	0.1	0.00	0.0	0.0	0.0
Eastern Woodrat	12	3	5.6	0.12	0.2	0.5	1.0
Muskrat	2	1	1.4	0.04	0.1	0.2	0.3
Domestic Dog	2	1	1.5	0.04	0.1	0.2	0.3
Gray Fox	2	1	2.4	0.06	0.1	0.3	0.5
Black Bear	35	3	115.4	1.89	3.6	8.2	15.9
Raccoon	18	3	26.0	0.49	1.0	2.1	4.2
Mink	1	1	0.3	0.01	0.0	0.0	0.1
Elk	1	1	0.2	0.01	0.0	0.0	0.1
White-tailed Deer	188	8	574.2	8.00	15.4	34.6	67.3
Native Species Total	8711	59	5751.7	51.80	100.0	51.8	100.0
Old World Domesticates							
Pig	3	2	8.3	0.18			
Cattle	5	1	119.4	1.95			
Sheep	4	1	15.3	0.31			
Grand Total	8723	63	5894.7	2.43			

Table A.12: Results of Faunal Analysis of Component 2 (page 1).

Taxon	Elements	MNI	Element Weight (g)	Biomass		Extrapolated Biomass	
				Weight (kg)	Per- cent	Weight (kg)	Per- cent
Mussels							
Unidentified	75		0.12	0.24	0.7		
<i>Eliptio complanata</i>	5	3	0.04	0.11	0.3	0.2	0.7
<i>E. crassidens</i>	7	4	0.07	0.16	0.5	0.3	1.0
Aquatic Snails							
<i>Elimia clavaeformis</i>	23762	23440	6.47	3.86	11.8	3.9	11.9
<i>Io fluviialis</i>	6	6	0.01	0.01	0.0	0.0	0.0
Crayfish							
Unidentified	9	5					
Fish							
Unidentified	67		0.01	0.13	0.4		
Redhorse	2	1	0.00	0.02	0.1	0.1	0.3
Yellow Perch	3	1	0.00	0.02	0.1	0.1	0.2
Amphibians							
Unidentified	41		0.01	0.08	0.2		
Salamanders	56		0.01	0.12	0.4	0.2	
American Toad	70	5	0.00	0.05	0.2	0.1	0.2
Frog	5	2	0.00	0.02	0.1	0.0	0.1
Turtles							
Unidentified	3		0.00	0.03	0.1		
Snapping Turtle	3	1	0.01	0.14	0.4	0.1	0.5
Painted Turtle	11	2	0.03	0.27	0.8	0.3	0.9
Eastern Box Turtle	133	4	0.09	0.66	2.0	0.7	2.1
Spiny Softshell	1	1	0.00	0.02	0.1	0.0	0.1
Snakes							
Unidentified	28		0.00	0.04	0.1		
Black Racer	10	1	0.00	0.02	0.1	0.0	0.1
Rat Snake	1	1	0.00	0.00	0.0	0.0	0.0
Kingsnake	2	1	0.00	0.00	0.0	0.0	0.0
Northern Water Snake	2	1	0.00	0.00	0.0	0.0	0.0
Timber Rattlesnake	44	2	0.01	0.13	0.4	0.2	0.5

Table A.12: Results of Faunal Analysis of Component 2 (page 2).

Taxon	Elements	MNI	Element Weight (g)	Biomass		Extrapolated Biomass	
				Weight (kg)	Per- cent	Weight (kg)	Per- cent
Birds							
Unidentified	292		0.06	0.84	2.6		
Pied-billed Grebe	4	1	0.00	0.03	0.1	0.1	0.2
Green Heron	1	1	0.00	0.01	0.0	0.0	0.1
Mallard	2	2	0.00	0.01	0.0	0.0	0.0
Wood Duck	6	1	0.00	0.05	0.2	0.1	0.3
Ruffed Grouse	8	3	0.00	0.07	0.2	0.1	0.5
Bobwhite Quail	8	2	0.00	0.03	0.1	0.1	0.2
Wild Turkey	14	2	0.04	0.57	1.7	1.2	3.6
Passenger Pigeon	1	1	0.00	0.00	0.0	0.0	0.0
Red-bellied Woodpecker	7	2	0.00	0.03	0.1	0.1	0.2
Unid. Perching Birds	2		0.00	0.00	0.0	0.0	
American Robin	1	1	0.00	0.00	0.0	0.0	0.0
Unid. Wood Warblers	2	1	0.00	0.00	0.0	0.0	0.0
Mammals							
Unidentified	3148		1.64	20.53	63.0		
Bats	3	1	0.00	0.01	0.0	0.0	0.1
Unid. Rabbit	8	2	0.00	0.09	0.3	0.5	1.6
Groundhog	1	1	0.00	0.06	0.2	0.3	1.0
Grey Squirrel	10	2	0.00	0.10	0.3	0.6	1.7
Fox Squirrel	1	1	0.00	0.02	0.1	0.1	0.4
Southern Flying Squirrel	2	2	0.00	0.01	0.0	0.1	0.2
Beaver	1	1	0.00	0.03	0.1	0.2	0.6
Marsh Rice Rat	4	2	0.00	0.04	0.1	0.2	0.8
Eastern Woodrat	2	1	0.00	0.01	0.0	0.1	0.3
Muskrat	10	2	0.01	0.24	0.7	1.4	4.3
Grey Fox	2	1	0.01	0.15	0.5	0.9	2.6
Black Bear	13	2	0.04	0.67	2.0	3.9	12.0
Raccoon	11	2	0.01	0.25	0.8	1.4	4.4
White-tailed Deer	63	6	0.16	2.59	7.9	15.0	46.4
Native Species Total	27973	23524	8.87	32.60	100.0	32.6	100.0
Old World Domesticates							
Sheep	1	1	0.01	0.12			
Horse	1	1	0.01	0.11			
Total	27975	23526	8.88	32.83			

Table A.13: Results of Faunal Analysis of Component 3 (page 1).

Taxon	Elements	MNI	Element Weight (g)	Biomass		Extrapolated Biomass	
				Weight (kg)	Per- cent	Weight (kg)	Per- cent
Mussels							
Unidentified	105		158.7	0.30	0.6		
Eliptio complanata	2	2	3.1	0.02	0.0	0.1	0.1
E. crassidens	6	5	51.5	0.14	0.3	0.4	0.8
Aquatic Snails							
Elimia clavaeformis	1420	1392	425.2	0.31	0.6	0.3	0.6
Io fluvialis	3	3	13.4	0.01	0.0	0.0	0.0
Crayfish							
Unidentified	3	2	0.5				
Fish							
Unidentified	98		9.9	0.19	0.4		
Minnows	2	1	0.1	0.00	0.0	0.0	0.0
Suckers	8	1	0.1	0.00	0.0	0.0	0.0
Black Basses	1	1	0.2	0.01	0.0	0.1	0.1
Yellow Perch	3	1	0.3	0.01	0.0	0.1	0.2
Amphibians							
Unidentified	296		21.6	0.31	0.6		
Salamanders	65	4	11.0	0.16	0.3	0.4	0.7
American Toad	77	3	3.9	0.05	0.1	0.1	0.3
Frog	3	1	0.9	0.01	0.0	0.0	0.1
Turtles							
Unidentified	1		0.3	0.01	0.0		
Snapping Turtle	6	1	15.0	0.19	0.4	0.2	0.4
Painted Turtle	51	2	51.5	0.44	0.9	0.4	0.9
Eastern Box Turtle	235	7	174.2	1.00	2.0	1.0	2.0
Snakes							
Unidentified	70		3.5	0.05	0.1		
Black Racer	4	1	0.4	0.01	0.0	0.0	0.0
Rat Snake	10	1	1.9	0.03	0.1	0.0	0.1
Kingsnake	1	1	0.2	0.00	0.0	0.0	0.0
Northern Water Snake	8	1	1.5	0.02	0.0	0.0	0.0
Pine Snake	1	1	0.1	0.00	0.0	0.0	0.0
Timber Rattlesnake	93	5	24.7	0.35	0.7	0.4	0.8

Table A.13: Results of Faunal Analysis of Component 3 (page 2).

