2. Modelling Optimality in Subsistence and Technology

Like many aspects of life, successful foraging depends on continuous monitoring and optimization of subsistence related behaviours to suit changing circumstances, so that returns in critical resources such as food, water, raw materials, etc. match or exceed the effort expended in procuring them. There are various ways in which people might improve their subsistence strategies in response to changing conditions. These include modifying techniques of locating, capturing and processing resources, as well as modifying the efficiency or other properties of the technologies that are vital to making a living.

We can better understand how people might optimize their subsistence and technological strategies to suit particular circumstances by considering various bodies of theory dedicated to understanding human-land interactions. The first is optimal foraging theory (OFT), which was developed within evolutionary ecology to understand which foraging behaviours work best given different situations and constraints. The second body of theory is derived from processual and behavioural archaeology and attempts to specify the best ways to organize technology given different foraging practices. The third is design theory, which attempts to determine how much energy should be invested in technology and which designs should work the best in any given situation.

Mithen has argued that attempts to improve foraging returns might aim at doing two things. The first is to try and increase returns in food, energy etc. in terms of the quantity of a resource harvested for a given amount of time. Mithen (1990) calls this strategy *utility increase*. Another is to try to reduce the risk of failure to harvest or process resources so as to avoid critical shortfalls. Mithen (1990) calls this second strategy *risk reduction*. Both of these strategies can be thought of as *meliorizing* strategies (Dawkins 1982) - that is, ways of 'doing better' in social and physical interactions so that the chances of success are increased, whether this is thought of in terms of social prestige, individual wellbeing or reproductive success (Smith 1983).

Optimal Foraging Theory

Four optimal foraging models are relevant to the problem of utility increase and risk reduction and these are briefly presented so as to later develop predictions about how technology and landuse might be expected to respond to different circumstances. OFT models are typically written out as formal mathematical models, but such descriptions are not required to understand the basic principles.

OFT and Utility Increase

Diet Breadth. The diet breadth model is designed to predict the food items a forager should attempt to 'handle' (i.e. pursue, capture, process, and consume), and those they should overlook in order to continue searching for something else that will provide greater returns (Hawkes and O'Connell 1992; Kaplan and Hill 1992:63; MacArthur and Pianka 1966). The model states that once resources are ranked in terms of their profitability after search and handling time are factored in, foragers should always choose to pursue resources that yield the highest rate of return upon encounter, irrespective of the encounter rate of each prey item. Lower ranked resources will be pursued in order of diminishing returns only when higher ranked resources are unavailable (Gremillion 2002). A drop in the density of higher ranked prey should result in foragers broadening the diet to include lower ranked resources.

Patch Choice and Time Allocation. The patch choice model specifies which areas a forager should choose to search in order to obtain the maximum return when resources are unequally distributed (i.e. patchy) (MacArthur and Pianka 1966). This model is similar to the diet breadth model in postulating that foragers should search higher ranked patches first (those yielding the highest returns after search and handling time are factored in), and should search lower ranked patches as higher ranked ones become depleted (Smith 1983).

Central Place Foraging and Field Processing. This model attempts to solve problems stemming from situations in which resources are located in a different place to where they will be consumed (Orians and Pearson 1979). This model examines the cost of bringing people and resources together once round-trip time from the patch to the place of resource consumption is factored in. The general rule is that larger load sizes and greater pre-processing will be more profitable the further one must transport the resource (Beck *et al*. 2002; Bettinger *et al*. 1997; Jones and Madsen 1989; Metcalfe and Barlow 1992; Rhode 1990).

Resource Depression and Patch Choice. Resource depression is defined as declines in the encounter rates for prey species in a given patch. It often results from over-exploitation, prey relocation, changes in prey behaviour that make capture more difficult, and microhabitat change through climate change or human land use (Broughton 2003; Broughton and O'Connell 1999; Charnov *et al*. 1976; Nagooka 2002). The central place foraging model suggests a strategy that might help foragers cope with resource depression. This predicts that more use should be made of less-depleted patches further out from the central place once closer patches become depleted. This is because more distant and previously under-utilised patches should contain higher densities of high-ranked prey. This makes longer-distance travel more worthwhile so long as the return rate is above that of nearer patches once travel costs are factored in (Broughton 2003:63). Foragers should relocate the central place (typically a residential base) when foraging returns fall below those that can be obtained elsewhere once relocation costs are factored in (Hayden 1981; Kelly 1992:46; Sahlins 1972:33).

