

## HUNTER-GATHERER ADAPTATIONS, ECONOMIC RISK AND TOOL DESIGN

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### INTRODUCTION

The purpose of this essay is to explore why hunter-gatherers develop and change their techno-logical strategies, and to determine if we, as archaeologists, can make more sense out of the observations we so fondly make on prehistoric stone tools. I present a series of relationships that are used to construct a general hypothetical model about the technological propensities employed by hunter-gatherers, and suggest some observations that could be made on stone tools for ultimately testing these hypotheses. Detailed and rigorous tests of these models cannot be presented in this paper, but a first approximately has been attempted (Bousman 1991). This essay should be viewed as a preliminary exploratory effort at hypothesis building, and rigorous proofs must wait.

At its fullest extent, this paper will discuss these ideas from an evolutionary viewpoint and include the initial development of technology by early hominids. I will touch on this issue, but the more limited primary objective of this essay will be to discuss technological change and possible reasons for these changes among modern hunter-gatherers and, by analogy, among recent prehistoric hunter-gatherers. Extreme care must be taken when using ethnographic data and pitfalls exist (Freeman 1968; Wobst 1978), but we should not discard the ethnographic record, because it is extremely useful for hypothesis building (Hodder 1982; Wylie 1985).

Below I suggest that the cost/benefit concepts developed by optimal foraging theorists can be used to provide a useful approach for investigating technological change. The employment of cost/ benefit analysis for analysis of prehistoric stone tools may be little utilized, but it is not new (Cooper 1954). It appears that these models have the potential to help archaeologists understand why hunter-gatherers alter their technology. If lithic techno-logical studies are to continue to contribute useful information toward human

pre-historic behavior and evolution, we must investigate how and why technology has benefited humans in the past.

In most cases, by the time archaeologists are involved, prehistoric technological remains have suffered a dramatic impoverishment because of the decay of tools made of organic materials. Archaeologists are often left with only stone tools and their manufacturing by-products. The study of these stone tools and their waste-products has grown tremendously over the last few decades. Even in areas like the American Southwest or Mesoamerica, where pottery has historically received the most analysis effort, archaeologists have expended an enormous amount of research energy on lithic materials. They often select a staggering number of variables for study, but these variables can differ widely between studies. These efforts have produced a great amount of detail on stone tools and their modes of production, but the factors identified as the principal determinants of technological choices by hunter-gatherers vary greatly among archaeologists. Some may see this degree of detail and diversity as a strength, but in my opinion these efforts have not resulted in a consolidated approach for investigating why pre-historic hunter-gatherers established and change their technological strategies. For the discipline of anthropology as a whole, we need to improve our understanding of past and present human techno-logical behavior. Clearly, more analytical detail, by itself, is not enough, and technological behavior cannot be understood in a vacuum.

Tools are made for a purpose, and archaeologists should not forget the roles that tools play in a society. A small group of archaeologists continues to investigate tool function using techniques such as wear pattern and organic residue analysis but, even ignoring their interpretative problems, these highly particularistic approaches are not enough on their own. Many archaeologists often attempt to extract specific information related to narrow problems from stylistic attributes, but in a number of cases it is debatable

whether this information was actually encoded on artifacts in the first place.

Another major issue is whether the information that we often obtain from prehistoric artifacts is actually worth collecting in the first place. Conducting a detailed and comprehensive analysis of lithic tools and their waste products is usually extremely expensive and time consuming. By now we should have a firm understanding of what we will learn from such an effort and whether or not it is actually worth our efforts, but we do not. The last 20 years has seen a shift in emphasis toward faunal analysis, distribution studies and formation processes, and many archaeologists apparently believe that the most "interesting" information on prehistoric behavior will not result from a study of artifacts. I disagree.

Many lithic analysts have not integrated their studies with a coherent body of theory nor have even outlined a set of clearly defined problems, but I suggest that lithic analysis should be undertaken within a theoretical framework. Foraging Theory is one approach that allows archaeologists interested in prehistoric technologies to obtain a greater understanding of the behaviors responsible for the creation and use of stone tools and their waste products. This also is not a new idea (Torrence 1983, 1989), but clearly lithic analysts have much remaining to accomplish. I do not claim that Foraging Theory is the only useful theoretical approach, and it cannot be used to explain all variability in the prehistoric technological record, nor all the behavior of modern hunter-gatherers. Nevertheless it does provide a beneficial framework that will help lithic analysts develop specific research questions related to the broader issues of hunter-gatherer adaptations, isolate pertinent variables for study, and identify the critical observations that need to be collected on stone tools. This is especially important because new observations, not normally recorded, may be required, and commonly made observations may not be useful for addressing specific issues.

It is also widely known that foraging theorists have not systematically investigated technology nor formally incorporated technological variables into their models and hypotheses. This omission has been purposeful (Smith 1991:174). Nevertheless, it is clearly a weakness in the ethnographic applications of this approach. It is

appropriate to forge a link now between technological studies and Foraging Theory, because combined they could provide archaeologists and cultural anthropologists with a more complete understanding of the diversity of hunter-gatherer foraging strategies and adaptations than we have currently.

## FORAGING THEORY

Foraging Theory consists of a number of models based on microeconomics and game theory (Stephens and Krebs 1986; Smith and Winterhalder 1992). Foraging Theory has two primary models that consider the costs and benefits of acquiring different resources: prey and patch models (McArthur and Pianka 1966; Charnov 1976). Prey models consider hunting or gathering individual prey in homogeneous environments, while patch models consider acquiring food from clusters of prey in spatially heterogeneous environments. These models were developed to account for the behavior of non-human foragers, and a number of recent reviews show that many of the particular aspects of human foraging are not adequately incorporated in these models (Durham 1981; Jochim 1983, 1988). Nevertheless, optimal foraging models provide a systematic framework for analyzing human foraging and, for the purpose of demonstrating how technological analysis could be integrated with foraging theory, the simple well-known models will suffice.

Normally these models measure returns as energy obtained from food, and costs are often measured in terms of time expended on search and handling activities. These are considered mutually exclusive activities for the purpose of analysis. Search costs represent the amount of time spent looking for either prey or patches, while handling costs consist of time spent in pursuit, capture, preparation, and consumption of food. I suggest that handling costs should also include the costs of technological production and transportation of tools and materials. Very few modern foraging studies include technology as a variable, and those few usually only consider the gains afforded by Western versus traditional killing weapons or transportation aids (Winterhalder 1981; Hames 1989; Wilmsen 1989). The varying costs and benefits of these technologies are rarely included, although see Smith (1991) and Carlson (1979). It is important to realize that gains afforded by technology can decrease search time through the use of

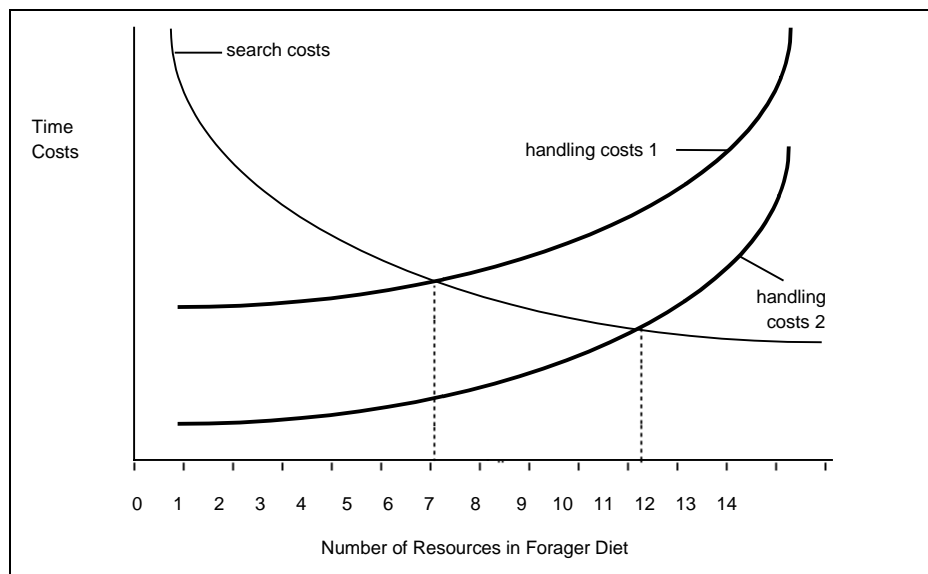
transportation aids such as canoes or snowshoes, or technology can increase the net food returns through the use of more efficient or effective extractive tools such as traps or bow-and-arrows (Carlson 1979). Technology has its costs, however.

### Prey and Patch Models

The classic prey model proposes that hunter-gatherers attempt to maximize returns while considering the costs and yields of different prey (MacArthur and Pianka 1966). The prey model estimates diet breadth. Winterhalder (1981) presents an anthropological test of the prey model for the Cree in Ontario, and O'Connell and Hawkes (1981) use the model in Australia to explain Alyawara diet changes. For a single hunting-gathering group, potential prey are ranked from high to low profitability. In most classic applications profitability is determined by prey size, density, distribution, and the technology used to exploit prey. But as Jochim (1976) demonstrated, fat content and palatability, as well as a balance between carbohydrates and fat versus lean meat (Speth and Spielman 1983) may play a role in ranking prey.

The model assumes that foragers exploit the most profitable resources first, then add less and less profitable resources to their diet. As foragers add new

resources to their diet, the time spent in search declines, because resources are encountered more often, but handling costs rise (Figure 1). At some point declining search costs are balanced by higher handling costs, and the addition of a new resource would drop profitability below a point of effective economic exploitation. This balancing point represents an optimal diet (just above the 6<sup>th</sup> resource on the X-axis using handling cost 1 curve in Figure 1). If handling costs decrease because of less expensive technologies, such as the use of a limited repertoire of multipurpose generalized weapons or more easily obtained raw materials, then the model predicts broader diets (the 10<sup>th</sup> resource on the X-axis using the handling cost 2 curve in Figure 1). On the other hand, narrower diets are predicted if more expensive technological strategies (e.g., a diversified set of specialized weapons) increase handling costs. At first glance this seems counterintuitive, since many anthropologists assume that greater diversity of weapons equals greater dietary diversity, but a quick review of the !Kung shows how diverse their diets actually are (Wilmsen and Durham 1988), yet they would be considered technologically simple (Lee 1979).



**Figure 1.** Prey model predicts diet breadth by considering search and handling costs and resource productivity (after MacArthur and Pianka 1966).