Taxon	Elements	MNI	Element Weight (g)	Biomass		Extrapolated Biomass	
				Weight (kg)	Per- cent	Weight (kg)	Per- cent
Birds							
Unidentified	515		143.9	1.88	3.7		
Pied-billed Grebe	7	3	4.2	0.08	0.1	0.5	0.9
Marsh Ducks	1	1	0.5	0.01	0.0	0.1	0.1
Merlin	2	1	1.1	0.02	0.0	0.1	0.3
Ruffed Grouse	1	1	0.2	0.00	0.0	0.0	0.1
Bobwhite Quail	1	1	0.2	0.00	0.0	0.0	0.1
Wild Turkey	8	2	11.8	0.19	0.4	1.2	2.3
Passenger Pigeon	5	1	0.9	0.02	0.0	0.1	0.2
Barred Owl	1	1	0.3	0.01	0.0	0.0	0.1
Red-bellied Woodpecker	6	3	1.0	0.02	0.0	0.1	0.2
Perching Birds	4		0.4	0.01	0.0	0.1	0.1
Brown Thrasher	1	1	0.1	0.00	0.0	0.0	0.0
Eastern Meadowlark	1	1	0.2	0.00	0.0	0.0	0.1
Mammals							
Unidentified	4954		3083.9	36.32	70.8		
Opossum	1	1	0.9	0.02	0.0	0.1	0.2
Eastern Mole	2	1	0.2	0.01	0.0	0.0	0.1
Bats	10	3	0.7	0.02	0.0	0.1	0.2
Unid. Rabbit	14	2	6.7	0.15	0.3	0.7	1.4
Groundhog	6	1	19.7	0.38	0.8	1.9	3.8
Grey Squirrel	15	2	3.7	0.09	0.2	0.4	0.8
Fox Squirrel	1	1	1.4	0.04	0.1	0.2	0.3
Southern Flying Squirrel	11	2	2.6	0.06	0.1	0.3	0.6
Beaver	4	1	5.2	0.12	0.2	0.6	1.1
Eastern Woodrat	5	2	2.3	0.06	0.1	0.3	0.5
Muskrat	2	1	1.7	0.04	0.1	0.2	0.4
Domestic Dog	4	1	2.3	0.06	0.1	0.3	0.5
Grey Fox	1	1	0.5	0.01	0.0	0.1	0.1
Black Bear	5	1	16.3	0.32	0.6	1.6	3.2
Raccoon	10	2	20.5	0.40	0.8	2.0	3.9
Striped Skunk	1	1	1.2	0.03	0.1	0.2	0.3
River Otter	1	1	0.4	0.01	0.0	0.1	0.1
Elk	4	1	45.5	0.82	1.6	4.1	8.0
White-tailed Deer	124	5	450.3	6.43	12.5	32.2	62.9
Total	8300	1482	4804.3	51.28	100.0	51.3	100.0

Table A.14: Results of Faunal Analysis of Component 4 (page 1).

Taxon	Elements	MNI	Element Weight (g)	Biomass		Extrapolated Biomass		
				Weight (kg)	Per- cent	Weight (kg)	Per- cent	
Mussels								
Unidentified	109		111.8	0.24	1.5			
<i>Eliptio complanata</i>	3	3	27.8	0.09	0.6	0.22	1.4	
<i>E. crassidens</i>	3	2	21.9	0.08	0.5	0.19	1.2	
Aquatic Snails								
<i>Elimia clavaeformis</i>	90	79	25.2	0.02	0.1	0.02	0.1	
<i>Io fluvialis</i>	1	1	0.8	0.00	0.0	0.00	0.0	
Crayfish								
Unidentified	8	3	0.9					
Fish								
Unidentified	35		2.6	0.06	0.4			
Minnows	1	1	0.2	0.01	0.1	0.02	0.1	
Redhorse Sucker	1	1	1.4	0.04	0.2	0.09	0.6	
Amphibians								
Unidentified	19		1.1	0.02	0.1			
Salamanders	34	4	6.3	0.09	0.6	0.10	0.6	
American Toad	1	1	0.2	0.00	0.0	0.00	0.0	
Turtles								
Snapping Turtle	1	1	5.5	0.10	0.6	0.10	0.6	
Eastern Box Turtle	49	3	31.2	0.32	2.0	0.32	2.0	
Snakes								
Unidentified	30		2.1	0.03	0.2			
Black Racer	1	1	0.2	0.00	0.0	0.00	0.0	
Northern Water Snake	8	1	0.9	0.01	0.1	0.01	0.1	
Timber Rattlesnake	58	3	10.9	0.15	1.0	0.18	1.1	

Table A.14: Results of Faunal Analysis of Component 4 (page 2).

Taxon	Elements	MNI	Element Weight (g)	Biomass		Extrapolated Biomass	
				Weight (kg)	Per- cent	Weight (kg)	Per- cent
Birds							
Unidentified	166		58.4	0.83	5.2		
Perching Birds	1	1	0.1	0.00	0.0	0.07	0.4
Pied-billed Grebe	1	1	0.2	0.00	0.0	0.12	0.8
Marsh Ducks	2	1	0.9	0.02	0.1	0.49	3.1
Blue-winged Teal	1	1	0.3	0.01	0.0	0.18	1.1
Mammals							
Unidentified	2345	905.5	12.06	75.5			
Short-tailed Shrew	1	1	0.1	0.00	0.0	0.03	0.2
Bats	6	1	0.2	0.01	0.0	0.05	0.3
Hoary Bat	1	1	0.1	0.00	0.0	0.03	0.2
Groundhog	1	1	0.8	0.02	0.1	0.17	1.0
Grey Squirrel	3	2	1.5	0.04	0.2	0.29	1.8
Southern Flying Squirrel	5	3	1.6	0.04	0.3	0.31	2.0
Beaver	2	1	1.9	0.05	0.3	0.36	2.3
Eastern Woodrat	1	1	0.3	0.01	0.1	0.07	0.4
Meadow Vole	4	2	0.8	0.02	0.1	0.17	1.0
Porcupine	1	1	0.3	0.01	0.1	0.07	0.4
Domestic Dog	1	1	0.5	0.01	0.1	0.11	0.7
Raccoon	9	3	9.4	0.20	1.2	1.54	9.6
River Otter	1	1	0.9	0.02	0.1	0.19	1.2
White-tailed Deer	36	2	79.3	1.35	8.4	10.46	65.6
Total	3040	129	1314.1	15.96	100.0	15.96	100.0

Table A.15: Results of Faunal Analysis of Component 5 (page 1).

Taxon	Elements	MNI	Element Weight (g)	Biomass		Extrapolated Biomass	
				Weight (kg)	Per- cent	Weight (kg)	Per- cent
Mussels							
Unidentified	47		40.0	0.12	0.4		
<i>Eliptio complanata</i>	1	1	5.6	0.03	0.1	0.1	0.3
<i>E. crassidens</i>	1	1	4.6	0.03	0.1	0.1	0.3
Aquatic Snails							
<i>Elimia clavaeformis</i>	126	126	27.0	0.02	0.1	0.0	0.1
<i>Io fluviialis</i>	11	11	29.9	0.03	0.1	0.0	0.1
Crayfish							
Unidentified	11	6	0.4				
Fish							
Unidentified	109		7.0	0.14	0.4		
Suckers	2	1	0.2	0.01	0.0	0.1	0.3
Yellow Perch	1	1	0.1	0.00	0.0	0.1	0.2
Amphibians							
Unidentified	219		5.5	0.08	0.2		
Salamanders	17		3.3	0.05	0.1	0.1	
American Toad	13	1	1.0	0.01	0.0	0.0	0.1
Turtles							
Unidentified	4		0.8	0.03	0.1		
Snapping Turtle	1	1	1.9	0.05	0.1	0.1	0.2
Painted Turtle	30	2	13.4	0.18	0.6	0.2	0.6
Eastern Box Turtle	68	3	32.9	0.33	1.0	0.3	1.1
Snakes							
Unidentified	13		1.1	0.02	0.0		
Black Racer	7	1	1.1	0.02	0.0	0.0	0.1
Rat Snake	3	1	0.1	0.00	0.0	0.0	0.0
Pine Snake	5	1	0.6	0.01	0.0	0.0	0.0
Timber Rattlesnake	52	2	10.9	0.15	0.5	0.2	0.5

Table A.15: Results of Faunal Analysis of Component 5 (page 2).