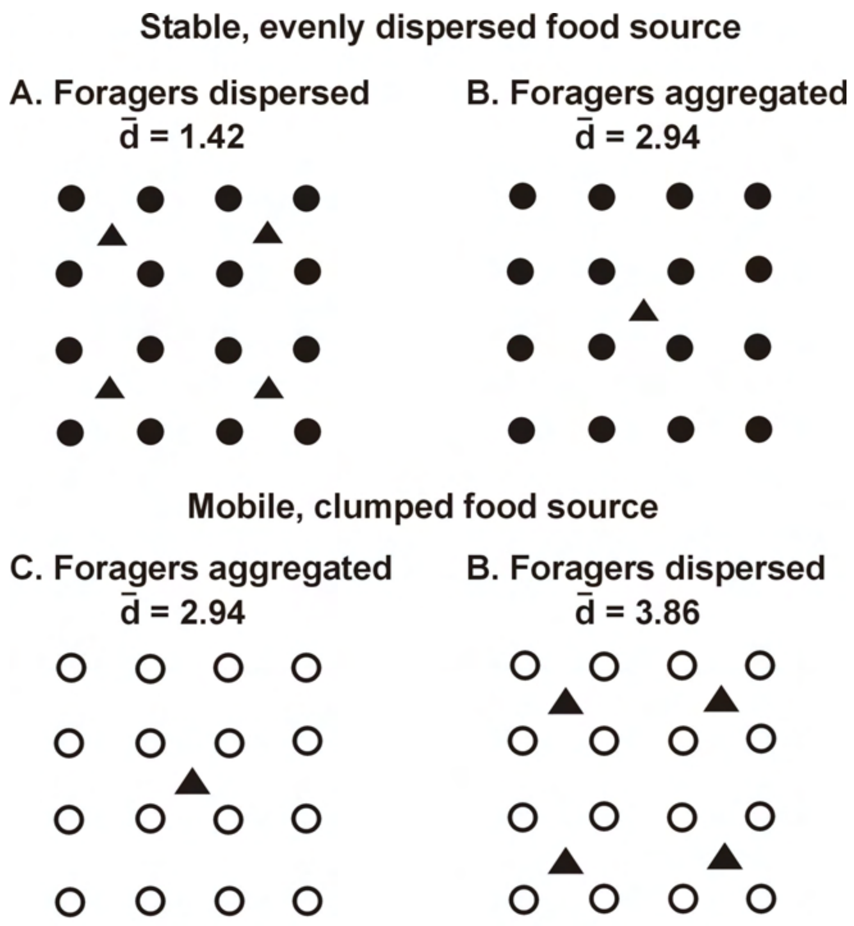
Mobility and Settlement Pattern. A fourth popular component of OFT specifies which settlement and mobility patterns will be optimal in fine-grained or patchy environments. The *geometric model of optimal dispersion* divides environments into two polar extremes – those with stable/evenly dispersed resources and those with mobile/clumped resources (Horn 1968). To minimize round trip time while foraging in each of these environment types, foragers should choose an optimal settlement location that also maximizes the probability of locating any resource clump. Travel costs increase as resources become more mobile or more clumped.

In stable/evenly dispersed environments a variety of resources will be within foraging distance of any camp, and hence foragers should choose to exploit resources in small dispersed social units, moving the residential camp frequently over short distances as needed in a more or less 'random walk' pattern (Figure 2.1) (Cashdan 1992; Smith 1983). Aggregation at a central location, on the other hand, is an optimal response to mobile/clumped resources, as moving closer to one resource would simply move the camp further from others (Figure 2.1) (Cashdan 1992; Smith 1983). Intermediate resource distribution patterns should favour a similarly intermediate settlement pattern (Smith 1983:634).

This OFT model (see Figure 2.1) is consistent with a range of predictions made by other researchers interested in the same question. For instance, Harpending and Davis (1977) found that people should aggregate in large groups when the amount of variance in total calories between patches is large, and that people should distribute themselves more uniformly in smaller groups if variance is small.

The mobility and settlement pattern model also corresponds closely to Binford's (1980) forager/collector continuum. In stable/evenly dispersed environments, Binford states that 'foragers' should make frequent residential moves over typically short distances, acquiring resources on an 'encounter' basis and 'mapping onto' the resources in the landscape. Binford (1980:7) suggests that the size of foraging units might also reduce in accordance with scarcity and dispersal of resources. In mobile/clumped environments, 'collectors' locate the camp at one resource and send out small foraging parties ranging over long distances and targeting specific clumps of resources in 'logistically organised' foraging trips.

Figure 2.1. The Horn (1968) geometric model of optimal dispersion. Optimal settlement locations (triangles) are predicted for stable/evenly dispersed environments (solid circles), and for mobile/clumped environments (open circles). The mean round-trip travel cost from settlement to resource locations, weighted by the probability of locating the resource, is given by *d*.



OFT and Risk Reduction

A second strategy for optimizing foraging returns is to find ways of reducing the risk of failing to obtain critical resources, as this can be a serious problem due to the highly variable (stochastic) nature of foraging environments. Stochastic variation presents two distinct problems: *uncertainty* due to imperfect information, and *risk*, or the consequences of unavoidable variation (Christenson 1982; Smith 1983; Winterhalder 1986; Winterhalder *et al*. 1999). In the case of uncertainty, foragers have incomplete information about their environment, making correct predictions about optimal foraging conditions more difficult.

Risk, or the *effect* of variation on foraging returns over a given period, may mean that people employ coping strategies that minimize variance rather than strictly following a utility increase strategy, especially if food storage is ineffective or costly and temporal variation in resources is substantial (Colson 1979; Minc and Smith 1989; Smith 1983). Risk can result from stochastic variation in such variables as the frequency, predictability or duration of resource availability (and can be associated with severe resource depression and climatic variability), or the spatial extent or spatial homogeneity of resources (Halstead and O'Shea 1989:2.3).