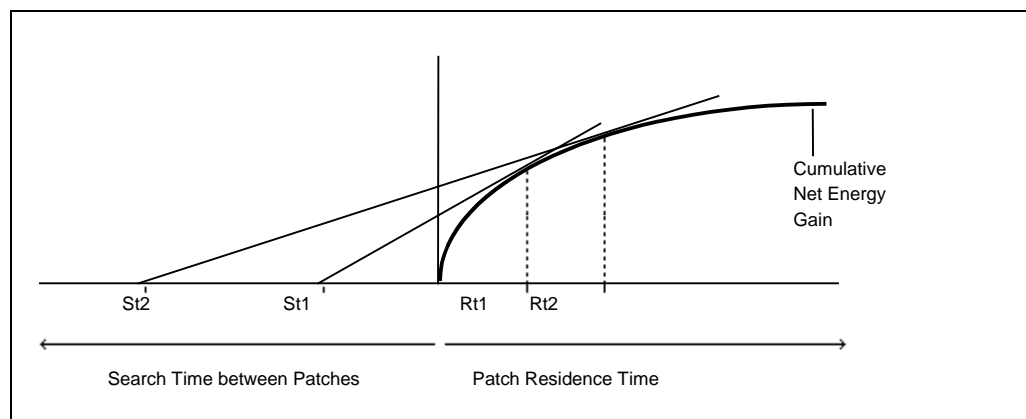
If search time should decrease because of greater resource density or the introduction of transportation aids, then narrower diets are predicted from the model. However, if search time increases because climatic changes cause food scarcity, then diets should become more diverse. These new foods, added when resources are particularly scarce, are known as starvation foods. In Figure 1 then only difference between the two handling curves is where they begin on the Y-axis. Hypothetically, if this difference is determined only by technological costs, then diet selection could be influenced solely by changes in technological strategies. Technological adaptations are not as simple as this, but the prey model can be used to suggest that failure to consider costs and benefits of technology in foraging models is completely unjustified.

Prey models usually assume that resources have homogeneous distributions in space, but this is not correct in many situations. Patch models deal with foraging strategies in spatially heterogeneous environments where resources are found grouped in clusters known as “patches.” The patch model assumes that resource return rates diminish exponentially as foraging time in a patch increases (Kaplan and Hill 1992). However, as search time between patches increases, the time spent in a patch will increase to offset the increased search cost. This relationship can be illustrated easily (Figure 2). All other factors being equal it is intuitively obvious that as patch density increases, so does the net energy gain, because foragers spend less time traveling between patches and more time exploiting resource patches during the initial

period of patch use when return rates are at their highest. Even without changes in resource distribution of abundance, transportation aids can reduce search time between patches and lead to increased net energy gains. Also, some technological strategies directly influence resource return rates and these can increase or decrease the slope of the net energy gain curve (see Figure 2). One implication of this change in the model is that greater resource return rates would allow (not require) more search time between patches or provide more time for non-subsistence activities.

### Time Allocation Among Hunter-Gatherers

Time allocation studies represent systematic attempts to deal with time scheduling (Hames 1992). These studies investigate important dimensions for technological analysis. They assume that foragers must engage in two major sets of activities in order to survive and/or to increase fitness. The first activity is reproductive, and results from the need to find a mate and provide care for offspring. I use “care” in its broadest sense to include education and training. These activities are critical for long-term group survival. Getting food, obtaining shelter, avoiding predators and, I would add, making and maintaining tools and implements comprise a second set of activities necessary for the survival of most individual hunter-gatherers. Much has been written on whether fitness should be measured in terms of individual or group fitness, but it seems obviously that people use both in their day-to-day decisions.



**Figure 2.** Patch exploitation model (after Stephens and Krebs 1986).

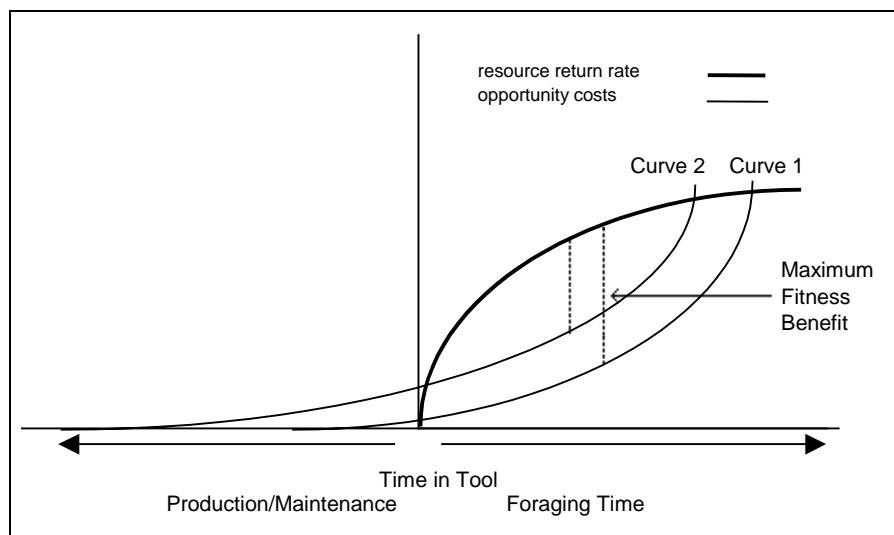
There is at least one other group of activities that potentially competes for the available time of any human group: rest, relaxation, socialization and ritual. These activities are mainly seen as regenerative or healing in nature for the individual and/ or group. Time allocation models assume that all of these diverse behaviors are necessary for survival, that they are mutually exclusive, that available time is limited, and that each activity has costs and benefits in terms of individual and group fitness. These assumptions are rarely met in specific situations, but they provide a starting point for investigating activity scheduling among hunter-gatherers.

Hunter-gatherers decide how to use their time and the apportionment of time is a reflection of the strategies used by particular groups. The costs of activities, known as opportunity costs, are difficult to measure in terms of survival or fitness, and often the time spent in an activity is used as a proxy measure. Also, opportunity costs can be viewed as opportunities lost because many activities do not occur simultaneously, and time engaged in one activity often prohibits spending time in another. Thus the allocation of time and scheduling of activities has an important impact on individual and group fitness. Embedded strategies obviously help to increase a hunter-gatherer’s exploitation efficiency by combining activities as opportunities allow.

Time allocation models assume that returns, in simple cases measured in amount of food obtained per

unit of time, will diminish as resources are exploited (Figure 3). The model predicts that time spent in a certain activity will continue until its opportunity costs begin to rise and foraging returns begin to diminish. This is the greatest distance between the convex energy return curve and the concave opportunity cost curve, and thus represents the maximum fitness benefit. On the X-axis this represents the optimal amount of time a hunter-gatherer will engage in a given activity. Beyond this point, fitness benefits decline and the efficient forager should switch to another, presumably more productive, activity.

Not all activities require tools nor have technological costs, but most foraging activities do (i.e., obtaining raw materials, manufacturing tools, maintaining tools, and transporting materials and tools). In Figure 3, I modified the standard time allocation model to include technological costs. The two plotted opportunity cost curves represent separate technological strategies requiring different production and maintenance efforts. If the rate of return remained the same for each, then the fitness benefit would be significantly lower for the more costly technological system (Curve 2). On the graph technological costs are incurred before foraging occurs, but among modern hunter-gatherers this is not necessarily the case, since tool maintenance, repair and replacement often occurs during foraging episodes.



**Figure 3.** Technology and foraging time allocation model.

It might be tempting to expect that hunter-gatherers who use more costly technological strategies are more efficient and might benefit from higher return rates that could offset the initial costs, but these relationships are determined by specific situations. One implication of the model is that hunter-gatherer using more costly technological systems need to exploit resources while resource return rates are high. The model does not imply that hunter-gatherers who exploit highly productive resources must use expensive technologies. Other factors, such as the seasonal availability of foods, and potential productivity, appear to influence the utilization of technological effort. However, once the resource return rate begins to decline, the model suggests that groups using costly technologies should switch to another, presumably more productive, set of activities or change their technological and foraging strategies. Hunter-gatherers that employ less expensive technologies might continue to exploit the same resource even after its rate of return begins to diminish.

Hypothetically, during the course of a year a complex series of sequential foraging episodes can be represented by linking such graphs in a chain of preparation and foraging events. The costs and benefits of each foraging episode could differ. The might range from high costs and high returns, to low costs and low returns, to low costs and high returns. High costs and low returns would be a regrettable, but not impossible, outcome.

One can view foragers as existing on a continuum with resource maximizers using "costly" technological devices at one end and time minimizers using "inexpensive" technologies at the other. Time minimizers attempt to spend as little time as possible in an activity while still getting enough food for survival, while resource maximizers strive to obtain food at the greatest rate possible. Gould (1980:64-65) describes time minimization among the Ngatatjara Aborigines, while Balikci (1970: 23-90) provides a view of resource maximization among the Netsilik Eskimo. Time minimization or resource maximization are strategies that provide solutions to different resource or scheduling problems, but many hunter-gatherer groups display a mix of the two strategies. As technology has a direct effect on foraging efficiency, I argue that technological strategies should differ for varying mixes of these two solutions. The time and energy spent on

technological production and presumably the resulting level of efficiency can vary greatly between groups (Oswalt 1976; Shott 1989). Thus, the costs and benefits resulting from technology should be considered when assessing the evolutionary ecology and general fitness of individual hunter-gatherer populations.

The foregoing brief discussion of Foraging Theory suggests that technology can play a critical role in determining the economic choices of hunter-gatherers, and that foraging theorists cannot fully understand hunter-gatherer foraging without integrating the costs and benefits of technology. While I have generally presented these models from the stance that technological costs can influence economic strategies, availability of resources will influence technological strategies. Lithic analysts should realize that technological strategies may be determined by their efficiency in the overall exploitative system. In isolating the determinants of technological strategies, economic risk may be a critical factor.

### **Scarcity, Risk and Uncertainty**

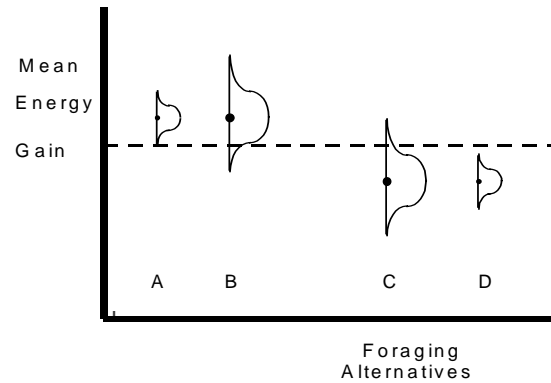
The above models do not explicitly incorporate resource variability into their formulations. Resources are not constantly available (Wiessner 1977: 27). Anthropologists know well that food scarcity and economic risk are important limiting factors on human survival, and the predictability of food has had a major impact on human adaptations (Halstead and O'Shea 1989). Risk is defined as the probability of economic loss, and perhaps it is best conceived in terms of unpredictable environmental variations that influence getting enough food to support a given population (Cashdan 1990). Uncertainty reflects a lack of information about these variations. In an archaeological context it may be difficult to distinguish between risk and uncertainty (although see Binford 1991). In the following discussion I use risk to mean both "risk" and "uncertainty".