Taxon	Elements	MNI	Element Weight (g)	Biomass		Extrapolated Biomass	
				Weight (kg)	Per- cent	Weight (kg)	Per- cent
Birds							
Unidentified	300		68.0	0.95	2.9		
Pied-billed Grebe	1	1	0.3	0.01	0.0	0.1	0.3
Ruffed Grouse	2	1	0.6	0.01	0.0	0.2	0.5
Wild Turkey	3	1	2.1	0.04	0.1	0.5	1.5
Passenger Pigeon	1	1	0.2	0.00	0.0	0.1	0.2
Red-bellied Woodpecker	3	1	0.6	0.01	0.0	0.2	0.5
Perching Birds	5		0.4	0.01	0.0	0.1	
Mammals							
Unidentified	5611		2033.3	24.97	76.7		
Short-tailed Shrew	1	1	0.1	0.00	0.0	0.0	0.1
Least Shrew	1	1	0.1	0.00	0.0	0.0	0.1
Bats	2		0.2	0.01	0.0	0.0	
Hoary Bat	1	1	0.2	0.01	0.0	0.0	0.1
Unid. Rabbit	2	1	1.3	0.03	0.1	0.2	0.6
Groundhog	5	2	6.8	0.15	0.5	0.8	2.6
Grey Squirrel	4	1	1.2	0.03	0.1	0.2	0.6
Fox Squirrel	3	1	1.1	0.03	0.1	0.2	0.5
Southern Flying Squirrel	4	2	1.0	0.03	0.1	0.2	0.5
Beaver	1	1	0.4	0.01	0.0	0.1	0.2
Muskrat	2	1	1.6	0.04	0.1	0.2	0.7
Porcupine	7	1	1.9	0.05	0.1	0.3	0.8
Domestic Dog	2	1	6.9	0.15	0.5	0.9	2.7
Grey Fox	2	1	1.3	0.03	0.1	0.2	0.6
Black Bear	3	1	4.8	0.11	0.3	0.6	1.9
Raccoon	17	4	21.9	0.42	1.3	2.4	7.5
Striped Skunk	1	1	0.4	0.01	0.0	0.1	0.2
Elk	5	1	44.7	0.80	2.5	4.6	14.3
White-tailed Deer	99	3	218.5	3.35	10.3	19.2	59.6
Total	6829	189	2607.3	32.57	100.0	32.6	100.0

assessed to some extent by comparison of the relative number of elements recovered from each, this ignores the obvious fact that animals differ in size. Obviously, in terms of the meat they represent, 10 fish bones are not equivalent to 10 bear bones. Tables A.11 - A.15 show the relative contribution of taxa to the total assemblage of faunal material from each component expressed in three additional ways.

The first measure of relative contribution is the zooarchaeologist's traditional measure (Grayson 1984) of minimum number of individuals (MNI). MNI expresses the minimum number of individuals required to account for the elements of its taxon recovered from a component. For the analysis of the Daugherty's Cave material this measure likely has little validity. This is because elements from entire components were aggregated to form the analytic unit from which MNI's were calculated. As the strata of the components likely took many years to accumulate, and the materials contained within them deposited during numerous discrete episodes of human activity, the MNI's for the bone assemblages are almost certainly under-representations of the number of individuals actually represented (see Grayson 1984 for a detailed treatment of aggregation problems in MNI calculations). The MNI figures are presented in the tables for tradition's sake, but the doubts surrounding their validity cannot be overstressed.

The second measure of the relative contribution of taxa to the entire faunal assemblage relies on the calculation of the live biomass represented by the bone or shell recovered from the site (cf. Reitz et al. 1983). This can be done since the skeletal or shell weight of an organism is related allometrically to the total weight of the organism. Formulae relating skeletal weight to vertebrate live weights, and invertebrate shell weights to live meat weights (Reitz and Quitmeyer 1988) were used in this study. The procedure used in this study was to apply the formulae provided by Reitz and Quitmeyer (1988) to the average weight of the elements of a taxon from a component, then multiply the allometrically determined average biomass weight by the number of

elements. Since the allometric formulae are logarithmic, different biomass figures can be obtained by applying the formulae to individual elements then summing the biomass figures, or by summing the element weights then applying the allometric formulae. The method used here produces biomass figures intermediate between the other two methods.

As a measure of relative contribution of taxa to total bone assemblages, the calculation of biomass is superior to MNI since it uses individual elements, thus avoiding the effects of aggregation. They are likewise superior to element counts, since by using element weight, they take into account the size differences of the animals. However, biomass calculations can be skewed if species of different classes are compared. In particular, shells of invertebrates, especially snails, are frequently recovered intact enough to allow a genus or species identification, but vertebrate remains are often comprised mostly of small fragments that can be identified only to class. Hence on a direct species to species comparisons, invertebrates may gain a specious importance. For example the biomass calculations for the component 2 faunal remains (Table A.12) indicates that aquatic snails contributed 12% of the biomass, while white-tailed deer contributed 8%. The apparent conclusion that snails were half-again as important as deer ignores the fact that 63% of the biomass is contributed by unidentified mammals; many of which were likely deer. This problem with biomass calculations can be mitigated, however.

The third measure of a taxon's relative contribution to the total bone assemblage of a component is a modification of the biomass calculation aimed at mitigating the influence of the biomass ascribed only to the level of class. To calculate this measure, the biomass calculations are performed as above, but the biomass ascribed to class is redistributed among the taxa identified from the class based on the relative proportions of the identified taxa. For example, if the biomass of mammals was originally calculated to represent 100 kg of unidentified mammals, 60 kg of deer and 20 kg of

bear, this would be recalculated as representing 135 kg of deer and 45 kg of bear. The "unidentified" 100 kg being distributed between deer and bear at a ratio of 3:1. This method of redistribution assumes, first, that all the taxa contributing to the "unidentified" category have been identified to a lower-level taxa, and second, that their relative proportions within the "unidentified" remains are the same as their relative proportions in the lower-level taxon. These assumptions seem generally reasonable given a large sample of remains and a skilled analyst.

The results of the "redistributed biomass" calculations are provided in the final two columns of tables A.11 to A.15. The redistributed biomass figures are considered the most representative measures of the relative contribution of the taxa to the total faunal assemblage of each component. These are the figures used in Chapter 5 in comparing the archaeological record to the outputs of optimal diet models and will be the basis for inferences below.

Results

Freshwater Mussels. Although freshwater mussels were recovered from every component, they appear to have been an insignificant part of the prehistoric diet. Only three mussels were identified from the Daugherty's Cave samples. Eliptio complanata, E. crassidens and Dysnomia sp. were, before modern habitat degradation, common in the Tennessee River drainage (Ortmann 1918). All prefer firm, gravelly bottoms and adequate current (Parmalee 1967). As Big Cedar Creek meets these criteria, it seems likely that the relatively few individual mussels recovered from Daugherty's Cave were obtained from the immediate environs of the site. Exploitation of the Clinch River mussel populations probably took place from locales much closer to the river.

Aquatic Snails. Aquatic snails were recovered in great amounts from Daugherty's Cave especially from the Mississippian components. Aquatic snails are frequently recovered from archaeological sites in the Eastern Woodlands frequently in

great quantity (Klippel and Morey 1988) and from both Archaic (Klippel and Morey 1988) and Woodland/Mississippian (Whyte 1989) period contexts. Although snail shells might be used for beads, and some of the Mississippian period pottery of southwestern Virginia is tempered with gastropods, there is no reason to think non-dietary uses account for their presence at Daugherty's Cave. First, only a few gastropod-tempered potsherds were recovered from Daugherty's Cave; most of the New River ware being mussel-shell-tempered. Second, the Daugherty's Cave rockshelter shows no evidence of being a locus of pottery manufacture. Further, it seems a poor location for such an activity, as it would necessitate carrying both clay and snails a considerable distance upslope to the shelter. Finally the snails at Daugherty's Cave are represented almost entirely by complete shells with no evidence of crushing, grinding or any other sort of intentional modification, but do have the whitened appearance and somewhat chalky texture that boiling produces. Although it cannot be disproved that the snails at Daugherty's Cave were carried to the shelter with some nongustatory intent then abandoned unused, Occam's razor argues for a dietary usage.

In the Mississippian component at Daugherty's Cave they seem to have ranked behind only deer and black bear in their relative contribution to the diet. However, in general their abundance is somewhat misleading, as the individual snails are so small, circa 0.15 g (Klippel and Morey 1986), that enormous quantities are required to constitute a meal. It seems most likely that snails were used as a flavoring agent for soups or broths, and as such may have contributed some water-soluble vitamins and minerals to the diet but perhaps little meat (Klippel and Morey 1986).