Populations affected by stochastic variation are said to be 'risk sensitive', and may either act in a manner that is 'risk averse', if attempting to reduce variation, or 'risk prone', if attempting to benefit from it. Attempts have been made to incorporate risk as an explicit component of many OFT models, including prey choice, patch use, group size and time allocation (Caraco 1979a, b; Caraco *et al*. 1980; Green 1980; McNamara 1982; Smith 1983; Stephens and Charnov 1982; Thompson *et al*. 1974). A major finding of this research is that risk-sensitive strategies can be predicted from the relationship between the minimum dietary needs of a forager and the expected benefits accruing from alternative strategies (Smith 1983). Stephens and Charnov (1982) have formalised this observation in the 'extreme variance rule', which simply states that foragers seeking to minimise the chance of falling critically short of resources should always choose the strategy that yields expected returns above requirements and with the *least variance*. However, if the mean expected returns for all strategies falls critically below the threshold for meeting basic requirements, then foragers should choose the strategy with the *most variance*. Although this last strategy is counter-intuitive, it simply means that under conditions of shortage, foragers should take greater risks in the hope of obtaining a return above minimum requirements. Cashdan (1985) makes the additional observation that the amount of effort foragers should invest in risk reduction strategies will depend on the cost of loosing the resource.

Five coping strategies for risk averse populations have gained attention. These are mobility, intensification, storage, diversification, group foraging, and exchange. Some of these strategies will be better suited to local conditions than others. Halstead and O'Shea (1989) also argue that their use may be employed in a hierarchical fashion, such that short-term, low-level risks may be locally addressed through the use of such strategies as mobility, diversification and local exchange. At much greater severity, however (i.e. where shortfalls are beyond the local capacity to absorb), high-level strategies may be employed, such as inter-regional exchange and intensification that could potentially lead to subsistence transitions (see also Hawkes and O'Connell 1992; Larson *et al*. 1996; Leonard 1989). Unfortunately, with the exception of group foraging, few of these models have received formal mathematical modelling and hence theoretical and empirical investigation of these concepts remains largely qualitative.

Mobility. Mobility can offset spatial variability in resource abundance by spatially redistributing people and food, either by moving people to food (residential mobility), or by moving food to people (logistical mobility) (Cashdan 1985, 1992; Sobel and Bettles 2000). Increasing mobility in situations of high variance in the distribution of resources may reduce risk by increasing the resource encounter-rate within and between patches. It may also help reduce uncertainty by enabling sampling of a much broader range of patches to obtain up-to-date information about fluctuating resource abundance.

Storage. The physical storage of resources can counter periodic shortages in availability by laying aside surplus in anticipation of later shortfalls. Storage typically involves large investments of time and effort in advance of need, and this added cost may reduce overall returns. People should therefore only invest in storage in times of surplus if resource abundance fluctuates severely, and if the production rate remains above minimum requirements after the preparation of foodstuffs and the manufacture of storage facilities is factored in. Transport costs entailed in moving surplus into storage, or accessing it later on, also decrease as mobility decreases, and hence storage should be more common among relatively sedentary peoples (Cashdan 1985). In some regions of the world (especially tropical regions), storage is difficult due to the rapid rate at which food stuffs spoil in hot and humid conditions, and foragers may be forced to look to other solutions to critical fluctuations in resource abundance.

Intensification. Another strategy for dealing with shortages is to intensify harvesting, processing, and/or food storage – in short, increasing the total time and effort spent foraging in order to reduce variance in supply. The term intensification is usually used in Australia to signify a broad suite of changes in subsistence, demography and social organisation and the rise of cultural complexity (Bender 1981; Lourandos 1985), but is taken here simply to mean greater investment of time and labour in foraging, or specialisation on a few key resources that yield the highest returns under sustained exploitation. Such a strategy is likely to be short-sighted, however, unless the productivity of the resource is resistant to intensive exploitation, or unless resource productivity can be enhanced, such

as through water control or the creation or regeneration of habitats (Bird *et al*. 2005; Jones 1969; Larson *et al*. 1996; Leonard 1989; Richerson *et al*. 2001; Winterhalder 1986). Intensification can therefore be thought of as a means of reducing risk through increasing the productivity of a given unit of land, rather than increasing the amount of land as might be attempted when reducing risk through increased mobility. Intensification may serve as a risk reduction strategy if the resources chosen for exploitation are hardy and resistant to the fluctuations causing shortage in other resources.

Diversification. Diversification is essentially identical to increasing diet breadth, except that it might mean regularly allocating more time to capturing and handling resources of lower-value if this reduces variance in returns while still meeting minimum requirements. Populations acting in a risk prone manner might be expected to continue targeting high-ranked, but highly unpredictable prey. The sexual division of labour in hunter-gatherer societies is sometimes seen as a means of incorporating both of these strategies into subsistence routines, where women typically target low-risk, low-ranked resources, and men target high-ranked prey with unpredictable returns (Hawkes 1990, 1991; Hawkes and Bliege Bird 2002; Hawkes and O'Connell 1992).

Group Foraging. Group living/foraging may also offer advantages to risk sensitive populations. Sharing information about environmental conditions, for instance, can help reduce uncertainty in prey location, while information can also be acquired from older people to help dampen the effects of temporal variation (Sobel and Bettles 2000). Secondly, cooperation in subsistence tasks may enhance efficiency through the division of labour, increasing the chances of locating prey, or by reducing foraging-area overlap. Thirdly, group living/foraging may help reduce variance in resource capture rates if yields are shared among group members. Different sharing rules can provide quite different predictions for optimal group size, including whether game is shared only between the foraging party itself (and their various dependants) or whether it is centrally pooled with other such parties and redistributed within a larger settlement.