Foraging Theory addresses risk from a quantitative point of view, and provides a framework for assessing how hunter-gatherers respond to risk. Risk-averse, risk-prone, and risk-indifferent foragers are identified by their response to average food intake levels and resource variability (Stephens and Krebs 1986: 139; Smith 1991:52-57). In other words, risk is a reflection

of food scarcity. Food scarcity is determined by local conditions and is relative to need. Given the minimum amount of food needed by a group for survival plus the mean and variance of resource yields, foragers must determine which potential food sources probably will meet their dietary requirements. Highly variable foods may not provide enough for group needs on some occasions.

If food acquisition meets daily requirements, then the model predicts that hunter-gatherers probably will choose risk-averse strategies and exploit less variable food sources, because even low yields would be enough for survival (Stephens and Krebs 1986: 137-140; Smith 1991). In Figure 4 this is Foraging Strategy A compared to Foraging Strategy B. Alternatively, during food shortfalls foraging models predict that foragers will be risk-prone, and exploit resources or environments with greater amounts of variability, because the chances of getting enough food are higher than with less-variable resources that would never provide the minimum food requirement. This is represented by Foraging Strategy C versus Foraging Strategy D.

In a dynamic situation hunter-gatherers can shift from a risk-prone to a risk-averse strategy or the reverse as the availability of resources fluctuates through time. With a diversified resource base provided by a gender-based division of labor and intra-group sharing, hunter-gatherers often balance the risk-averse exploitation of predictable resources (usually plants or fish) against the exploitation of unpredictable resources (usually terrestrial mammals) by risk-prone strategies. Wiessner (1977: 62-63) describes such a situation among the Kalahari !Kung men who shift from the risk-prone hunting of large ungulates to risk-averse hunting and trapping of small animals in response to a reduction of plant foods collected by women. Jochim (1988) suggests that simple foraging models that lump male and female foraging strategies into a single model designed for one homogeneous type of forager cannot adequately account for the patterns observed among many human hunting and gathering groups. He suggests that realistic modeling requires separate models that account for the normally risk-averse strategies of female foragers and the often (but not always) risk-prone foraging strategies of males.



**Figure 4.** Resource mean-yield and variance, and foraging alternatives (after Smith 1991).

A recent computer simulation of “encounter” hunting decision-making provides a model of risk responses among hunter-gatherers (Mithen 1990). This study proposes that hunters constantly alter their strategies by juggling a set of long-term and short-term goals in a dynamic environment. Decisions, as whether to exploit a resource or not, must be made away from camp and possibly alone. Mithen suggests that the basic long-term goal is to determine whether or not the exploitation of a certain resource will increase a forager’s current foraging efficiency. This goal is incorporated into the classic prey model. However, short-term goals, such as always getting something to eat each day, may become increasingly important as an unsuccessful hunting day wars on. Obtaining some food, any food, may take precedence over other foraging decisions even if it decreases the overall efficiency of the forager. This short-term decision process reflects an option that reduces the “risk of not eating” on any particular day.

Other events can be best understood as short-term, constraint-releasing mechanisms on hunter-gatherer decisions. A good example of such an event is that after a large animal is killed, hunters may ignore other potential prey even if killing other animals would increase their overall average foraging efficiency. The needs of the hunter-gatherer groups are satisfied for that day. Mithen suggests that hunter-gatherers use a strategy that attempts to improve upon existing exploitation efforts rather than strategies that provide optimal solutions.

In such a model it is clear that the decision of whether to exploit a resource or not is made independently by each individual foraging unit based on information that is shared by the residential camp group and supplemented by the daily resource encounters of the individual foraging groups. The composition of these groups (e.g., individual hunters on daily forays versus group hunters on long-distance trips or groups collecting plant foods in a groups versus an individual collecting alone), the length of time away from a camp, the composition of residential camps, and the degree of food sharing each evening by foragers could alter the balance between short-term and long-term goals among hunter-gatherers. A mathematical model of this complexity for foraging does not exist; however, models such as Mithen's are a step in the right direction toward mathematically depicting the responses of many hunter-gatherer groups to a dynamic environment.

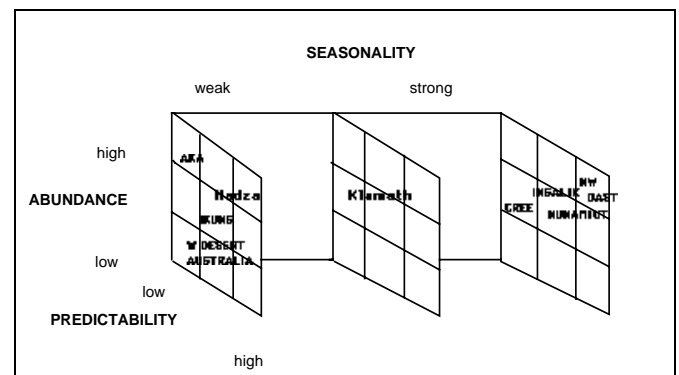
### Components of Risk

Risk itself is not a simple variable; different levels of risk are related to variations in the structure of resources and to the predictability of these resources. In one study of human territorial responses to resource variation, Dyson-Hudson and Smith (1978) suggested that two variables, resource abundance and predictability, characterize resource structure. Cashdan (1992), looking at sets of resources, stressed the importance of varying multiple interacting temporal and spatial cycles of availability that determine resource predictability. Alternatively, Halstead and O'Shea (1989) proposed that risk is a function of resource variability, and they view resource risk and resource certainty as opposites. Risk is characterized by severity as well as by temporal and spatial parameters. For example, resources may be low-risk even though their seasonal availabilities are very cyclical as long as they are highly predictable from year to year, whereas risks are much greater if resource availability is highly unpredictable.

I suggest that a matrix of resource abundance, temporal availability, and dispersion in space be used to characterize resource structure (Figure 5). This looks like a three-dimensional chess game laid on its side. Resource predictability independently occurs in terms of abundance, space and time. While this scheme is a

simplification, it is a useful starting point for discussing resource structure. These variables reflect specific dimensions to which hunter-gatherers adapt and are particularly useful for an analysis of hunter-gatherer technological strategies.

While resource abundance normally is used to refer to edible resource density, one should not lose sight of the importance that size or bulkiness of resources might have on subsistence decisions, as these can influence search and handling costs. The spatial dimension reflects a random-to-clumped distribution of resources on the landscape. Resource patchiness is a major consideration in optimal foraging studies, but detailed analyses of hunter-gatherer responses to resource patchiness are virtually non-existent (Kaplan and Hill 1992). The temporal dimension of resource availability can vary from constant to long-term (Rowley-Conwy and Zvelebil 1989; Cashdan 1992).



**Figure 5.** The structure of sets of resources exploited by different hunter-gatherers plotted in terms of abundance, patchiness and temporal variability (data from Murdock 1967).

Many anthropologists have discussed predictability as if it were a simple variable; it is not. Colwell (1974) suggests that predictability has two components: constancy and contingency. If a resource is constantly available in known amounts at certain locations throughout the year, and year after year, then this resource has an extreme amount of constancy. Alternatively, if a resource is always available at a certain location and in known amounts during a specific season but totally absent in other seasons, then that resource exhibits a high degree of contingency. Colwell provides mathematical measures of contingency and

constancy, and argues that the overall level of a resource's predictability is the sum of its constancy and contingency. No ethnographic field studies have actually measured human responses to resource predictability in terms of contingency and constancy, although proxy measures have been employed. Low (1990) used rainfall predictability as a proxy measure of resource predictability in a coarse-grained study that considered responses of hunter-gatherers, pastoralists, and agriculturalists to environmental variables. Goland (1991) used measurements of constancy and contingency to study food storage and sharing among the Ainu and Kalahari San.

Examples of resources with high measures of constancy include some coastal or freshwater aquatic resources. Resources with high measures of contingency include anadromous fish such as salmon on the Northwest Coast, migratory caribou in Alaska, agave in the Chihuahuan Desert on North America, and migratory wildebeest and antelope on the Serengeti Plains of East Africa. Resources with low predictability due to both low constancy and contingency include bison in the Southern Plains of North America and antelope in the Kalahari Desert. Goland's (1991) analysis of dog salmon runs in the Tokachi River, Hokkaido, between 1955-1960 suggests that these resources have equally high estimates of contingency and constancy, while rainfall in the Kalahari has low estimates of these two variables.

Individual resources, and sets of resources, can be measured for their constancy and contingency. In the Kalahari Desert the complete set of resources exploited by the G/wi San reflect low levels of contingency and constancy (Tanaka 1980; Silberbauer 1981). Overall predictability for sets of resources would increase among the !Kung San because of the significantly higher degree of contingency afforded by mongongo nuts (Lee 1979; Wilmsen and Durham 1988), even though the mongongo nuts are subject to failure (Wilmsen 1989). Binford's (1980) serial specialists appear to exploit a set of resources that individually have low measures of constancy but perhaps fairly high measures of contingency. When viewed as a set, the resources exploited by serial specialists offer a high degree of constancy with few gaps in availability throughout the year, but the resource locations shift seasonally with the availability of resources. This

stimulates a movement in residential camp locations. This scheme suggests that economic risk among hunter-gatherers can be split into different components and that the adaptive responses will differ depending on the nature of risk.

### **Proxy Measures of Risk for Prehistoric Contexts**

Few ethnographic studies report environmental or resource data that can be used to develop even crude estimates of risk among modern hunter-gatherers (but see Wilmsen and Durham 1988). Thus it is difficult to suggest reliable measures of risk from data collected ethnographically, and few archaeological studies span the period of historical meteorological records. Of necessity, archaeological studies must devise proxy estimates of risk and most of these studies will be forced to assume that environmental or dietary evidence reflect resource structure and risk (Cashdan 1992). However, it is impossible to list variables that will always provide adequate estimates of risk. A study of coastal and inland Alaskan Eskimos clearly illustrates the potential problems.

Minc and Smith (1989) have reconstructed detailed inland and coastal resource fluctuations in historical Northern Alaska. In the interior the primary food source is migratory caribou. Changes in the availability of caribou occur because of short-term range shifts and long-term changes of population size. Range productivity and winter deaths control caribou population numbers, but predators cannot stimulate a population decline among a healthy large herd. Cold, wet conditions increase winter snow leading to more winter deaths among caribou, and these weather conditions reduce range productivity. Warm, dry years stimulate increased range productivity and allow greater winter survival among the caribou.

In Alaska, coastal resource patterns are the reverse. Exploitation on the coast focuses on bowhead whale and ringed seal hunting. Warm conditions allow sea ice to break and melt early. This shortens the seal hunting season in the winter and makes hunting seal pups very difficult. With reduced sea ice, whales are able to range over much larger areas, making search costs prohibitive and success unlikely. Detailed paleoclimatic reconstructions, based on the analysis of tree rings, demonstrate that caribou herd size and whaling success closely but

inversely co-vary with climatic conditions (Minc and Smith 1989), and coping strategies must deal with these variations in the resource base. Similar climatic conditions in one area reduce food scarcity and the risk of hunting and gathering, but increase them in an adjacent area.