Where snails are locally abundant and water conditions satisfactory, gathering snails can be accomplished readily. Exploitation of snails, like that of freshwater mussels, is usually considered a summer-fall activity, as the low water levels of those

seasons facilitates location and collection of the bottom dwelling creatures (Klippel and Morey 1988; Parmalee 1967; Bobrowsky 1982).

Elimia snails are common snails of the Tennessee River drainage (Burch 1982). In the present day, Elimia clavaeformis thickly cover the algae-covered rocks of Big Cedar Creek immediately below Daugherty's Cave. Io fluvialis are endemic to the upper Tennessee River drainage of southwestern Virginia, where they are frequently recovered from archaeological sites (Holland 1970). The snails from Daugherty's Cave, like the mussels, were probably collected from the immediate site environs.

Crayfish. Included in the Daugherty's Cave faunal material are 31 distal tips of crayfish claws. Crayfish are rarely reported archaeologically (Whyte 1989:216) but are known from historic accounts to have been eaten by some Native Americans in the Carolinas (Lefler 1967:218). The remains from Daugherty's Cave may represent human food, but equally likely is the possibility that they were deposited in the shelter by some animal such as an opossum or raccoon. The crayfish remains were not included in the calculation of biomass due to the lack of an established allometric formula.

Fish. Fish do not seem to have been of much importance at Daugherty's Cave. In no component do they ever contribute as much as 1% of the animal biomass. The yellow perch, golden redhorse and freshwater drum are common fishes of streams and rivers of southwestern Virginia, as are numerous species of minnows, suckers and catfish. Based on modern distributions and abundances, the black bass identified in the sample is most likely the smallmouth bass, but the spotted bass is possible (Lee 1980). Of the fish identified in the Daugherty's Cave samples, all would be expected parts of the Big Cedar Creek community with the possible exception of the freshwater drum. The freshwater drum generally prefers larger, more turbid rivers but is sporadically found in smaller streams (P. Smith 1979). It may have been taken from a pool in Big

Cedar Creek, or it may have been obtained from the Clinch River, although the Clinch is hardly turbid.

Amphibians. Remains of amphibians were quite common in the rockshelter, but these are not thought to reflect on human activities. Rather it is considered that the salamanders and toads were commensal species that lived in the shelter. These animals were frequently represented by nearly complete skeletons suggesting they died naturally in their burrows. It seems less likely that frogs would have remained as far from the streambank as a life in the shelter would have necessitated. On the other hand, some predator using the shelter as a den could easily have introduced their remains. At any rate the rarity of frogs in the samples - only eight elements - does not suggest them to have been of any importance.

Turtles. The remains of one terrestrial and four aquatic turtles were recovered from the samples. The eastern box turtle is a common woodland turtle whose carapace was much favored by Native Americans for use as a utensil. Hence its substantial representation among the faunal elements should not be assumed to reflect its dietary importance. It seems reasonable to assume, however, that Native Americans usually collected box turtles whenever they were encountered. This would, of course, involve nothing more than picking them up. Aquatic turtles can sometimes be collected by hand, although the spiny softshell is considered too swift and wary to make this practical (Ernst and Barbour 1972). Most likely aquatic turtles were taken with set lines or basket traps. Even assuming that the sometimes poisonous box turtles were eaten (Ernst and Barbour 1972), turtles supplied only about 3% to 4% of the diet at Daugherty's Cave.

The snapping turtle and painted turtle are quite common in the area, but prefer quiet, well-vegetated waters (Martof et al. 1980). They may have been taken from a pool in Big Cedar Creek or perhaps from a sinkhole pond. The spiny softshell prefers

larger streams with sandy bottoms (Martoff et al. 1980); hence it was most likely taken from the Clinch River.

The turtles represented by the Daugherty's Cave remains hibernate from October to March-April (Ernst and Barbour 1972), so their presence at the site likely reflects an occupation during the late spring to mid-fall.

Snakes. According to John Lawson, some historic period Native Americans ate snakes and some did not (Lefler 1967). At most, snakes seem to have made up less than 1% of the animal food at Daugherty's Cave. Furthermore, the black racer, rat snake, kingsnake, pine snake and timber rattlesnake may have occupied the shelter naturally. Of course if encountered by humans there, they may have entered the diet. The northern water snake is a denizen of the water's edge, so it seems unlikely it would have ventured so far upslope as to inhabit Daugherty's Cave (Martoff et al. 1980). Like the frogs, however, its remains may have been introduced by some nonhuman predator. Of course human predation is equally likely. All of the snakes would have been available in the immediate environs of the site during the warm seasons.

Birds. At least 20 species of birds are represented in the Daugherty's Cave samples, but birds contribute only about 3% to 5% of the animal biomass. Gallinaceous birds, particularly wild turkey and ruffed grouse, are the most important followed by waterfowl, especially marsh ducks and grebes.

Wild turkey is the most important avian species in every component except the thin Early Woodland levels, from which it is absent. Wild turkey was an important game species for Eastern Woodlands Native Americans during historic times (Swanton 1946) and is frequently recovered archaeologically as well (Smith 1975; Cleland 1976). Fall, seems to have been the preferred season for Native American turkey hunting, as that is when turkeys congregate in large flocks to feed on mast (Swanton 1946).

The prevalence of waterfowl at Daugherty's Cave is somewhat surprising. Southwestern Virginia is not a primary wintering or breeding area, nor is it on a major

flyway (Johnsgard 1975). The wood duck is a year round resident of southwestern Virginia, and mallards winter to some extent everywhere in the continental U.S. (Johnsgard 1975)). Southwestern Virginia is within the breeding range of the pied-billed grebe, where it is likely to be present from late March to perhaps November (Palmer 1962). It prefers ponds with well-vegetated shores as breeding habitat, so they likely occupied the numerous sinkholes of the area. The blue-winged teal and hooded merganser are unlikely to have been present in the area except during their fall or spring migrations (Johnsgard 1975). Overall, some waterfowl would have been available in the Daugherty's Cave area throughout the year. However, since they are generally small in size, their contribution to the diet was always less than their numbers in the samples might indicate. Judging by the biomass calculations, all the waterfowl combined do not seem to have equalled the dietary contribution of wild turkey alone, except in the small Early Woodland period sample. Of course, the fact that upland game birds were more important than waterfowl is hardly a surprising result from mountainous southwestern Virginia.

In historic times in the Eastern Woodlands, passenger pigeons were harvested in tremendous numbers during the fall and winter by Native Americans (Lefler 1967:50). However, passenger pigeons, like waterfowl, were recovered with some regularity at Daugherty's Cave but do not seem to have made much dietary impact.

The wide array of small birds recovered from Daugherty's Cave are of dubious association with the human occupations. However, Native Americans possessed snares and traps designed for taking small birds (Cooper 1938), and bones of small birds were identified in human paleofeces from Salts Cave, Kentucky (Yarnell 1969).

Nonetheless, it seems as likely that some other predator (or scavenger) is responsible for their presence there. The merlin could certainly account for them, but it seems an unlikely cave inhabitant. The barred owl may have used the cave as a roost, but as a

nocturnal predator is more likely responsible for the abundance of small mammals in the site than for the diurnal birds.

The presence of eastern meadowlark in the Middle Woodland levels of the site is of interest as an indication of non-wooded habitat. It is tempting to link this evidence of forest clearance with the evidence for Middle Woodland gardening. However, it must be admitted that meadowlarks undoubtedly evolved their habitat preferences prior to the origin of Native American agriculture. Alas, a single meadowlark does not a farmstead make.

Mammals. Mammals are clearly the most important class of animals at Daugherty's Cave. And, as expected, white-tailed deer is clearly the most important mammal. Deer make up from 46% to 67% of the animal biomass represented by the component samples. Raccoon was recovered from every component. It makes up from 4% to 10% of the animal biomass of the components. Black bear is absent from the small Early Woodland period sample but otherwise makes up from 2% to 16% of the biomass. It is more important in the historically disturbed and Mississippian components (16% and 12% of biomass respectively) than in the lower three components (3%, absent, and 2%, respectively). Elk suggests the opposite pattern. It is most important in the Late Archaic period component (14% of biomass), followed by 8% of biomass in the Middle Woodland period component. Only a single element of elk bone is recovered from levels above the Middle Woodland. It is absent from the small Early Woodland component as well. Clearly the mammal procurement strategies of the Daugherty's Cave inhabitants were quite focal centering on deer, bear, raccoon and to a lesser extent elk. The primary importance of deer, bear and raccoon is typical of other studies of Eastern Woodlands archaeological sites (Cleland 1966) and with historic accounts of Native American hunting (Swanton 1946; Lefler 1967).