Exchange. Reducing risk by way of exchange can extend beyond the foraging group to regional networks. These networks can act as a kind of 'social storage' by setting up mutual obligations between people that can provide assistance in times of shortage (Weissner 1982). This may take the form of *balanced reciprocity*, otherwise known as 'trade', where goods assessed to be of equivalent value by both parties are exchanged to obtain vital resources. In ethnographic cases, these systems often involve the transformation of surpluses into non-perishable goods for exchange during bad times (Sobel and Bettles 2000). Reciprocity can also take the form of *generalised exchange*, where an extensive network of partners agree to aid one another in times of shortage, thereby pooling risk so that variance is minimized by spreading losses over a much larger unit than the individual or local group (Cashdan 1985; Weissner 1982). Reciprocal exchange systems often operate by individuals making small, regular and predictable losses or contributions in return for larger, uncertain payoffs later on. Non-reciprocal exchange, otherwise known as theft or raiding, can also be a risk reduction strategy (Sobel and Bettles 2000). Such a strategy should be considered 'risk prone' in the sense that payoffs can be large, but the consequences can also be severe.

Predicted Foraging Responses to Changing Resource Structure and Abundance

The OFT models reviewed above make a number of useful predictions about possible human responses to changing resource abundance and spatial and temporal variability in resource availability. Together, they predict that as high-ranked prey become scarce through resource depression, or as conditions become more variable, foragers pursuing a goal of utility increase and/or risk reduction should:

- broaden the diet to include lower-ranked prey, or, specialise on a few sustainable resources
- include a wider range of patches in the itinerary, including closer, lower-ranked patches and more distant, higher-ranked ones
- intensify production where possible, such as by creating suitable habitats for high-ranked or dependable resources

- as foraging range increases, spend more time field processing resources found at greater distance to the central place
- form larger social groups that enhance energetic efficiency through cooperative foraging, allowing the pooling of information and a reduction in variance through sharing
- invest in physical food storage, or if impractical, invest in mechanisms of social storage such as reciprocal exchange (if risk averse) or theft and raiding (if risk prone)

If environments within the foraging range are patchy, or become patchier as a result of climate change or human alteration of the landscape, we should expect to see a greater tendency toward aggregation at a central location and logistical forays mounted to exploit surrounding patches. Over time, aggregation at a central place will likely result in resource depression in the surrounding area (Hames 1980), resulting in the same set of alterations to pursuit, processing and patch selection noted above. Alternatively, if there is no change in patchiness, but a reduction in overall prey density, people may be forced to spend more time overall engaged in the food quest. In the context of stable/evenly distributed resources where people essentially employ a 'random walk' encounter pattern (Brautingham 2003), this may simply involve higher mobility aimed at covering more ground, and an increase in total foraging range. In the case of logistical mobility, resource depression will probably involve travelling further to more productive patches.

Alterations to foraging patterns that result from resource depression and microhabitat change may also be reflected in changes to the organisation of technology. Broadening the diet (i.e. increasing handling time) and exploiting more distant patches (i.e. increasing travel time), for instance, could place greater demands on technology and may lead people to invest more time in improving the energetic efficiency of subsistence-related technologies (Jeske 1992). Likewise, large amounts of time spent travelling to and from distant, higher-ranked patches will reduce time and energy budgets left for foraging (Torrence 1983, 1989). Hence designing technologies that increase prey capture rates, reduce travel, handling or other costs, or altering the organisation of technology in ways that reduce opportunity and subsistence costs may all be beneficial strategies.

The Organisation of Technology

A second body of theory derived from processual and behavioural archaeology explores ways in which people can modify the spatial and temporal organisation of technology to improve foraging returns in different contexts. These strategies are centred on hunter-gatherer technologies in which human labour forms the bulk of the energy inputs, and the harnessing of external energy sources such as solar, water, wind or fossil fuels is largely unpracticed (Torrence 1989).

Utility Increase and the Organisation of Technology

Much of the theorizing about the organisation of technology has built on a dichotomy between 'curated' and 'expedient' technologies. These terms are typically used to distinguish between organised, planned, and carefully designed, executed and husbanded technologies in the former case and technologies that lack these properties in the latter (Bamforth 1986; Parry and Kelly 1987). In reality though, all subsistence technologies are likely to incorporate a degree of planning and design, with much of the variability between systems likely to reflect emphasis on different performance characteristics that enhance utility increase in specific contexts. Only in extremely rare cases where raw materials are truly ubiquitous, there are no constraints on time, and almost any tool will do the job, would we expect to find a total lack of planning and design in hunter-gatherer technologies.

The use of these terms also often seems contradictory in the literature and hence some debates can become confusing. For instance, Nelson (1991:63) suggests that transporting prepared cores to a workplace can comprise a 'curation' strategy by mitigating the "incongruity between availability of tools or raw material and the location of tool-using activities". She then states that the subsequent use of these stockpiled materials as needed constitutes an 'expedient' strategy. This example is typical of the kind of confusion that has plagued debates about the organisation of technology.

Because of this confusion, the following sections attempt to break down the concepts of curation and expedience into their various components, which are here termed performance characteristics after Schiffer and Skibo (1987; 1997). They are recombined later using the concept of technological provisioning as discussed by Kuhn (1995).