Unfortunately, few areas have such completely studied ecosystems matched with high resolution paleoenvironmental records afforded by tree-rings, and in these other areas reliable proxy measures are often more difficult to construct. Many archaeologists are tempted to use rainfall and in many cases this variable is reasonable. However, a re-analysis of Gould's (1980) ethnographic data on the Ngatatjara Aborigines shows that food abundance increases and diet breadth decreases during droughts (Pate 1986). This is because some plant foods decay in moist conditions, but are naturally preserved on the vine or on the ground in droughts. Other plant foods are desert-adapted and thus their abundance, distribution and season of availability are little affected by short-term droughts. In most other areas detailed studies of ecological relations and change simulated by variations in climate seemingly provide the most reliable indicators of resource fluctuation and risk, but care must be taken.

### Responses to Risk

Hunter-gatherers calculate daily where they will get their next meal, and the several meals thereafter. This calculation deals with partly predictable changes in the total amount, availability through time, and distribution of food and water across the landscape. Of course, other items, such as nonfood resources, are of concern (Jochim 1976), but food is so basic that secondary material resources play an insignificant role in the calculation of risk.

Wiessner (1977, 1982) identifies four coping strategies that hunter-gatherers use to buffer against risk: prevention-of-loss, resource pooling, storage, and transfer-of-loss. Additional studies suggest that a fifth response to risk is temporary or permanent abandonment of large areas in order to escape food scarcity (Butzer 1988; Rowley-Conwy and Zvelebil 1989). The mix of these coping strategies used by an individual group should reflect the nature and structure

of the environmental and social risks encountered by individuals.

Prevention-of-loss can occur over very short to longer time periods. Changes in hunting weapons, transportation aides, economic diversification, organization of exploitation labor, information exchange, or spacing strategies such as mobility patterns, all help prevent loss (Wilmsen 1973; Binford 1980, 1991; Wiessner 1982; Halstead and O'Shea 1989; Torrence 1989; Cashdan 1992). Wiessner (1977: 64) also suggests that trance-curing among the !Kung is a coping strategy that offsets the effects of risk, as continuing illness can prohibit a hunter or gatherer from performing their respective economic tasks.

Binford (1980) has argued that hunter-gatherer mobility patterns can be viewed along a continuum. At one extreme are hunter-gatherers who exploit resources by moving residential camps to the resource locations and bringing resources back to camp for processing (not all processing occurs in camps, however). These groups are called foragers by Binford. At the other extreme are hunter-gatherer groups who do not move residential camps as often, but organize task groups to exploit resources, often in bulk, and bring these resources back to the residential base camp for the entire group. These task groups cover greater distances than possible on a daily basis by the entire camp. Binford calls these groups collectors. This restricted and specialized usage of the term "forager" will be used throughout the remainder of this paper. Binford (1980) and Kelly (1983) provide ample evidence to suggest that variation in hunter-gatherer mobility is a response to resource structure.

Resource pooling or sharing is a common strategy used by a single group of hunter-gatherers who live in areas where abundance is not great. Ideally the successes and failures of multiple foragers are spread among the larger group exploiting a diverse set of resources so that every one has access to food each day. Among groups who cooperatively exploit single sets of resources, like caribou, food sharing will not reduce the daily amount of resource variation, and food sharing is uncommon. However, labor sharing, in terms of cooperative exploitation activities, will increase economic security (Binford 1991), but perhaps this type of sharing should be seen as a prevention-of-loss

strategy. Hunter-gatherers pool resources through numerous mechanisms and on many different scales. Kinship or age-groups and camp layout provide a means for sharing among many hunter-gatherer groups (Yellen 1977; Gargett and Hayden 1991; Binford 1991, Whitelaw 1991). On a regional basis Hxaro exchange among the !Kung provides a mechanism for resource pooling when the local resources of a single group fail (Wiessner 1977, 1982).

Most hunter-gatherer groups store small amounts of food for short periods, but a few groups use stored food as a major nutritional source over long periods of time when foods are unavailable. Intensive storage is a strategy that extends the availability of foods into period of scarcity, and often it is employed by hunter-gatherers who depend on resources with marked seasonal variations and gaps in availability (Binford 1980; Testart 1982; Halstead and O'Shea 1989; Rowley-Conwy and Zvelebil 1989).

Transfer-of-loss consists of shifting food from one group to another and it can take two forms. The first form is voluntary, and economic rituals such as potlatches are one example. Raiding is a second form (Wiessner 1982) that results in involuntary transfer-of-loss.

In terms of risk reduction among hunter-gatherers, the front-line strategy is, of course, prevention-of-loss, while resource pooling, storage, and transfer-of-loss are backup strategies. Population abandonment by hunter-gatherers in most areas is a last desperate alternative. It seems likely that prevention-of-loss strategies are linked directly with variations in resource structure, and that the backup coping strategies are mediated to a large degree by social variables. Most modern ethnographic and ethnoarchaeological, and many archaeological, studies have focused on the backup strategies and their expressions in terms of social structure and social relations almost to the exclusions of prevention-of-loss strategies (but see Kelly 1983; Torrence 1989; Smith 1991). Nevertheless, much archaeological data initially emanate from behaviors that would be the result of prevention-of-loss strategies, and these are the focus of this present study.

## TOOL DESIGN DECISIONS AMONG HUNTER-GATHERERS

A limited corpus of ethnographic data exists from which to extract rules about technological strategies employed by hunter-gatherers that reduce risks associated with food acquisition (Bleed 1986; Shott 1989; Kuhn 1989; Nelson 1991). Bleed (1986) suggests that hunter-gatherer tools can be analyzed by the same design goals as those used by modern engineers. Their primary object is greater efficiency, and efficiency translates directly into the cost-benefit structure of the previously described foraging models. Efficiency can be measured by at least four criteria: 1) quicker production time (a knife costs less in energy and/or material); 2) increased use-life (a longer lasting knife); 3) increased effectiveness (a sharper knife); 4) increased production volume (more knives per unit of raw material). In terms of making an effective tool, modern engineers often strike a compromise among these qualities, and modern hunter-gatherers seem to do the same. Hunter-gatherers might stress the first quality and make an expedient tool, or the second quality and make a maintainable tool, or the third quality and make a reliable tool, or the fourth quality and use an efficient technology. These design goals are not mutually exclusive, Bleed restricted his analysis to hunting weapons, but these general goals have wider application. Also I use labels such as expedient tool or reliable tool, but this is only a short-hand manner of referring to the actual strategies and design goals that produce the tools. I am not trying to erect a typology.

Expediently made and used tools, (I call them expedient tools or the "instant tools" of Gould 1980:72) are characterized morphologically by little alteration or secondary shaping. Nelson ((1991) has argued that expediency, as discussed by Binford (1973, 1979), can be split into true expedient technological strategies and opportunistic technological behaviors. Opportunistic technological behavior is an unplanned technological response to an unanticipated need. On the other hand, Nelson suggests that expedient technology is a planned response to an expected task incorporating minimal technological repair of tools, short period of use, and artifact discard at the activity locus. However, it is extremely difficult to propose independent criteria that would separate these two strategies based on the morphological condition of artifacts or the context of

use as preserved in an archaeological site. If expedient technological strategies *sensu* Nelson (1991) are used, then readily available raw material are a necessary precondition. Thus expedient technologies dramatically reduce the costs associated with transporting raw materials to manufacturing and use locations, and their use reduces time spent on tool manufacture and repair. It appears that chimpanzees use this type of expedient technology in their construction of simple extractive tools (chimpanzees do not make maintenance tools), so even nonhumans have the forethought necessary for this type of technological strategy (Boesch and Boesch 1993; McGrew 1993). The earliest manufacture of stone tools in East Africa by early hominids appears to be expedient, but early hominid tool manufacture is distinguished by the transportation of tools and raw materials over the landscape (Potts 1988; Toth and Schick 1993).

The use-life of a maintainable weapon, on the other hand, is extended by some form of repair or resharpening. Maintainable tools can be multipurpose and made to work even after broken. They can also be used for tasks other than those for which they were originally designed, i.e., recycled. These tools are often light and portable, they can be repaired quickly and easily, and they have a modular design. An example of a maintainable weapon is the Aché (Guayaki) bow and arrow (Clastres 1972: 146-147). When broken, their bows are made into digging sticks. Arrows are used to kill many different animals and the wooden arrow points are very long and resharpened often as the brittle tip breaks. Maintainable tools help reduce the costs of raw material acquisition by extending the use-life of an artifact. Maintainability is designed into hunter-gatherer weapons possibly to cope with the erratic timing of a wide range of resource availabilities and their associated risks in a less predictable environment. Possible maintainable tools first occur in the Oldowan and related industries, but maintainable tools are the hallmark of the Acheulian Industry, and perhaps their development marks its inception (Toth and Schick 1993). Mobility and transportation of lithic raw materials apparently increases from the late Pliocene to the early Pleistocene and the development of reliable tools may be related to this change in mobility.

According to Bleed (1986), reliable weapons are often functionally specialized and are characterized by

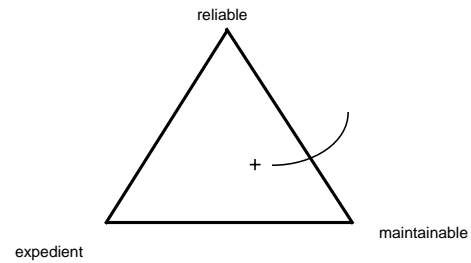
extra-sturdy construction, over-designed critical parts, high quality fitted parts, spare parts, and a special repair kit. The Angmagsalik toggle-headed seal harpoons with throwing boards and sealskin floats are an outstanding example of a reliable weapon (Oswalt 1976:99). Reliable weapons are used when the risk and consequences of failure to obtain food is great and possibly when the resources occur in large packages or can be exploited in bulk. This level of risk makes failure critical and reliability in a weapon aims to buffer the hunter against the severity of this risk. In terms of raw material acquisition and transportation costs, reliable tools are very costly. It can be argued that reliable weapons reflect a great degree of advanced planning, and perhaps in an evolutionary sense the initial development of reliable tools in the Pleistocene reflects a increasing mental ability for forethought (Binford 1989). It is difficult to identify the earliest manufacture and use of reliable tools, but perhaps they are represented by Howiesonspoor back segments produced during the Middle Stone Age of Southern Africa (Singer and Wymer 1982; Volman 1984; Thackeray 1989). If correct, this has significant implications for current models concerning origin and timing for the evolution of *Homo sapiens sapiens*.