According to historical accounts (Swanton 1946), fall and winter were the usual times for deer and bear hunting. The season of death of four juvenile deer can be

inferred from the Daugherty's Cave remains. The age-at-death for the four deer were 2.5 to 4 months, 3 to 4 months, 4 to 7 months and 7 to 9 months. Assuming a fawn birthing date of about May 1 for western Virginia (Scalon and Vaughan 1983), the indicated seasons of death for the deer are July to September, August to September, September to November, and December to February. Thus, the deer hunting period at Daugherty's Cave might have spanned the mid-summer to late winter. On the other hand, a much shorter fall-winter hunting season of September to December could account for the deer remains as well.

The other mammals exploited at Daugherty's Cave do not seem to have been nearly as important. Groundhog, beaver, and grey squirrels were recovered from every zone, but generally contributed little to the animal biomass. Groundhog, however, does seem to have rivaled raccoon in importance during Middle Woodland times and bear in the Late Archaic period. In addition muskrat was about as important as raccoon in the Mississippian period component. Groundhog is a true hibernator, and as such, indicates a warm season period of exploitation. During the excavation of Daugherty's Cave, groundhogs were observed basking on the rocky slopes near the mouth of the shelter.

Many of the mammals recovered from Daugherty's Cave are likely to have been natural cave occupants. In particular moles, shrews, bats, voles, mice and rats are expected components of the rockshelter fauna. This expectation is reinforced by the fact that the fossorial mammals were frequently recovered as nearly entire skeletons suggesting they died natural deaths in their burrows. Of course, commensal small mammals could have been eaten by the Native Americans (cf. Yarnell 1969 for direct evidence of mice consumption). Insectivores, however, exude a strong musk that apparently prevents their consumption by carnivores (Martin et al. 1985; Nowak and Paradiso 1983:150). The dog remains may represent a commensal of another sort. The fragmentary dog remains show no butchering marks, but its inclusion in the human

diet cannot be ruled out. The dispersal of its bones throughout the midden parallels that of the presumed food animals.

A number of the smaller, nocturnal mammals probably represent the prey of nonhuman cave occupants. The mice, rats, flying squirrels and mink seem more likely targets for an owl than a Native American. Of course they might have been taken in traps set for other animals.

Only general inferences as to the habitats near Daugherty's Cave can be offered. The meadow vole inhabits damp meadows (Webster et al. 1985). Given the propensity of mountain streams for springtime flooding, such a habitat along the banks of Big Cedar Creek or the Clinch River would be unsurprising. White-tailed deer, grey fox, groundhog and rabbit are species that prefer woodland edges or early successional communities (Webster et al. 1985); hence their presence at Daugherty's Cave indicates some environmental disturbance. However, the abundance of these species in the site does not seem to be temporally patterned; thus an argument for changes in anthropogenic disturbance through time cannot be offered. A predominance of grey squirrels relative to fox squirrels, as exemplified by the Daugherty's Cave faunal remains, has been suggested to indicate the presence of an expansive mature forest (Flyger and Gates 1982). The black bear is a denizen of dense forests as well (Webster et al. 1985). Overall, it appears that throughout the Late Archaic to Mississippian periods the Daugherty's Cave locale supported mammal communities favoring both mature forest and early successional habitats. A forest with disturbed patches is indicated. The disturbances could have been created by natural factors (e.g. wildfire), anthropogenic factors (e.g. fire drives) or a combination of both.

Three mammals recovered from Daugherty's Cave - elk, porcupine and marsh rice rat - are of zoogeographical interest as they are no longer extant in southwestern Virginia. Both elk and porcupine were extirpated in the historic period (Webster et al. 1985). The eastern subspecies of elk was driven to complete extinction, while the

southern range of porcupine no longer extends beyond south central Pennsylvania (Webster et al. 1985). The marsh rice rat is found today only in the coastal plain and lower piedmont of Virginia and North Carolina; however, it does occupy the mountains of South Carolina (Webster et al. 1985). Apparently in late prehistoric times it occupied the mountains of southwestern Virginia as well.

BOTANICAL REMAINS (Tables A.16, A.17)

Methods

Recovery of carbonized plant remains was a principal focus of the 1982-83 excavations at Daugherty's Cave. Twenty liter soil samples were taken from each 10 cm level and floated using a SMAP-type machine (Watson 1976). Light fractions were collected in a 500 micron mesh sieve screen, while heavy fractions were collected in window screen with a mesh size of a little less than 1.6 mm (1/16th inch). Heavy fractions were chemically floated in a solution of zinc chloride sufficiently concentrated to float both bone, shell and dense charcoal fragments. The faunal material was submitted to Gregory Waselkov for zooarchaeological analysis.

Many soil samples were so rich in charcoal that only five-liter samples could be floated without risk of overflowing the light fraction collection sieve. Therefore each soil sample was floated in five-liter subsamples, but the heavy fractions were allowed to accumulate. Thus each 20 l liter sample produced four light fractions but only one heavy fraction.

Analytic procedures were those standard to the Research Laboratories of Anthropology (Yarnell 1974). Briefly the charcoal was sieved through stacked geologic sieves then examined with a binocular microscope at 7X to 30X magnification. Seeds from all size categories were identified to the most restrictive taxon possible and quantified by count. Non-seed material greater than 2.00 mm was

Table A.16: Carbonized Plant Remains from Daugherty's Cave (g).
Normed to 100 l fill.

Component	Unid.	Wood	Nutshell					Cultigens			Seeds	Total Plants	Actual Volume Analyzed (l)
			Hickory	Walnut	Butternut	Acorn	Hazel	Corn cupule	Squash rind	Gourd rind			
1. Historic	6.3	318.3	4.5	1.1		0.13					0.35	394.1	15
2. Mississippian	12.3	726.3	110.2	43.6	19.9	1.47		1.988			0.82	1266.6	19
3. Mid. Woodland	4.8	385.3	123.0	20.9	4.0	0.37	0.04	0.007	0.060		0.35	610.3	38
4. Early Woodland	5.2	290.7	169.8	26.2	3.3	0.14	0.02		0.036		0.39	552.7	35
5. Late Archaic	2.0	150.2	87.7	11.0	3.9	0.01			0.001	0.002	0.10	293.6	90
Total (500 l)	30.6	1870.8	495.1	102.8	31.1	2.12	0.06	1.995	0.097	0.002	2.01	3117.3	197

**Table A.17: Carbonized Seeds from Daugherty's Cave (counts).
Normed to 100 l fill.**

Component	Cultigens						Fleshy Fruits			
	to- bacco	corn	bean	sump- weed	chen- opod	may- grass	grape	bram- ble	ground cherry	hack- berry
1. Historic	7	7								
2. Mississippian		32	5				4			
3. Middle Woodland				3	99	11	16	11	3	
4. Early Woodland					6	131	3			
5. Late Archaic										1
Total (500 l)	7	39	5	3	105	142	23	11	3	1

Component	Commensal Weeds						Unidentified				Total seeds	
	purs- lane	bed- straw	ama- ranth	le- gume	grass	mus- tard?	type A	type B	type C	other		
1. Historic					7						40	60
2. Mississippian	5	2	5		2						62	117
3. Middle Woodland				3	5	3	13	27			95	287
4. Early Woodland	3				6				3		54	206
5. Late Archaic		1							1		19	22
Total (500 l)	8	3	5	3	20	3	13	27	4	270	692	

identified to category, e.g. wood, hickory nutshell, corn cupule, etc, and quantified by weight using an electronic top-loading balance. The composition of the non-seed charcoal between 2.00 mm and 0.07 mm in size was estimated by assuming the relative proportions of plant remains in the < 2.00 mm fraction were equivalent to those in the > 2.00 mm fraction. Material less than 0.7 mm in size was examined and all seeds quantified, but otherwise does not enter the tabulations. A total of 1.677 kg of carbonized plant remains have been analyzed to date.

Analysis of light fractions and heavy fractions has been somewhat unbalanced: light fraction material derived from 197 l of soil and heavy fraction material derived from 301 l of soil have been analyzed. Also, the sample sizes are not uniform among the five components. Thus inter-component comparisons cannot be made on a gram-to-gram, seed-to-seed basis. In order to make useful comparisons possible, the material recovered from the light and heavy fractions of each component has been normalized to a standard sample size of 100 l. The procedure for the "norming" was as follows: The weights and seed counts of each category of material from all light fractions of each component were summed, then multiplied by 100 l/soil sample volume. The same was done for the heavy fractions, then the products of the heavy and light fraction "normings" were summed. These data are presented in tables A.16 and A.17.