Organising Technologies Through Time Budgeting. The time-budgeting model developed by Torrence (1983) states that by scheduling activities such as raw material procurement, implement manufacture and tool maintenance in such a way that they do not interfere with food-getting or other important activities, opportunity costs (that is, lost opportunities to pursue subsistence activities) can be minimized without compromising tool functionality or availability. In essence, all foraging activity is time-limited, as overall utility gain is partly defined by time spent searching for and harvesting resources. Hence, foragers should seek to minimise the time spent making the necessary technologies ready for use when subsistence opportunities present themselves.

Binford (1977; 1979) found that the arctic Nunamiut foragers could reduce opportunity costs and/or increase energetic efficiency by 'embedding' various technological activities within more important subsistence tasks, thereby reducing costs associated with travel, or by restricting technological activities to periods of 'down-time' (such as during lean seasons, while waiting for game, or after dark while in camp). This allowed the Nunamiut to manufacture tools long in advance of use so as not to detract from pursuit or handling time. However, the time saved in travel by embedding procurement will be offset by the limited quantity of material that may be transported if foraging has already resulted in obtaining a full load (Myers 1989:85). In the absence of substantial transport technology, group foraging might assist in this situation if unsuccessful foragers within the group are available to carry raw materials or other processed resources back to camp.

Organizing technological activities so as not to compete with important subsistence tasks, and to reduce overall energy expenditure through embedding, should have specific consequences for assemblage variability. These are:

1. the types of raw materials present in assemblages should reflect patch visitation, as procurement should be embedded within foraging trips
2. there should be higher levels of anticipatory manufacture, maintenance, and reworking of toolkits at locations where more downtime is expected to occur. This should lead to more complex assemblages accumulating at these locations

Organising Technologies under Mobility Constraints. The OFT models presented above predicted that increasing mobility will enhance returns in situations where resources are mobile/unstable, or where higher returns can be obtained from more distant patches. However, increasing mobility comes at a cost. An individual encumbered by too much equipment may experience reduced success in searching for and capturing prey as well as incurring greater travel costs due to excessive weight or the awkwardness of the load. As most hunter-gatherer groups are mobile (because 'naturally' occurring crucial resources are often unevenly distributed in time and space) and typically make little use of transport technology, carrying costs are expected to be quite high and to limit the number of specialised tools that can be deployed (Kuhn 1995; Shott 1989:19; Torrence 1983:13).

Ethnographic research has demonstrated that in situations of frequent residential mobility (as typically occurs in fine-grained/stable environments), foragers typically reduce the number of transported items in the toolkit, and make use of a more limited number of multipurpose tools (Ebert 1979; Kelly 1988, 1992; Shott 1989; Torrence 1983). Binford (1979) calls these transported toolkits *personal gear*. Shott regressed toolkit diversity and mobility data for contemporary hunter-gatherer populations and found a highly significant inverse relationship between mobility frequency and toolkit diversity. However, Shott also found mobility to be multidimensional (Kelly 1992), as is predicted by the settlement and mobility models presented above. In contrast to this first pattern, Shott found that toolkit diversity showed a different pattern among groups that carried out long-range logistical forays from a central place in order to exploit clumped/mobile resources. The toolkits

employed by these groups showed increased diversity, presumably because logistical forays tended to target specific resources that were better handled using specialised tools.

The central place foraging model presented above also predicts that as the magnitude of mobility increases (i.e. distance out from a central place), foragers should process more resources at the source rather than transport them unprocessed. Such long distance transportation is more likely to characterise logistical forays. Foragers intent on field processing distant resources must carry with them not only those technologies that aid capture, but also those needed to process the resource. An increase in tool complexity might therefore be expected when foragers aim to process resources far from the residential base, as the transported toolkit is expected to perform both capture and handling related functions. This is exactly what Shott found when he plotted the range of foraging trips against the complexity of toolkits.

Alternatively, foragers may occasionally choose to transport bulkier tools to frequently used processing sites. Binford (1979) calls these items *site furniture*. Infrequent high cost exercises like the establishment of site furniture can be thought of as 'investment now for higher payoff later'. When mobility magnitude is low, foragers should simply transport the resource back to the residential camp for processing, and hence no additional technologies need be transported. Alternatively, residentially mobile foragers can simply transport themselves to the resource and thereby circumvent all additional transport costs. The use of site furniture may be profitable in any situation (i.e. either high or low mobility - logistical or residential) where people regularly return to a processing site.

Binford also suggests that mobile foragers will often make use of *situational gear*, or technological items procured from local contexts, retrieved from caches or recycled from existing personal gear, as situation dictates, and without considerable forward planning. Such a strategy is likely to occur most frequently among foragers engaged in high residential mobility, where toolkit diversity is low, and hence the necessary tools must be cobbled together from available materials.

A number of predictions can be made from this discussion of strategies for utility increase under highly mobile conditions. These include:

1. reduced toolkit diversity and complexity as residential mobility increases
2. greater toolkit diversity and complexity as logistical mobility increases
3. greater processing of resources at procurement locations as logistical mobility increases
4. greater use of site furniture if site revisitation is frequent or predictable
5. increased local procurement, opportunistic scavenging and recycling of technological gear as mobility increases

Risk Reduction and the Organisation of Technology

The following set of organisational strategies play a direct role in dampening the effects of variation on subsistence returns, mostly by planning for periods of time-limited foraging and unpredictable shortfall by ensuring that technologies are functional where and when they are needed (Torrence 1989). Torrence (1989) argues that unlike risk reduction in the subsistence strategies described above, which typically involve long-term investments aimed at spreading losses over many months or years, technological risk reduction (among hunter-gatherers at least) typically alleviates risk over very short periods (i.e. minutes to days).