Recent research on Middle Paleolithic scrapers indicates that their morphology changed from one type to another because of many maintenance episodes during the course of their active use-life (Dibble 1987). This model has a lengthy history (Homes 1919; Frison 1968), but the modern form originated with an analysis of Dalton projectile points (Morse 1971; Goodyear 1974), and it has been applied to Midwestern and Great Basin projectile points (Hoffman 1985; Flenniken and Raymond 1986; Flenniken and Wilke 1989). These and related studies suggest that many extractive and maintenance tools are maintainable tools. One implication of this has ramifications for artifact typology and taxonomy, and it implies that even if maintainable tools contain stylistic information (*sensu* Wiessner 1983, 1984) when they are first produced, by the time a maintainable tool is discarded, it is unlikely to contain or preserve this information because it has been altered so much by resharpening and other use generated alterations. Stylistic information associated with differing "styles" of hafting among maintainable tools may be an exception (Keeley 1982; Hoffman 1985). However, reliable tools which are not as inten-

sively altered by maintenance would be better candidates for retaining stylistic information. Expedient tools probably carry little stylistic information, except perhaps patterns that can be considered isochrestic forms of style (Sackett 1982).

Efficient technologies that increase the number of tools per unit of raw material are legion in archaeology, and this strategy would decrease the costs of raw material acquisition. The best known example is the shift from Middle Paleolithic flake technology to Upper Paleolithic blade technology (Leroi-Gourhan 1943). This concept has been discussed in terms of bifacial technologies and mobility strategies in North America by Kelly (1988), who argues that changes in mobility patterns toward the “collector” pattern with high logistic mobility should be associated with more efficient use of raw materials and thus efficient technologies. He suggests that duration of bifaces as cores may be an expression of this in the Great Basin. However, other evidence suggests that changes in tool design also can act as a catalyst for stimulating the production of more efficient technologies, and that these attributes are not linked to changes in mobility patterns or size of exploited region. Bousman (1991) demonstrated that bladelets instead of flakes were produced as blanks for specific tools (straight backed bladelets) in Interior Wilton assemblages from Southern Africa in order to speed or ease manufacturing efforts, and an efficient technology was not used to reduce transportation or raw material availability costs.

Bleed’s (1986) reliable and maintainable tool design dichotomy can be merged with Binford’s (1973, 1979) expedient/curated tool classification. Curation has many different meanings in archaeological literature (Bamforth 1986), but these two classifications complement each other if non-curated, instant (expediently made and used) tools are accepted as a specific design goal (Nelson 1991), and reliable and maintainable tools are considered a different strategies for designing curated tools. A single tool can incorporate elements of all three design goals in varying degrees, and Figure 6 suggests how an individual hypothetical tool’s design might reflect a mix of these three design goals.



**Figure 6.** Tri-polar plot of hypothetical tool design goals.

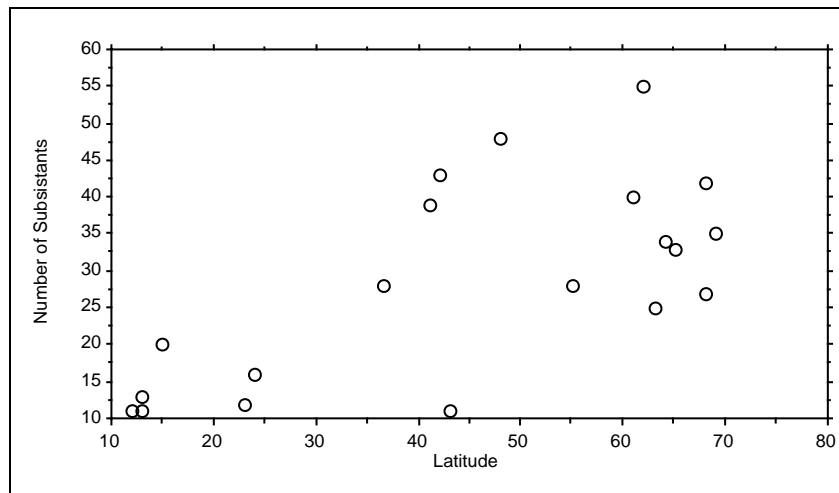
### Hunter-Gatherer Tool Production and Repair Strategies

It seems reasonable to expect that all hunter-gatherers would use reliable tools, but reliable tools carry a number of hidden costs. They are bulky, require special spares and may require great investment in production and transportation. Reliable tools are appropriate for hunter-gatherers who exploit abundant resources in bulk, but resources that are available only for limited seasons or other similar high risk situations. Collectors (*sensu* Binford 1980) tend to use reliable tools. Maintainable tools are often used by groups that could be considered foragers Binford.

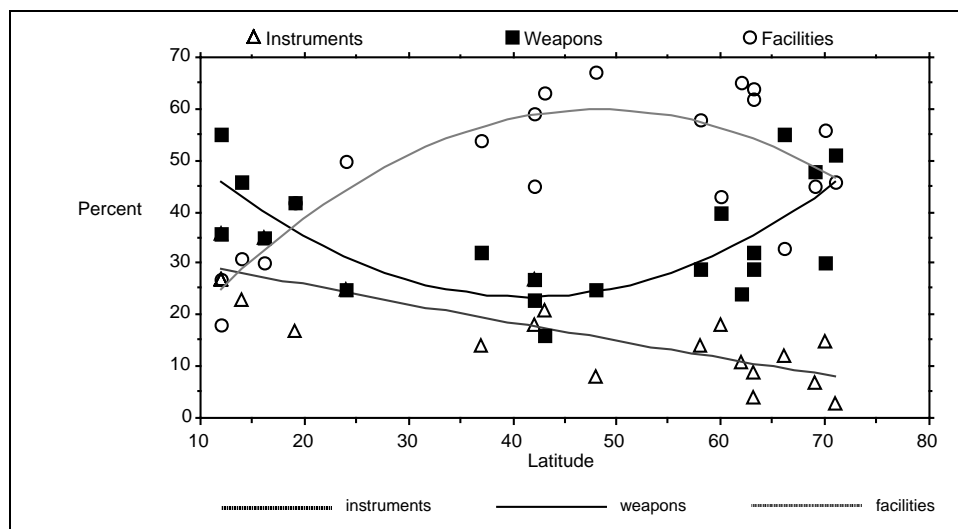
Torrence (1983) proposes that archaeologists document assemblage composition, assemblage diversity and tool complexity to effectively investigate hunter-gatherer technological organization. She uses Oswalt’s (1976) classification of “tools used to obtain food” (extractive tools *sensu* Binford and Binford 1966) to inspect the structure of artifact assemblages. Oswalt calls a single compete tool a “subsistant” and an individual part of a composite tool, such as the sinew binding on a spear, a “technounit.” He classifies tools as instruments, weapons, and tended and untended facilities. Instruments such as digging sticks are used to obtain immobile foods, while weapons and facilities are used on mobile food sources. Torrence (1983) has shown that hunter-gatherers who live at higher latitudes construct more diverse tool assemblages than those manufactured by hunter-gatherers at lower latitudes (Figure 7). Many of these higher latitude hunter-gatherers could be classified as collectors who use specialized tools for short intensive bursts, and Torrence argues that the limited time that resources are

available require hunter-gatherers to use a variety of specialized tools. This creates diverse artifact assemblages. Not all factors that stimulate assemblage diversity are environmental. Creel (1991) argues that increased exchange for bison hides between Late Prehistoric Southern Plains bison hunters and nearby agricultural groups stimulated the increased production of end scrapers and beveled knives among the bison hunters.

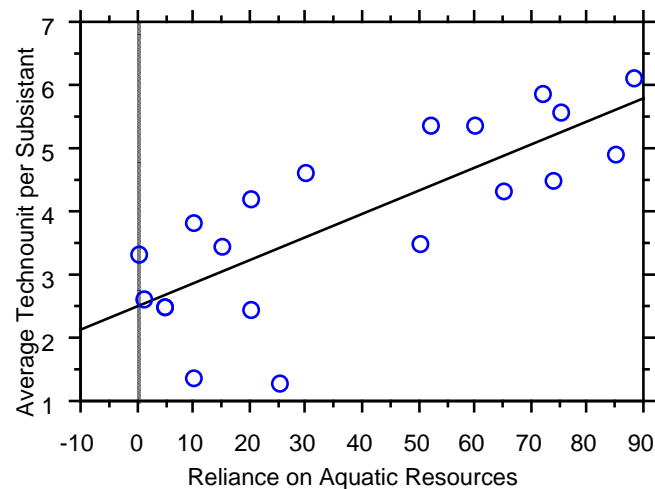
The data presented by Torrence (1983: Table 3.2) can also be used to suggest that important differences occur in the percent composition of extractive tools and facilities (Figure 8). Groups near the equator use a combination of weapons and instruments. Instruments decline in relative frequency with increasing distance from the tropics. In the middle latitudes facilities are important but weapons decline. In higher latitudes instruments are rare, facilities are somewhat reduced, and weapons are the most common extractive tool.



**Figure 7.** Number of subsistants (extractive tools) for individual hunter-gatherer groups by latitude (after Torrence 1983: Figure 3.1) Hunter-gatherers include Tiwi, Andamanese, Ingura, Chenchu, Naron, Aranda, Owens Valley Paiute, Surprise Valley Paiute, Tasmanian, Klamath, Twana, Tlingit, Tanaina, Ingalik, Nabesna, Caribou Eskimo, Angmaksalik, Iglulik, Copper Eskimo, and Taremiut.



**Figure 8.** Percent composition of tool and facility inventories in relation to distance from equator for the same hunter-gatherers as shown in figure 7 (data from Torrence 1983: Table 3.2 and Murdock 1967). Facilities:  $r^2=0.680$ ,  $p=0.0001$ ; instruments:  $r^2=0.658$ ,  $p=0.001$ ; weapons:  $r^2=0.523$ ,  $p=0.0019$ .



**Figure 9.** Average extractive tool complexity (total technounits/total substant) plotted against reliance on aquatic resources for the same hunter-gatherer groups as in Figure 7 (data from Torrence 1983: Table 3.1 and Murdock 1967):  $r^2=0.614$ ,  $p=0.001$ .

Torrence (1983) suggests that individual tool complexity is also related to latitude, but an even stronger relationship exists between extractive tool complexity and the exploitation of aquatic resources (Figure 9). Hayden and Gargett (1988) have suggested that tool specialization as reflected by tool complexity is related to the frequency of task performance and the need to exploit resources in high volume, i.e., in bulk. In these situations there is a greater need for specialized tools that can reduce the work effort. Hayden and Gargett's (1988) hypothesis relating to tool specialization supports the concept that collectors are resource maximizers and foragers are time minimizers. The increased efficiency of specialized tools offsets the increased production and transportation costs, which complements Hitchcock's (1982) discovery that greater residential mobility correlates with less technological baggage among the Kalahari San. The implications is that the costs of transporting tools and weapons is too great for hunter-gatherers with high residential mobility, so they reduced their transportation costs by using multipurpose or flexible purpose tools. With increased residential sedentism, as seen among collectors, many hunter-gatherers were likely to have more possessions and greater tool specialization. Collectors, who have low residential mobility, could select specific reliable tools from an arsenal of weapons

for logistic forays aimed at acquiring specific prey. When not in use tools were usually cached at permanent or semi-permanent residential sites so entire tool kits were rarely transported, as is so common among foragers. These three comparisons suggest that the structure of the resource conditions the structure of tool assemblages with respect to assemblage diversity, assemblage composition and tool complexity among hunter-gatherers.