Results

Wood. Wood charcoal comprises the majority of the carbonized plant remains from Daugherty's Cave. No attempt was made to identify wood charcoal to species, but hardwoods seem to dominate the samples. This would be the expected pattern in the Ridge and Valley. It is noteworthy that except for a slight reversal during the Early Woodland period the weight of wood in the samples (after normalization) shows a fairly steady increase through time. This pattern may reflect an increasing intensity or frequency of use of the site through time. However the Woodland period strata of

Daugherty's Cave contain many thin laminae of ash. Such ash layers are thought to indicate prolonged or high-temperature burning (Butzer 1982:82). Thus the particularly high intensity of use during the Mississippian period suggested by the wood charcoal data may be more apparent than real. However, any inference as to the intensity or frequency of site use must be tempered with caution, especially considering the small area of the shelter excavated.

Mast. As is expected from Eastern Woodlands archaeological sites, remains of hickory nuts, walnuts, butternuts, acorns and hazelnuts dominate the plant food assemblage from Daugherty's Cave. Since nuts vary in their ratios of meat to shell and in their likelihood of surviving deposition and recovery, interpretation of carbonized nutshell weights are somewhat controversial.

The remains of hazelnut are the most easily interpreted. Hazel does not appear ever to have been an important resource at Daugherty's Cave or elsewhere in the Eastern Woodlands for that matter (Yarnell and Black 1985; Asch and Asch 1985). It is interesting, however, that its peak usage at Daugherty's Cave is during the Middle Woodland period. This is the same pattern seen in the lower Illinois River valley (Asch and Asch 1985). Since hazel is a heliophilic shrub, it is tempting to ascribe its increased presence at Daugherty's Cave to increased forest clearance linked to Middle Woodland gardening.

Some paleoethnobotanists consider acorn to be vastly underestimated relative to hickory nuts (Lopinot 1982) and suggest applications of correction factors of up to 50X (Yarnell and Black 1985) to make carbonized acorn shell comparable to carbonized hickory nutshell.

If a 50X multiplication factor is applied to the normed acorn shell figures from Daugherty's Cave, acorn ceases to be the last ranked nut in three of the four components. Its increased value of 74 g in the Mississippian period makes it the second-ranked nut behind hickory. Its increased values of 19 g in the Middle

Woodland component and 7 g in the Early Woodland component make it the third-ranked nut behind hickory and walnut. Its increased value of 0.5 g in the Late Archaic component is insufficient to remove it from last place. Notably, the 50X multiplication factor does not cause acorn to surpass hickory nut in any component. Hence the Daugherty's Cave nutshell remains agree with the modeled diets in offering no support of the suggestion that acorn was the most important plant food in the Southeast prior to the Mississippian period (Yarnell and Black 1985).

Although it seems intuitively reasonable that acorn shell is under-represented archaeologically compared to hickory nutshell, I hesitate to assign "correction" factors to the database in order to make it match our intuitions. While it is simple to correct for the differences in the edible portions of the various nuts (cf. USDA 1984), it is more difficult to account for differential preservation and recovery. However, ethnoarchaeological experiments can inform the former (Lopinot 1982), and standardization of recovery and analysis techniques should minimize the effects of the latter. Still, these factors can account only for differences in physical properties of the nuts. It seems much more difficult to account for cultural factors which might differentially favor the archaeological preservation of certain species of nutshell.

For example it is frequently suggested that hickory nutshell may have served as fuel, thus increasing their probability of carbonization. On the other hand, hickory nuts seem to have been processed most usually by boiling. The sodden nutshell resulting from this would seem an unlikely fuel compared to the shells of acorns, walnuts or butternuts, since they later would not be exposed to water during processing. I see no means of assigning numerical coefficients to the effects of different processing methods.

However, I do not argue that archaeologically recovered nutshell is a direct measure of the importance of the various nuts, since the physical differences among the nuts does make the underrepresentation of acorn seem quite likely. Furthermore,

historical observers of southeastern Native American subsistence from Hariot (Quinn 1955) to Adair (Williams 1930) mentioned acorns as an important food. However, neither the archaeological record nor mathematical modeling of Eastern Woodlands subsistence strategies supports the historical observations. The archaeological record is, of course, biased due to differential preservation and recovery. The models are, of course, limited in that they omit numerous, complicating variables such as variations in annual nut yields (Fowells 1965), resource depression near established human settlements (Vickery 1980), the sexual division of labor (Hill 1989) or varying opportunity costs (Winterhalder 1983). The fact that simple mathematical models omitting these factors fail to account for observed patterns of nut usage suggests that one or more of these factors (or perhaps some other) is essential in structuring Eastern Woodlands subsistence strategies. Obviously, many interesting aspects of prehistoric Eastern Woodlands subsistence ecology remain to be explored. I fear, however, that our need to understand prehistoric subsistence more completely may be disguised by the application of correction factors that bring our interpretations of the archaeological record into accord with our intuitions.

Cultigens. Seven or perhaps eight cultigens were represented in the Daugherty's Cave samples. These are tobacco, beans, maize, sumpweed, maygrass, squash, gourd, and chenopod. The latter, however, does not display the thin testas or truncate seed margins characteristic of domesticated chenopods (Smith 1987b).

A single tobacco seed was recovered from the historically disturbed zone of the shelter. Presumably this derived from the Mississippian period strata, but this cannot be demonstrated.

Beans were recovered only from the Mississippian period strata of the site. The lower-most bean was recovered from the 45-50 cm level of 0N12E, which produced a radiocarbon date of AD 900 \pm 60 (uncorrected). This is somewhat earlier than the eleventh century AD date for beans at the Little Roundtop site in New York.

However, the 30-40 cm level of 0N12E produced a fifteenth century radiocarbon date. The proximity of the levels producing such disparate dates is a cause for suspicion. The AD 900 date may be too early, or the bean may be a contaminant from a higher level.

Maize is represented by both cupules and kernel fragments. All were recovered from the Mississippian or later levels except for one cupule recovered from the 65-75 cm level of 1.5S10.5E. This level yielded a radiocarbon date of AD 580 \pm 60. In addition Benthall (1975) reports the recovery during the 1967 excavations of a carbonized maize cob from his Zone A level three. A feature from that level produced a radiocarbon date of AD 320 \pm 70 (uncorrected). Hence it is possible to argue from the Daugherty's Cave data that maize was present in southwestern Virginia in the late Middle Woodland period. This is not impossible, as maize has been directly dated to the second century AD from the Icehouse Bottom site in eastern Tennessee (Chapman 1985). However, my inclination is to consider the apparent Middle Woodland maize remains at Daugherty's Cave contaminants from the Mississippian strata.

A single sumpweed seed was recovered from the Middle Woodland levels of the site. The carbonized seed measures 5.3 mm X 3.8 mm. This indicates an uncarbonized achene size of 7.4 mm X 5.5 mm (Asch and Asch 1978:163). This size is within the range of other late Middle Woodland period sumpweed achene samples, but is larger than the mean sizes (Yarnell 1985). Cultigen sized sumpweed has been recovered from the dry rockshelters in eastern Kentucky from contexts as early as the Terminal Archaic - Early Woodland period (Cowan 1984; Gremillion and Ison 1989). It is present in the Little Tennessee River area during Early Woodland times as well (Chapman and Shea 1981). It has been recovered in Mississippian period contexts in the Appalachian Summit region of North Carolina (Yarnell 1976). Its presence in Virginia during the Middle Woodland period is not surprising but was previously undocumented.

Dry rockshelters in eastern Kentucky have also produced evidence of domesticated chenopod circa 1500 BC (Smith 1987b). The Early and Middle Woodland period chenopod from Daugherty's Cave, however, does not display the truncate margins and thin testas of domesticated chenopod, so it cannot be stated with certainty that the seeds represent a crop plant. Although the Daugherty's Cave seeds might derive from the exploitation of a wild or weed population, there seems little reason to doubt that they served as human food. Given its importance elsewhere in the Eastern Woodlands during Middle Woodland times (Fritz 1988), and their co-occurrence in the Middle Woodland levels of Daugherty's Cave with domesticated sumpweed, and the presumed domesticates, maygrass and squash, it seems likely that chenopod was a garden crop as well.