Scheduling and Risk Reduction. Torrence (1983; 1989) argues that temporal constraints can create 'time-stress' if foragers are caught unprepared for urgent tasks (such as capturing seasonal or mobile prey whose availability is extremely limited or whose location is difficult to predict) or if competing activities (such as manufacturing tools or harvesting prey) are poorly managed. She argues that foragers can reduce the risk of failure to capture resources in such situations by planning for future time-limited opportunities and scheduling technological activities so that they do not interfere or compete with other important tasks at crucial times. This goal can be achieved by dividing technological activities such as procurement, maintenance and discard into small time parcels and 'juggling' these to meet

the range of needs at the appropriate times. The archaeological signature for this strategy should be essentially the same as that for time-budgeting above.

Retooling and Raw Material Procurement. In times and places where the availability of resources is highly variable, foragers may be uncertain about when the next opportunity for raw material procurement and retooling will present itself. Foragers faced with such uncertainty about future movements and opportunities should procure materials whenever they are encountered if there is room in the toolkit for new material. Such a practice would help reduce the risk of being caught without tools and tool-making potential at times of critical need. Frequent retooling would also help ensure tools are always at their most functional.

Brantingham's (2003) 'neutral procurement' model, although designed for other purposes, helps explore the effects of such a procurement strategy in fine-grained environments where foragers follow a random walk model and raw materials are distributed randomly throughout the landscape. Brantingham makes four assumptions for this model: 1) that there are limits on what foragers can carry and that new material will be procured only when the transported supply needs replenishing (the zero-sum game), 2) that raw materials are consumed at a constant rate over time, and 3) that all raw materials will be procured on encounter if toolkit supply is below the maximum irrespective of abundance or quality, and 4) that enough stone will be procured to refill the toolkit to maximum capacity.

The applicability of these assumptions in real world situations is obviously questionable in some cases. For instance, we should expect foragers to meliorate their behaviour in response to changing circumstances, such as when transported stone supply is low. Such responses might include slowing the rate of material consumption if a certain amount of time has elapsed and no new source has been encountered (presumably at the expense of tool performance), or moving purposefully to the closest source rather than continuing a random walk pattern that might take them further from a source and allow stone supply to 'clear' entirely. However, it is necessary to make assumptions of this kind if models are to retain generality, and these assumptions are not unreasonable.

Brantingham's simulation of 5000 time-steps indicates that raw material richness does not vary by much in a fine-grained environment (that is, when raw material diversity is calculated as a ratio to sample size), but the proportions of different materials in the toolkit does show pronounced distance decay relationships as time since procurement increases. Unfortunately, Brantingham does not model situations where raw materials are unevenly distributed, which is likely to be the case for most environments. However, we can predict that in such cases the rate of material consumption should be curvilinear, with foragers slowing the rate of consumption as they move further from a source to ensure that the toolkit is not entirely cleared before more stone can be procured. Torrence also argues that to increase overall toolkit performance in risky situations, foragers should select higher quality materials wherever possible. Risk reduction may therefore sometimes result in foregoing local raw materials (and perhaps slowing the rate of raw material consumption) and holding out until higher quality materials can be procured. In this way, Bamforth (1986) is right to argue that raw material procurement has its own costs, even if it is embedded in other activities.

We can therefore modify earlier predictions about the meaning of raw material variability to include the following:

1. in fine grained/stable environments the proportions of raw materials in an assemblage will reflect time since last procurement
2. under risky conditions, the rate of raw material consumption will vary according to uncertainty over supply
3. under risky conditions, raw material proportions may be out of phase with patch use history

Design Theory

A third set of theory helpful in understanding ways in which foragers can optimize subsistence returns draws on the design theory that is deeply embedded in Schiffer's behavioural archaeology. Modifying

the design of technologies can enhance certain performance characteristics to solve different technological problems (Fitzhugh 2001; Hayden *et al*. 1996).

Like time-budgeting and the particular solutions to mobility constraints, modifications to toolkit design should also leave identifiable traces in the archaeological record. For instance, as costs associated with search and capture of prey go up as encounter rates with high-ranking prey decrease, evolutionary ecologists predict that foragers should invest in improving the design of technologies that reduce costs upon encounter (Broughton and O'Connell 1999:155). This is because energy returns are largely intrinsic to resources, and the best way to increase returns as diet breadth increases is to increase the efficiency with which resources are handled by making better designed tools (Bright *et al*. 2002; Ugan *et al*. 2003).

A number of studies have examined performance characteristics under the control of the manufacturer that might be emphasized for tools designed to perform specific functions. For instance, penetration might be enhanced in projectile point design by reducing tip thickness, increasing leading edge sharpness, and decreasing cross-sectional area and the angle of intersection of the distal margins (Ahler and Geib 2000; Guthrie 1983). Killing power might be enhanced by increasing the depth of projectile penetration, and this can be achieved by designing the projectile to cut a wide enough hole that 'haft drag' created by binding and haft elements is reduced (Friis-Hansen 1990; Frison 1989). Symmetry and weight will also affect the balance and stability of the projectile (Beck 1998). However, these performance characteristics come at a cost. Wider points increase penetration depth, for instance, but also reduce ease of penetration. Tip thinness increases ease of penetration, but at the cost of higher breakage rates. Sharper tips mean more frequent sharpening etc. Thus the user will be forced to balance a number of trade-offs between ease and depth of penetration and resistance to breakage (see also Schiffer and Skibo 1997:31-32). Other performance characteristics will be emphasized in other contexts: high edge angles for scraping tasks, edge length and low edge angle for cutting tasks, a stout point for drilling etc.