Tool manufacture and repair strategies also differ between "foragers" and "collectors." Foragers repair tools almost on a daily basis, a trait described as "make and mend" among the G/wi (Silberbauer 1981), while collectors schedule special "gearing-up" sessions when the primary object is to make and refurbish their tools (Binford 1980). Gearing-up sessions are scheduled during slack seasons when collectors, such as the Nunamiut or Tlingit, depend heavily on stored food resources (Binford 1980; Oberg 1973).

### Tool Curation among Hunter-Gatherers

In archaeology curation has come to mean: 1) a tool made long before it was used, 2) a tool transported between sites and used over a long period, 3) a tool regularly maintained during its life, 4) a tool designed

for many uses and used over a long period of time, 5) a tool reshaped for other uses, or 6) a tool cached for later use (Bamforth 1986; Nelson 1991). As Kelly (1988) suggests, cores can also be curated for many of the same reasons.

Curation must be understood by considering tool discard. Discard can be purposeful or accidental. In general, tool discard occurs as a result of one or more of the following scenarios: manufacture breakage; instant tools discarded soon after use; breakage during use resulting in discard; tools lost during transport or use; tools cached and never recovered; tools replaced if they appear to be near failure; or tools discarded if worn out and no longer maintainable (Gould 1980; Kuhn 1989; Shott 1989; Tomka 1990).

Curation has not often been considered in relation to other hunter-gatherer adaptive strategies. A number of years ago Ammerman and Feldman (1974) suggested that three elements affect the relative frequencies of artifacts: 1) the relative frequency of each activity, 2) the "mapping" relations between tools and activities, and 3) the tool droppage rate. The droppage rate refers to the probability at which a tool is abandoned and incorporated into the archaeological record. Drop-page rate reflects the longevity of a tool, and longevity of a tool can be conditioned by raw material, intensity of use, tool efficiency, intensity of maintenance, or a number of other factors. The authors stated that archaeologists regularly underestimate the effect of droppage rates on the formation of archaeological assemblages. After 20 years this observation is still pertinent.

Torrence 1983: 11-13) suggests that tool production long in advance of use is due to "time stress" among collectors, and gearing-up sessions are a reflection of these scheduling conflicts. Time stress does not appear to be common among "foragers;" nevertheless, some foragers take a long time to make some tools, and these tools are transported between residential camps in a unfinished state (Yellen 1977; Lee 1979). Foragers may be distinguished in this regard from collectors, who transport finished tools and/or cache finished tools in greater frequencies (Osgood 1940; Lee 1979).

### Tool Use-life and Production Costs Among Hunter-Gatherers

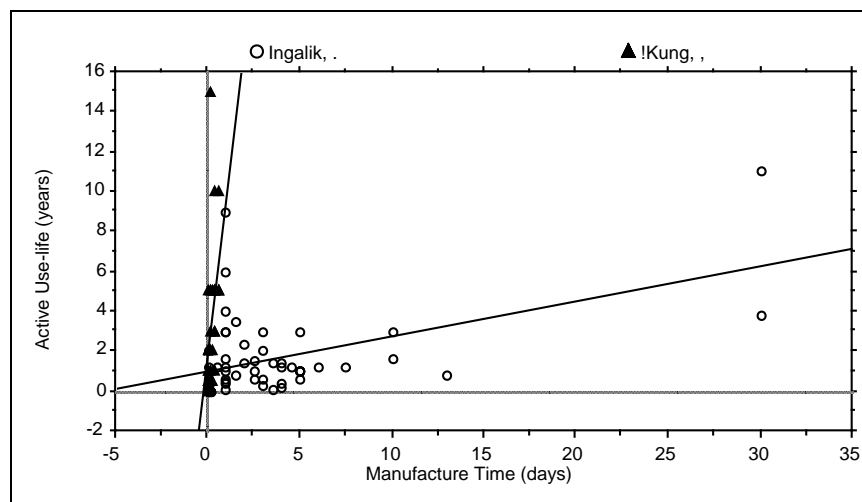
Length of tool use-life might also be expected to vary among foragers and collectors. The Kalahari !Kung San, Australian Western Desert Aborigines and Northern Athabaskan Ingalik from Alaska offer the best information on tool use-life (Osgood 1940; Lee 1979; Gould 1980). The mean use-life for Ingalik (a collector group) artifacts is  $2.6 \pm 7.9$  years, while the mean use-life for the !Kung (a forager group) artifacts is  $3.7 \pm 3.4$  years, and the mean use-life for the Western Desert Aborigines (another forager group) artifacts is  $1.7 \pm 3.0$  years. This suggests that curation (as measured by longer use-life, *sensu* Shott 1989) is at least as intensive among forages as collectors. This clearly does not support Binford's (1973) original proposition, nor does it support Kelly's (1988) interpretation. However, these figures do not consider the effects that differing raw materials have on use-life. Of the three groups, the !Kung use more metal and other durable materials of European manufacture than the other groups, so use-life estimates do not have enough reliability to be used alone.

Another way to look at tool production strategies among hunter-gatherers is to examine the relationships between production cost and tool use-life. Shott (1989) argues that, among foragers, as the effort and time invested in a tool's manufacture increases so does its use-life. He demonstrates this relationship with Lee's (1979) Dobe !Kung data, but confuses multi-tool production costs with single tool use-life estimates for ostrich eggshell canteens. When this is corrected, a better but still moderate statistically significant correlations exists between use-life and production time ( $r^2=0.47$ ,  $p=0.005$ ). Among the Ingalik, Shott (1989: 22) suggests that no such relationship exists between production time and tool use-life, but he omits a number of Ingalik tools from his analysis. More importantly, however, is the distinction between active and passive tool use-life. The Ingalik seasonally cache tools (Osgood 1940), and this should be considered as a tool's passive use-life. When only active use-life and production time of Ingalik tools are analyzed, there is a weak but nevertheless significant linear correlation between these variables ( $r^2=0.248$ ,  $p=0.0001$ ). Unfortunately, a similar comparison is not possible for

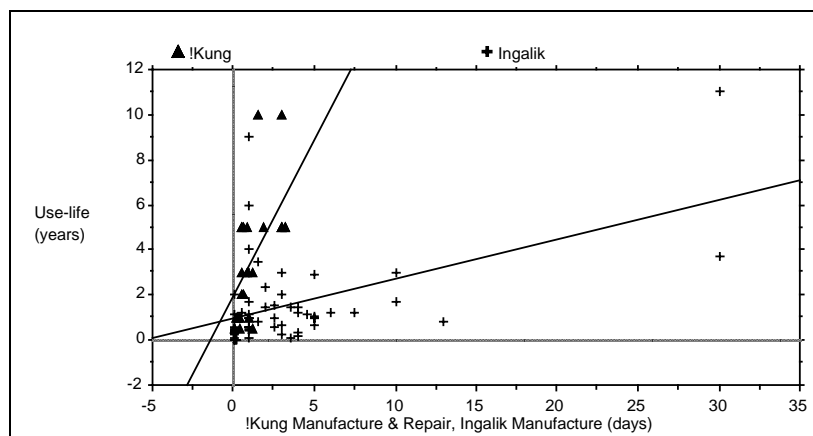
Western Desert Aborigines because their production costs were not recorded.

When the !Kung and Ingalik data are plotted on a graph along with their regression slopes, it becomes clear that marked differences exist between the two groups (Figure 10). From these admittedly limited samples it appears that these two groups use very different strategies for making and using tools. Foragers get much more use-life for their production effort while collectors expend a great deal more energy producing tools but with no appreciable gain in tool use-life.

It could be argued that the amount of time invested in tool repair and maintenance also extends its use-life (Shott 1989). Unfortunately no quantitative data exist on tool repair costs for the Ingalik, but the !Kung data do show a positive correlation between maintenance time and use-life ( $r^2=0.313$ ,  $p<0.0001$ ). It could also be argued that, in terms of use-life, the production and maintenance costs of foragers' tools equal only the production costs of collectors' tools. If this is so, then the combined production and repair time expended by the !Kung should be equal, or nearly so, to the production time of the Ingalik. As Figure 11 shows, this



**Figure 10.** Linear regressions between manufacturing time and use-life for Dobe !Kung and Ingalik tools (data from Lee 1979 and Osgood 1940).



**Figure 11.** Linear regressions between total manufacturing and repair time by use-life for the !Kung tools and manufacturing time by use-life for Ingalik tools. Ceremonial hats and sleds were not included with the Ingalik data set. Flint and steel fire kits were omitted from the !Kung data. !Kung  $r^2=0.352$ , Ingalik  $r^2= 0.248$  (data from Lee 1979: Table 9.10, and Osgood 1940).

is not the case, as the Ingalik production costs per unit of use-life are still higher than the production and repair costs of the !Kung. The pattern is not 100 percent dichotomous, however. One !Kung artifact, the fire kit, and one Ingalik artifact, the ceremonial hat, reflect the opposite pattern.

In general it appears that the !Kung keep production and repair costs low by making their tools last as long as possible and discarding them only when completely worn out. On the other hand, the Ingalik invest heavily in the production of tools, which they discard and replace fairly often. Kuhn (1989) has argued that collectors replace tools before they wear out because of fear-of-failure, while foragers seem to use tools until they are completely exhausted. Collectors must have highly reliable weapons; if their weapons fail, many of these hunter-gatherers would starve. Foragers, on the other hand, can fall back on other foods if they fail to obtain the targeted resource. Clearly the structure of their resources and the types of risk each faces is different, and these differences influence or condition their replacement strategies.

### Use-Life of Maintenance Tools Versus Extractive Tools

Bleed's (1986) original dichotomy between maintainable and reliable tools was formulated for weapons only, and not for the tools used to make and repair them (maintenance tools). Maintenance tools (sensu Binford and Binford 1966) probably were not used and repaired in the same ways as implements and weapons (extractive tools). It appears that the initial invention of maintenance tools (also called secondary tools) may be significant in terms of the evolution of tool use (Kitahara-Frisch 1993). It seems reasonable

that modern foragers and collectors would use maintenance and extractive tools differently because of the different nature of their resources and types of risk related to resource availability. The data available to shed light on this problem are limited to the !Kung, Ngatatjara and Ingalik. Table 1 shows that the Ingalik seem to take greater care of their repair kits and maintain them longer, while the !Kung and Ngatatjara are more cavalier with their repair kits (including greater use of expediently-made maintenance tools, but try to get their extractive tools and weapons to last longer. In Table 1 the M/E ratio (maintenance/extractive tool use-life ratio) demonstrates the difference between collectors and foragers. A number of ethnographic and ethnoarchaeological studies have documented expedient tool using strategies; in most cases expedient use is rarely exhibited in extractive tools and in each case raw materials are readily available (Stow 1905; MacCalman and Grobbelaar 1965; Gould 1968, 1977, 1980; While 1968; Strathern 1969; While and Thomas 1972; Isaac 1976; Miller 1979; Sillitoe 1982; Binford 1986).