Maygrass is recovered from the Early and Middle Woodland levels of Daugherty's Cave but is much more abundant in the Early Woodland period levels. Although archaeological maygrass displays no morphological characters that can be ascribed to domestication, its common association in archaeological sites with demonstrable domesticates such as chenopod, sumpweed and sunflower, and the extension of its prehistoric range beyond its native range are considered evidence of prehistoric domestication (Cowan 1978). Maygrass has been recovered from the Little Tennessee river area in the Late Archaic period and from dry shelters in Kentucky in the Early Woodland period (Cowan 1978). Both areas, like southwestern Virginia, are beyond the native range of maygrass. Maygrass ripens in late spring to summer (Radford et al. 1968), so a warm season harvest is indicated. However it could have been stored for consumption in later seasons.

Fragments of squash rind were recovered from Middle Woodland, Early Woodland, and Late Archaic levels at the site. Squash is currently considered a native Eastern Woodlands plant whose domestication took place by 1000 BC (Smith 1987b).

Bottle gourd is represented by rind fragments found only in the Late Archaic strata. The lowermost level producing gourd, the 135-145 cm level of 1.5S10.5E, was radiocarbon dated to 2350 ± 80 BC (uncorrected). The earliest evidence at present of bottle gourd in the Eastern Woodlands is from the Windover site in Florida, where bottle gourd appears in the Middle Archaic period, circa 5350 BC (Smith 1987b).

Fleshy Fruits. Only four fleshy fruits are represented in the samples. A single hackberry seed was recovered from the Late Archaic component, and a single grape seed was recovered from the Early Woodland component. Otherwise, all fleshy fruits were recovered from the Middle Woodland levels. Grape, groundcherry and bramble (including blackberry, raspberry and dewberry) were recovered from the Middle Woodland strata. All are commonly recovered from archaeological sites in the Eastern Woodlands (Yarnell and Black 1985).

Grape vines are common along stream banks and other forest edges. Their fruit is usually available from August to October (Radford et al. 1968). Bramble is a common early successional plant, and as such is found in disturbed places. Its fruits are available from late May to August (Radford et al. 1968). Groundcherry is a weed of disturbed places that produces small edible berries from June to October (Radford et al. 1968). Hackberry is a large forest tree that fruits from August to October (Radford et al. 1968). The recovery of bramble from the Daugherty's Cave indicates that the shelter was utilized during summer. The other fleshy fruits could have been acquired from late summer to fall.

Commensal Weeds. Seeds of commensal forbs and grasses were found scattered throughout the levels of Daugherty's Cave, but are more common in the Mississippian and Middle Woodland levels. These weeds are colonizers of disturbed places. Thus they may have inhabited the immediate environs of the site as result of anthropogenic disturbances. Their recovery from Daugherty's Cave may not reflect utilization by the site inhabitants. Their increased frequencies in the later levels of the site may indicate

an increase in anthropogenic disturbances near the site through time. This pattern would be in accord with the evidence of the increased wood charcoal:float volume ratios that suggests that the intensity of site utilization increased through time.

Purslane and amaranth could have been used as potherbs (Medsger 1966) as could the presumed mustard. (The identification of the latter is questionable, since most members of this family are Old World introductions). Bedstraw is commonly recovered from archaeological sites in the Eastern Woodlands (Yarnell and Black 1985). The plant can be used for bedding or thatch, but its bristly fruits could have been introduced to the site by adhering to skin or clothing. The adherent quality of the fruit gives the plant another common name of "cleavers". The small fragment of a legume seed could not be identified, but it is not a domesticated bean. It may be beggars lice. The unidentified grass are mostly fragments of caryopses. Many of the fragments are probably maygrass but lack diagnostic characters. Other caryopses seem to derive from smaller seeded species such as panic grass or fescue.

The unidentified seed category is dominated by small unidentifiable fragments of seeds. Three "unknowns", however, were recovered repeatedly. The type A unknown is about 3 mm in length, flattened-trigonous in cross section, has a reticulated seed coat and a lateral groove running along one side. The type B resembles a huckleberry seed, but its hilum is located midway along the lateral edge of the seed, not near the seed base. The type C unknown appears to be the seed of violet, but all but one species of this genus are Old World introductions (Radford et al. 1968).

DISCUSSION

The focus of the 1982-83 excavations at Daugherty's Cave was on the recovery of a systematically collected sample of subsistence remains. The subsistence remains were to serve as a test of optimal diet models and to allow the empirical study of prehistoric subsistence patterns in southwestern Virginia. The collection of subsistence

remains was highly successful. Over 55,000 elements of faunal material and nearly 1.7 kg of carbonized plant remains were collected and analyzed. Unfortunately, although a sizable sample of artifactual material was recovered during the 1982-83 excavations only a small area of the shelter was opened. Hence, generalizing about the Daugherty's Cave site is difficult. A few comments seem in order, however.

Small non-riverine sites such as Daugherty's Cave are often described as fall season extractive camps used by deer hunters and nut collectors (e.g. MacCord 1973). Certainly the abundance of deer bone, projectile points, and nutshell would support such an interpretation. Likewise the dearth of storage pits, burials and formal processing tools from either the 1982-83 or larger 1967 excavation suggests the site was not occupied for long periods of time. Overall it does appear that Daugherty's Cave was used principally as a short-term base from which foraging could be conducted. However, the season of occupation cannot be ascribed solely to the fall. The utilization of the site during warm seasons is indicated by the presence of turtles, fish, shellfish, blackberries and perhaps by grebe and maygrass. It is worth emphasizing that except for the shellfish and turtle shell, the warm season indicators are unlikely to have been recovered by 1/4" dry-screening. Failure to pursue the full range of subsistence remains from a site invites spurious conclusions. However, in the case of Daugherty's Cave, the abundance of deer bone and nutshell relative to the warm season indicators does suggest fall as the principal, but not exclusive, season of occupation.

The material culture recovered from Daugherty's Cave, in particular the ceramic types, indicates that southwestern Virginia was culturally affiliated with the eastern Tennessee region. This is unsurprising since the principal rivers of southwestern Virginia, the Powell, Clinch and Holston, form the headwaters of the Tennessee River. During the Early and Middle Woodland periods, the association with the Tennessee River region seems to have been particularly strong. The vast majority

of the pottery recovered from the Early and Middle Woodland components at Daugherty's Cave can be easily assigned to established Tennessee River Valley types, especially Mulberry Creek plain, Candy Creek cordmarked, Wright check-stamped and Longbranch Fabric Marked. The occurrence of check-stamped pottery from Daugherty's Cave and the nearby Fox Meadows Apartment site seems to mark the northernmost extent of the southeastern carved-paddle-stamped ceramic tradition. No carved-paddle stamped ceramics have yet been recovered from further upstream (Egloff 1986).

Although southwestern Virginia displays little evidence of burial ceremonialism or the production or trade of sumptuary goods in the Early and Middle Woodland periods, in other regards it does not appear to be a particularly marginal area. The recovery of Late Archaic period squash and gourd and of Middle Woodland period maygrass, chenopod and sumpweed suggest that the transition to food production took place in southwestern Virginia at about the same rate as it did in the Tennessee River valley region (Chapman and Shea 1981). The recovery of cut mica and crested and prismatic blades from Daugherty's Cave and the Fox Meadows Apartment site indicate that southwestern Virginia participated in the Hopewell interaction sphere.

The Daugherty's Cave excavations do not provide much insight into the Late Woodland period in southwestern Virginia, as this period was poorly represented in the units excavated. This problem is compounded by the fact that separating the Late Woodland Radford Series ceramics from similar Middle Woodland types is difficult on small collections of sherds. Some of the upper levels of the Middle Woodland component actually may represent a Late Woodland occupation. The presence of late Middle - Late Woodland period Jack's Reef projectile points suggests this may be the case.

During the Late Woodland period in southwestern Virginia, net-impressed surface treatments become a common ceramic attribute (Egloff 1986). This treatment

is not typical of the Tennessee River region but is of the piedmont of Virginia and North Carolina (Coe 1952; Davis 1986). Apparently during the Late Woodland period, southwestern Virginia began to be more influenced by societies further east (Egloff 1986).