Improvements in the regularity and processing efficiency of millstones in central Australia (Gorecki *et al*. 1997; Smith 1985) serves as a good example of how people might have invested in technology to obtain higher returns from low ranked resources. Indeed, improvements in grindstone design could have been a major factor associated with colonisation of truly arid 'barrier deserts' out of better-watered Pleistocene and early Holocene 'refuges' (Veth 1993a, b; but see David 2002 for an argument for a late-Holocene advent of seed grinding millstones). First colonisation of these environments would likely have resulted in rapid depression of higher-ranked prey that are extremely sensitive to over-predation, and the concomitant use of more labour intensive resources such as starchy seeds from trees and grasses (Cane 1984; Devitt 1988; O'Connell and Hawkes 1984). Investing more effort in procurement, design and processing efficiency of millstones would likely have made these food items more attractive as dietary staples, and probably greatly facilitated the occupation of these arid regions.

The assumption of design theory in the context of optimising subsistence strategies is that people should invest more effort in designing and manufacturing tools if doing so helps achieve returns above minimum requirements. Ugan *et al*. (2003) and Bright *et al*. (2002) have found that for a sample of common hunter-gatherer technologies, greater investments of 'techtime' are typically associated with higher rates of return.

Utility Increase and Tool Design

The following observations about technological design criteria could result in utility increase in specific situations, although it is difficult to know which ones in particular since empirical studies of this sort have not been undertaken.

Standardisation. One way in which to reduce time spent manufacturing and maintaining tool components and thereby obtain higher returns in resource handling may be to employ standardised components so that the costs incurred in manufacturing one component of a technology need not be incurred again in order to accommodate new components when old ones need replacing. An example

would be the standardisation of stone projectile tips used within composite technologies such as spears, arrows or darts, where the haft typically takes much longer to manufacture than the point (Hayden 1979; Keeley 1982; Odell 1994; Torrence 1989). Reducing variation in the size and shape of the inserts would minimise additional expenditure on modifying the haft to accommodate the new tip.

Another case in which standardisation may result in utility increase is in minimising wastage of time and materials in procuring and manufacturing tools. A common assertion in lithic studies, for instance, is that technologies that produce flakes of equal size and shape in sequence from a block of stone with little waste or failure between blows (as in formal blade technologies or recurrent Levallois production), can maximise cutting edge for raw material usage, thereby increasing efficiency in tool manufacture and reducing procurement costs (Nelson 1991). Standardisation may also assist in regularising tool performance and in making estimates of probable tool use-life (Hiscock 2005).

Hafting. Hafting is a clear example of a way in which tool design can result in utility increase. Keeley (1982) explains that hafting can achieve this in a number of ways, including 1) by making particular tool forms functional in ways that they otherwise would not be (e.g. projectile points, or tools with small cutting edges), 2) by increasing the force that may be exerted during work by increasing leverage, 3) by enhancing the efficiency or precision of work (e.g. drill bits, gravers), 4) by conserving lithic material by exposing only small portions of the edge to use-damage, and 5) by decreasing the likelihood of loss.

Portability. Shott (1989) reasons that higher mobility will not only reduce toolkit diversity and tend to increase toolkit complexity, but will likely also result in a reduction in the size of the mobile toolkit if travel costs are severe. This might mean transporting a small number of larger tools if toolkit diversity is low (as in the case of high residential mobility), or a number of smaller ones if toolkit diversity is advantageous (as in cases of higher logistical mobility).

Versatility. Assuming that the number of tasks performed by foraging groups remains much the same, Shott's (1989) analysis indicates that changes in mobility should generally result in changes in toolkit diversity, with high mobility frequency leading to low toolkit diversity, and high mobility magnitude leading to high toolkit complexity. Essentially, what is implied in this argument is that logistical forays tend to target specific resources, and that the use of specialized tools that are more efficient at performing certain tasks will result in greater returns than could be achieved with more generalised tools. This relationship between number of tools and number of functions is termed *versatility*, and higher versatility is expected when toolkit diversity is low.

Flexibility. In contrast to versatility, flexibility refers to the potential for a tool or raw materials to be recycled for use in some other task (Nelson 1991; Shott 1986). As residential mobility increases and toolkit diversity decreases, foragers might be more inclined to make greater use of situational gear. An additional design element for low diversity toolkits then may be to build in flexibility in such a way that toolkits can be opportunistically recycled to perform a range of unscheduled tasks. In contexts of low mobility, and of predictable requirements for tools in particular locations, it is often suggested that foragers should stock-pile raw materials at the central place or locations of anticipated use (Kuhn 1992, 1995; Nelson 1991). The central place foraging model, however, suggests cases in which this pattern might not hold - principally where raw materials are being transported over long distances. In contexts of low residential mobility, or where logistical forays are also relatively short, there may be little need to pre-process materials, and stockpiling at the residential base would be the optimal strategy for providing maximum flexibility.