### A General Model for Lithic Analysis of Hunter-Gatherer Tool Kits

From these limited and admittedly biased data, it appears that various groups of hunter-gatherers emphasize different qualities of efficiency during the production and use of their extractive and maintenance tools. In this section I continue to use Binford's forager-collector terms, but only with extreme caution and more out of desperation than conviction. The pattern I attribute to either foragers or collectors are very tentative and future research may show that these labels are wholly inappropriate. Thus I now use these terms in

**Table 1.** Extractive and maintenance use-life (years) for forager and collector hunter-gatherers. M/E ratio equals maintenance tool use-life/extractive tool use-life (data from Gould 1980; Lee 1979; Osgood 1940).

	<i>Extractive Tools</i>	<i>Maintenance Tools</i>	<i>M/E Ratio</i>
<b><i>Foragers</i></b>			
!Kung	4.2±3.2 (n=7)	3.3±2.5 (n=18)	0.79
Ngatatjara	2.4±3.4 (n=7)	0.04±0 (n=3)	0.02
<b><i>Collectors</i></b>			
Ingalik	1.3±1.3 (n=16)	4.7±12.8 (n=6)	3.62

quotation marks. I am not intending nor suggesting that we define “foragers” or “collectors” with prehistoric technological data. Rather we would profit by investigating the reasons why these seemingly opposing strategies are used by a few groups that could be classified as “foragers” or “collectors”. This technological model would be greatly improved by larger data sets from all continents. Then we might be more certain that these patterns are not simply idiosyncratic or ethnosyncratic patterns present in a few groups that were studied by anthropologists by pure chance.

“Foragers” favor increased use-life with their extractive tools, while shorter production and maintenance costs are stressed in their repair kits; thus, in relation to tool production “foragers” can be considered time minimizers. “Collectors,” with their attendant differences in resource structure and risk, choose increased effectiveness in their extractive tools, and this concern is translated into greater production and maintenance costs in their repair kits. Among “collectors” greater efficiency is measured mainly by increased effectiveness; thus “collectors” appear to be resource maximizers. “Foragers” are able to assume a more relaxed and possibly less taxing posture in terms of tool production and maintenance.

The “collector” pattern of greater tool kit diversity (i.e., tool specialization) and tool complexity, accompanied with a dependence on reliable tools and fear-of-failure replacement, along with intensive maintenance strategies, is a response to a specific resource structure (i.e., specific resources that can be exploited in bulk and are available for limited periods with few available backup resources). The typical “forager” use of a simplified tool kit composed of multipurpose tools, the exhaustion of extractive tools, and expediency among maintenance tools is stimulated by the exploitation of a wider but unpredictable set of re-sources many of which may be obtained on any specific day.

Short-term variations of resource risk, or food scarcity, also stimulate specific changes in technological replacement and maintenance strategies. This brings about greater rates of extractive tool replacement-before-exhaustion and more intensive repair of maintainable tools. However, changes in tool

kit specialization may not occur. If this is the case, then greater or lesser degrees of tool maintenance and replacement-before-failure should be observable in diachronic records of historically linked hunter-gatherers, and these technological changes should correlate with proxy measures of risk (scarcity). If risk and resource structure have “independent” effects on tool replacement and maintenance strategies, then collectors tending toward “forager” technological strategies and foragers tending toward “collector” technological strategies are possible.

The logic for this dual affect can be seen by reviewing the prey model (see Figure 1). If handling costs increase, in part because of greater technological diversity brought on by a significant change of resource structure, then narrower diets are predicted. However, if search costs rise because of greater food scarcity, then a wider range of food sources should be exploited, but not necessarily accompanied by greater technological specialization and diversity. Both vectors could lead to “collector” extractive tool replacement strategies and maintenance tool repair strategies; thus it becomes critical to have high resolution dietary and paleoenvironmental records to compare to technological strategies. Some may suggest that hunter-gatherers do not change their technological strategies so rapidly, but if Wiessner (1977) or Mithen (1990) are correct, then hunting strategies could change in the course of a single day, and it is not unreasonable to assume that technological strategies could alter over short periods as well.

It should be noted that at least three factors complicate the above model. The first is raw material durability, which cannot simply be equated to Western/European materials versus local natural materials. Different raw materials have different fracture and wear characteristics, and these influence the length of a tool’s use-life. Further groups-to-group comparisons may necessitate taking raw material durability more fully into account.

The second factor relates to raw material access (Bamforth 1986) and the effects that greater transportation costs have on replacement strategies and maintenance schedules. Efforts must be made to control for these effects. One strategy for controlling both is to look at long archaeological sequences at single sites

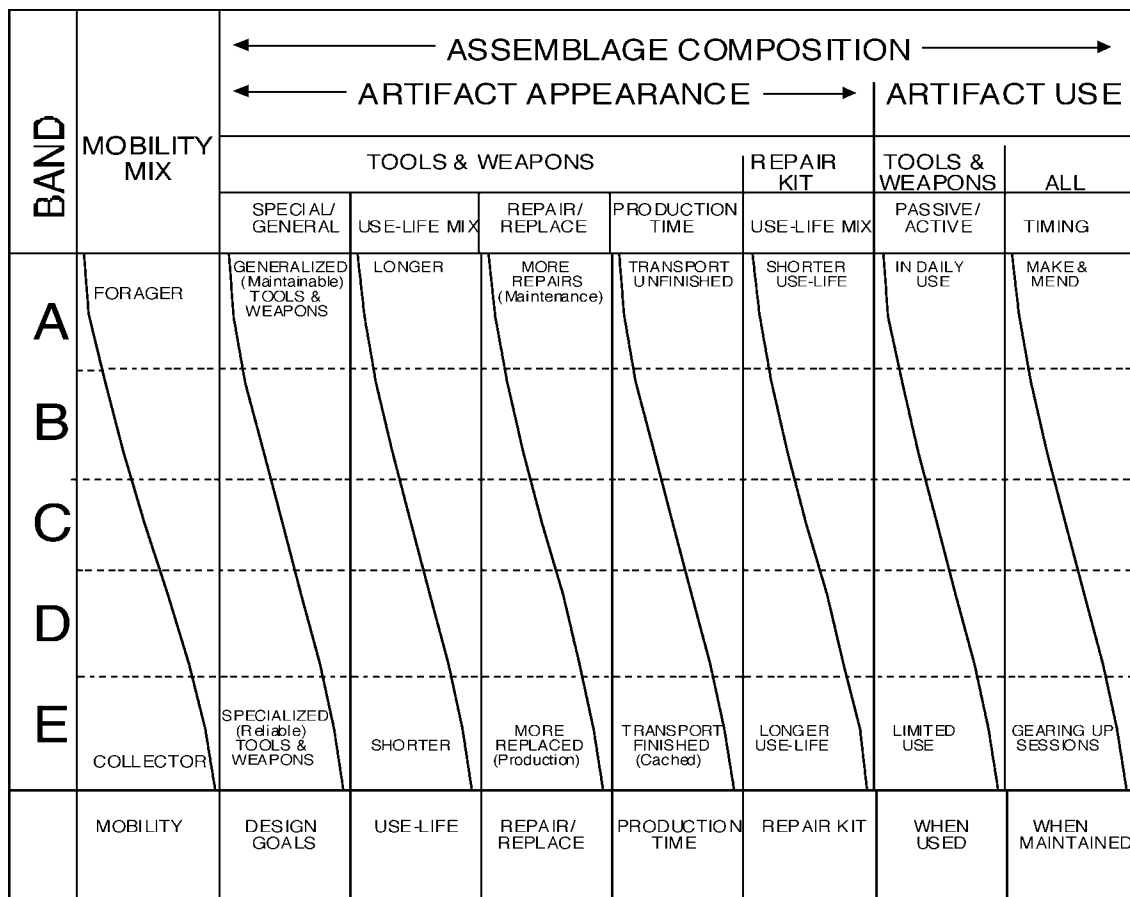
with good paleoenvironmental and paleodietary records. Availability of raw materials would not change except perhaps through exhaustion of a source (which is unlikely) or thorough sources exclusion by competing social groups. Without significant changes in raw materials, it is unlikely in these situations that variations in material availability would be important. Raw material availability would be a function of mobility, range size, and exchange. The third process is historical, frequently referred to as tradition. Traditions in lithic tool manufacture limit technological approaches, but within these broad “lanes” technological variability can fluctuate.

The model depicted above is testable in the archaeological record by comparing morphological characteristics that reflect use-life and the use-intensity of extractive tools and maintenance tools, and comparing these changes with subsistence evidence and

other proxy measures of resource availability and predictability. Figure 12 presents the expected changes predicted for technology. Site function must be factored into this model and one must consider how hunter-gatherers differentially use and discard tools on various types of sites (e.g., the probable greater use and discard of expedient tools on kill/butchery sites than on residential base camps). However, the model illustrated in Figure 12 is not enough. Additional steps are required to operationalize the model to identify specific observations to be made on prehistoric artifacts.

**Artifact Flow Models**

A useful step for the archaeologist is the construction of a pathway model that helps tract the life history of an artifact. Such models are not new (Collins 1975; Schiffer 1976), but they provide a systematic way to map how hunter-gatherers organize their technolo-



**Figure 12.** Assemblage composition and settlement pattern model for a continuum of hypothetical bands.

gical strategies. The specific life histories of various artifacts are dependent on the material used for making an artifact, the methods employed for manufacture and maintenance, and the organizational strategies used. Previously not enough emphasis was placed on the latter process. Figure 13 shows one possible pathway model for bifacial chipped stone artifacts, although not all bifacial tools would necessarily proceed through

these exact steps. The pathway model shows processes employed while artifacts are in a systemic context and the specific artifacts that might be recovered from an archaeological context.