During the Mississippian period, southwestern Virginia displays an array of traits from different regions. Nine sites along the Powell and Clinch Rivers have yielded Pisgah ceramics (Egloff 1986), and Daugherty's Cave produced one sherd combining the traits of limestone tempering and net-impressed surface treatment with a typical Pisgah rim. In southwestern Virginia, limestone-tempering continued as an important ceramic trait throughout the Mississippian period (Evans 1955; Holland 1970; Egloff 1986), unlike the Tennessee River valley or Fort Ancient areas. Shell-tempered ceramics are common in southwestern Virginia, as well, but become less common as one moves upriver from Tennessee (Egloff 1986). Generally the shell-tempered ware continued to have the plain, net-impressed or cordmarked surface treatments that characterized the earlier Late Woodland period. In general, the Mississippian cultures of southwestern Virginia appear to be somewhat attenuated, "Woodlandized" versions of the more elaborate Tennessee River valley cultures.

Daugherty's Cave indicates that the societies of southwestern Virginia grew the familiar Eastern Woodlands staples of corn, beans, and squash by the Mississippian period. Corn, beans and squash remains are reported from other Mississippian sites in the area (MacCord 1981; Egloff and Reed 1980), but none have been identified by a trained paleoethnobotanist. There is no reason to suspect that southwestern Virginia lagged behind the rest of the Eastern Woodlands in adopting corn agriculture. It has been suggested, however, that the dearth of agriculturally productive bottomland in the rugged Ridge and Valley may have selected against the establishment of large, agricultural villages (Bott 1981). There is some evidence that the Mississippian settlement pattern in southwestern Virginia is somewhat dispersed: settlements are more

numerous on upland terraces along small streams than along the major rivers (Bott 1981).

Somewhat surprisingly, the most intense utilization of Daugherty's Cave, based on the quantity of cultural material recovered per volume of soil excavated, was during the Mississippian period. No other Mississippian period sites are reported from the Daugherty's Cave locale (Egloff 1981), but there has been little survey in the area. Presumably some as yet unidentified village or hamlet served as the principal residence of the Mississippian period utilizers of Daugherty's Cave. It seems most reasonable to conclude that Daugherty's Cave served as an temporary base from which they could conduct foraging activities at some distance from their villages. Sedentary agriculturalists typically experience resource depression in the near environs of their villages (Vickers 1980). Long-distance foraging is one strategy for alleviating the scarcity of wild resources while maintaining a sedentary agricultural settlement. During the historic period, some Native Americans in the Eastern Woodlands relied on fall-winter deer hunts that took place at considerable distance from their villages (Swanton 1946; Wasellkov 1977). Southwestern Virginia had by the historic period, in fact, become a distant hunting ground claimed by the Cherokee but not occupied by them (Summers 1903). Unfortunately, except for one possible brass arrowhead recovered in 1967 (Benthall 1975), Daugherty's Cave bears no testimony to this last period of Native American hegemony in southwestern Virginia.

APPENDIX B
COMMON AND SCIENTIFIC NAMES OF PLANTS AND ANIMALS
MENTIONED IN THE TEXT

PLANTS

Amaranth	<i>Amaranthus</i> sp.
Beans	<i>Phaseolus vulgaris</i>
Bedstraw	<i>Galium</i> sp.
Blackberry	<i>Rubus</i> sp.
Bramble	<i>Rubus</i> sp.
Butternut	<i>Juglans cinera</i>
Chenopod	<i>Chenopodium</i> sp.
Chestnut	<i>Castanea dentata</i>
Corn	<i>Zea mays</i>
Gourd	<i>Lagenaria siceraria</i>
Grape	<i>Vitis</i> sp.
Grass	Poaceae
Groundcherry	<i>Physalis</i> sp.
Hackberry	<i>Celtis</i> sp.
Hazel	<i>Corylus</i> sp.
Hickory	<i>Carya</i> sp.
Legume	Fabaceae
Maize	<i>Zea mays</i>
Maygrass	<i>Phalaris caroliniana</i>
Maypops	<i>Passiflora incarnata</i>
Mustard	<i>Brassica</i> sp.
Oak, Black	<i>Quercus velutina</i>
Oak, Chestnut	<i>Quercus prinus</i>
Oak, Red	<i>Quercus rubra</i>
Oak, Scarlet	<i>Quercus coccinea</i>
Oak, White	<i>Quercus alba</i>
Pines	<i>Pinus</i> sp.
Purslane	<i>Portulacca</i> sp.
Squash	<i>Cucurbita pepo</i>
Sumpweed	<i>Iva annua</i>
Sunflower	<i>Helianthus annuus</i>
Tobacco	<i>Nicotiana rustica</i>
Walnut	<i>Juglans nigra</i>

ANIMALS

Bass, Black	<i>Micropterus</i> sp.
Bat, Hoary	<i>Lasiurus cinereus</i>
Bats	Chiroptera
Bear, Black	<i>Ursus americanus</i>
Beaver	<i>Castor canadensis</i>
Birds	Aves
Birds, Perching	Passeriformes
Catfish	Ictaluridae
Cattle	<i>Bos taurus</i>
Crayfish	Cambarinae
Deer, White-tailed	<i>Odocoileus virginianus</i>

Dog	<i>Canis familiaris</i>
Drum, Freshwater	<i>Aplodinotus grunniens</i>
Duck, Wood	<i>Aix sponsa</i>
Ducks	Anatidae
Elk	<i>Cervus elaphus</i>
Fish	Osteichthyes
Fox, Grey	<i>Urocyon cinereoargenteus</i>
Frogs	<i>Rana</i> sp.
Grebe, Pied-billed	<i>Podilymbus podiceps</i>
Groundhog	<i>Marmota monax</i>
Grouse, Ruffed	<i>Bonasa umbellus</i>
Heron, Green	<i>Butorides striatus</i>
Horse	<i>Equus caballus</i>
Kingsnake	<i>Lampropeltis</i> sp.
Mallard	<i>Anas platyrhynchos</i>
Mammals	Mammalia
Meadowlark, Eastern	<i>Sturnella magna</i>
Merganser, Hooded	<i>Lophodytes cucullatus</i>
Merlin	<i>Falco columbarius</i>
Mink	<i>Mustela vison</i>
Minnnows	Cyprinidae
Mole, Eastern	<i>Scalopus aquaticus</i>
Mouse, White-footed	<i>Peromyscus leucopus</i>
Muskrat	<i>Ondatra zibethica</i>
Mussels	Unionidae
Northern Water Snake	<i>Nerodia sipedon</i>
Opossum	<i>Didelphis virginiana</i>
Otter, River	<i>Lutra canadensis</i>
Owl, Barred	<i>Strix varia</i>
Perch, Yellow	<i>Perca flavescens</i>
Pig	<i>Sus scrofa</i>
Pigeon, Passenger	<i>Ectopistes migratorius</i>
Porcupine	<i>Erethizon dorsatum</i>
Quail, Bobwhite	<i>Colinus virginianus</i>
Rabbits	<i>Sylvilagus</i> sp.
Raccoon	<i>Procyon lotor</i>
Racer, Black	<i>Coluber constrictor</i>
Rails	Rallidae
Rat, Marsh Rice	<i>Oryzomys palustris</i>
Rattlesnake, Timber	<i>Crotalus horridus</i>
Redhorse	<i>Moxostoma</i> sp.
Robin, American	<i>Turdus migratorius</i>
Salamanders	<i>Caudata</i> sp.
Sheep	<i>Ovis aries</i>
Shrew, Short-tailed	<i>Blarina brevicauda</i>
Skunk, Striped	<i>Mephitis mephitis</i>
Snake, Pine	<i>Pituophis melanoleucus</i>
Snake, Rat	<i>Elaphe obsoleta</i>
Snakes	Serpentes
Softshell, Spiny	<i>Trionyx spiniferus</i>
Squirrel, Fox	<i>Sciurus niger</i>
Squirrel, Grey	<i>Sciurus carolinensis</i>
Squirrel, Southern Flying	<i>Glaucomys volans</i>
Squirrels	<i>Sciurus</i> sp.

Sucker	<i>Catostomus</i> sp.
Teal, Blue-winged	<i>Anas discors</i>
Thrasher, Brown	<i>Toxostoma rufum</i>
Toad	<i>Bufo americanus</i>
Turkey, Wild	<i>Meleagris gallopavo</i>
Turtle, Box	<i>Terrapene carolina</i>
Turtle, Painted	<i>Chrysemys picta</i>
Turtle, Snapping	<i>Chelydra serpentina</i>
Turtles	Chelonia
Vole, Meadow	<i>Microtus pennsylvanicus</i>
Wood Warblers	Parulidae
Woodpecker, Red-bellied	<i>Centurus carolinus</i>
Woodrat, Eastern	<i>Neotoma floridana</i>

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