Procurement and reductive and are created through a series of general sequential stages such as initial shaping, primary trimming, secondary trimming and haft modification (Collins 1975). Here I

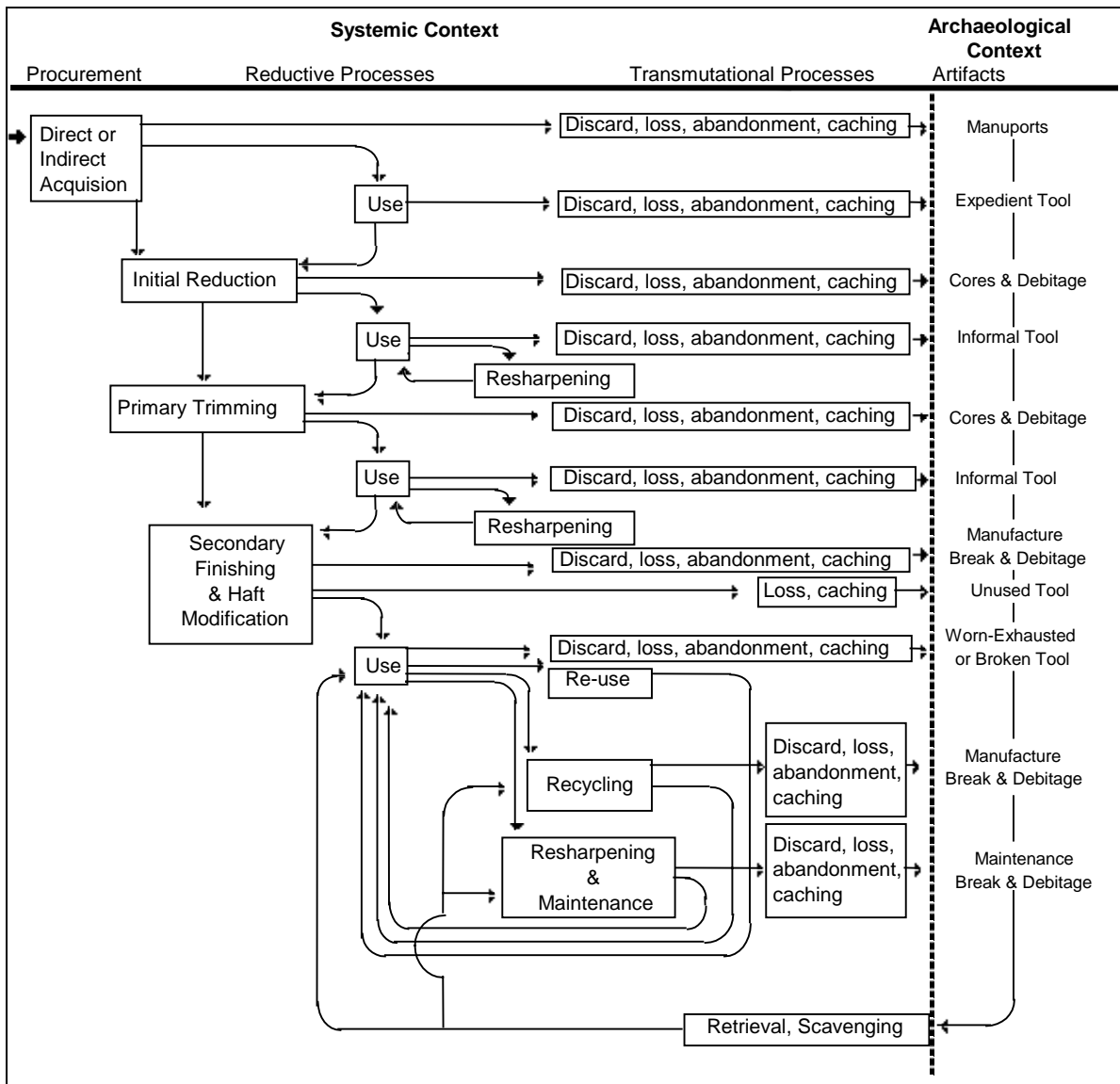


Figure 13. Hypothetical use-life flow model for bifacial tool.

classify transmutational processes affect chipped stone technologies. Procurement can be either direct or use damage, re-use (using an artifact for an unintended use), recycling (physically changing the design of the artifact for another use), and resharpening and other forms of maintenance as reductive processes. Re-use, recycling, and maintenance extend the use-life of an artifact and can be placed between reductive and transmutational processes on the flow chart. Transmutational processes transfer artifacts to a different context (systemic or archaeological) or keep the artifact from transferring from one context to another. Specific processes such as discard, loss, abandonment and caching allow artifacts to pass permanently or temporarily from a systemic context to an archaeological context. Retrieval and scavenging bring artifacts out of an archaeological context back to a systemic context, and may place an artifact into a new systemic context, i.e., a different group or time. This simple model does not fully account for every possible permutation of artifact conditions, nor does it explain why certain processes are used, but it is simply an organizational tool that helps the lithic analyst map technological patterns.

### Observations of Lithic Artifacts

The shape and form of an artifact can significantly change through use. This is exemplified by Dalton projectile points, which appear to have undergone multiple resharpening episodes (Goodyear 1974). Maintenance tools such as Tula adzes from Australia (Cooper 1954) have also been altered through resharpening episodes. Dibble (1987) argues that Middle Paleolithic "Bordian" scraper types are mostly a reflection of use intensity, and their type designations can change as they are resharpened. Gallagher (1977) and Clark and Kurashina (1981) use ethnographic observations of Ethiopian hide tanners to show that end scraper morphology changes with intensity of use. These examples suggest that tool shape and size are transitory. The value of a tool can be

defined by its utility, and when a tool's utility declines to a certain level then the tool is discarded. Direct measures of utility are unknown, but proxy measures have been suggested by Kuhn (1989, 1990), who distinguishes between the residual and expended utility of a tool. Residual utility means the potential remaining

indirect (McAnany 1988). Direct procurement includes embedded procurement. Bifacially flaked stone tools use-life of a tool, and expended utility means the consumed use-life. Figure 14 illustrates the relationships between tool utility and manufacture and resharpening costs. In this graph tools have no utility until they are manufactured, and their utility is replenished by resharpening. At some point costs outweigh residual utility, at which point the tools are discarded.

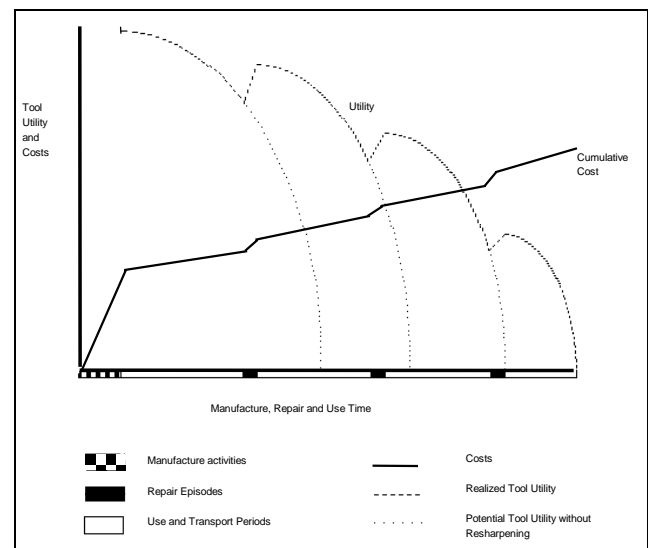


Figure 14. Tool utility and costs for a hypothetical tool.

Proxy measures of utility can provide revealing data on technological strategies of hunter-gatherers. For example, Bousman (1991) measured end scraper lengths and counted broken versus complete microliths on Interior Wilton assemblages from southern Africa as a gauge of maintenance tool residual utility (end scrapers and replacement strategies for extractive tools (microliths).

### A Preliminary Example

Testing this model with archaeological data is beyond the scope of this essay, but the use of these concepts can be applied to certain Paleoindian assemblages in Texas. I have recently inspected the projectile points from the Plainview Site and Levi Rockshelter (Sellards, et al. 1947; Alexander 1963). Most of the projectile points from the Plainview site, a

Paleoindian kill site on the Llano Estacado, are complete, but many are resharpened almost to exhaustion (i.e., many have blunt points extending only a short distance beyond the lateral haft grinding). The number of complete projectile points suggest that they were accidentally or purposefully discarded at the kill site. The shortness of the tips implies that the occupants were intensively resharpening these extractive tools, but it is unlikely that many could function after very many more episodes of resharpening.

In the Angostura layer at the Levi Rockshelter in Central Texas, projectile points consist primarily of broken bases, medial sections and distal tips. Most of the projectile points were broken 2-3 cm above the base at the point where the lateral grinding stops, and many of the medial sections and distal tips were long and not intensively resharpened. Most of the Angostura point appear to have snapped upon impact. The lateral grinding on the Plainview points extends further from the base than that on the Angostura points, indicating different hafting strategies. None of the Angostura bases matched the distal tips at Levi Rockshelter. It is possible that many Angostura points were broken during use. Bases could have been removed from hafts at the site and replaced by complete points. Distal tips may have been transported back to camp in animal carcasses, but these were not refurbished into points even though they are still fairly long.

Thus Plainview projectile points at the Levi Rockshelter appear to have been more intensively maintained and reused than those of the Angostura component. An additional difference between Plainview and Angostura points is the oblique parallel flaking on Angostura points. This trait is often used by archaeologists to evoke stylistic excellence, but from a cost-benefit analysis it implies a more costly production of angostura than Plainview points. In Kuhn's terminology Angostura points exhibit more potential residual utility than Plainview points. The extractive tools suggest that the Plainview occupation falls on the "forager" side of technological strategies, whereas the Angostura is on the "collector" side. I am not ready to say that Plainview hunter-gatherers were foragers and Angostura hunter-gatherers were collectors. Other factors could be at work, but this first and admittedly brief look suggests that these two groups did not

produce, use, or maintain projectile points in quite the same manner.

Maintenance tools were not inspected, but the model predicts that scrapers and other forms of maintenance tools would have been intensively resharpened by Angostura hunter-gatherers. Maintenance tools were not recovered at the Plainview site. Similar forager/collector technological strategies have been observed, although not recognized as such, in Paleoindian assemblages from the woodlands and plains of Texas and Oklahoma (Johnson 1989). An alternative interpretation is that raw material was very scarce near the Plainview site but abundant near Levi Rockshelter. Raw material availability can affect tool maintenance (Bamforth 1986), and the difference in resharpening between the Plainview site and Levi Rockshelter may be due to transportation costs and raw material availability.

Additional analysis of Paleoindian assemblages will provide a more accurate picture of the strategies employed by these hunter-gatherers than we currently possess. For years Paleoindian groups have been seen as unique hunter-gatherers that could not be directly compared to Archaic and modern hunter-gatherers. By placing all prehistoric hunter-gatherers in a comprehensive framework, we can begin to understand their specific technological and adaptive strategies.

### **Spanish Summary**

Se explora un método de análisis para el desarrollo y cambio en las estrategias tecnológicas entre los cazadores-recolectores, aplicando principios derivados de la Teoría de la Depredación. Tras presentar una breve reseña sobre los conceptos en los cuales se fundamenta la propuesta –modelos de presa, tiempo de residencia, riesgo e incertidumbre, etc.--, se discute como ellos pueden afectar diferentes estrategias en la manufactura de artefactos. Como resultado de ello, se desarrolla un modelo general para el análisis de tool kits de cazadores-recolectores, ejemplificando posteriormente con el caso de conjuntos Paleindios de los sitios Plainview y Levi Rockshelter.

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