Use-Life. One insight gained from modelling optimal technological investment concerns the period of tool use required to recoup and build on the costs in time and energy incurred in raw material procurement and tool manufacture. In the case of complex technologies, for instance, outlays of time and energy may be substantial even before a tool is used. However, in cases where greater initial investment results in utility increase, this initial outlay is cost-effective so long as the artefact survives long-enough to repay investment and reap the long-term benefits of improved performance (Ugan *et al*. 2003).

In the context of stone artefact technologies, use-life can be extended by designing implements with the potential to undergo more resharpening/recycling events per unit weight, a concept Hiscock (2005) and Macgregor (2005) call *extendibility*. They argue that certain classes of artefacts, generalised retouched flakes ('scrapers') and bifacial points for instance, are likely to be quite different in the degree to which use-life can be extended. Scrapers are typically retouched in a single plane, and increasingly encounter step terminations and high edge angles as reduction continues, such that each retouching event reduces the potential for another. Bifacial technologies, on the other hand, facilitate longer use-lives by allowing step terminations to be removed from the opposite edge, are more successful at maintaining edge angles, and benefit from the establishment of scar patterns on both faces that help flake detachments run to the centre-line without terminating abruptly (Kelly 1988; Kelly and Todd 1988; Macgregor 2005; Whittaker 1994). Bifacially flaked ground edge axes probably represent the quintessential extendable technology, as they possess many of the advantageous characteristics of bifaces (in terms of their potential to overcome flaking errors and maintain required geometry), but have the added advantage of additional size and weight (which enables many more rejuvenation events before exhaustion) and a ground edge that can be easily rejuvenated to provide a highly functional edge in chopping tasks for long periods (Hiscock 2005).

Similarly, Beck (1995; 1998) has explored the issue of use-life for projectile points in terms of the costs of manufacture and repair. She examined failures in side and corner-notched Great Basin points, and found that side-notching tended to weaken points at their centre, making them more likely to break in half. A central break means that less of the original tool is left for re-tooling. A way of minimizing the costs of breakage then is to encourage points to break as near to the tip or as near to the base as possible, an explanation she adopts for the rise of corner-notching as the dominant strategy in Great Basin point manufacture after c. 5,000 BP.

Embedding points deep within the haft or resin so that only the tip is exposed might constitute an additional strategy for minimizing loss through breakage (Ahler and Geib 2000). Mulvaney (1969) and Akerman (1981) have made similar observations regarding the use of an extensive resin casing to protect the fragile edges of Kimberley points. Akerman (1981:488) also suggested that affixing points to a slotted haft rather than a split haft, and using a large piece of resin rather than bindings and notches, might help reduce breakage rates by allowing points to break free of the haft when excessive lateral force is applied. Lashing and notching would make the point too rigid, and may result in snapping the tip and the foreshaft (if used). The use of large amounts of resin adhesive also allows the mounting of extremely small points, aiding penetration, although at the expense of cutting potential. As small points might often be expected to result from extensive reworking and resharpening, such a strategy might enable the use of these points to be extended until replacement points were available.

An advantageous spin-off of long use-life implements that are resharpened many times is that many flakes are produced from their edges that are often well-suited to fine cutting tasks such as skinning and butchering (Kelly 1988; Kelly and Todd 1988). The selection of high quality raw materials may also extend the use-life of tools as high quality cryptocrystalline rocks are generally better suited to the fine retouching that characterizes most resharpening events (Goodyear 1989; Gould and Saggers 1985).

Increasing the use-life of tools therefore increases the long-term payoff when manufacturing costs are high, and should be detectable in stone artefact assemblages as attempts to increase the extendibility of implements through retouching, improved geometry and the selection of high quality raw materials.

Tool Design and Risk Reduction

Certain technical performance characteristics can also serve to reduce risk. In one sense all of the technical strategies described so far may help reduce risk, if by increasing capture rates and processing efficiency foragers can ensure production remains above minimum requirements despite the effects of stochastic variation. Foragers should therefore invest more heavily in technology when risk is a significant factor. However, the design criteria reviewed so far do not specifically target the reduction

(or harnessing) of variance in foraging returns. Three aspects of tool design in particular are likely to aid in risk reduction.

Reliability and Maintainability. Foraging time will be limited by the functionally effective life of the tools on which successful capture depends (Ugan *et al*. 2003). In time-limited situations that result from fleeting encounters with mobile game or reductions in search time due to longer travel times to and from a patch, foragers may benefit from increasing the length of time for which a technology is functional before repairs are needed. For example, Binford (1979) found that there was little time for the Nunamiut to undertake tool maintenance during the thirty days or so in which caribou are available, and hence they invested a great deal of energy in advance of use in ensuring their tools would perform reliably for the required duration.

Bleed (1986) has examined the design principles that help ensure technological reliability, and has contrasted these with maintainability. Tools designed to be reliable will tend to be sturdy and over-designed to withstand more than the range of stresses they are expected to have to endure during use. This might entail increasing the size of a tool if this adds strength, or it might involve added attention to joints or fitting, or the use of redundant or standby components that ensure continued functioning if one or more components fail.

Because reliable technologies are designed not to breakdown, their repair often requires longer maintenance periods using specialised repair kits capable of fixing any damaged component. Reliable technologies therefore also tend to be maintained by specialists and in contexts where a range of maintenance tools are available. The repetitive tasks to which reliable technologies are best suited will also mean they are not as versatile as maintainable ones, and truly reliable technologies might therefore be expected to accompany higher toolkit diversity.

In contrast, Bleed (1986) sees maintainable technologies as likely to be simpler than those designed for reliability. They may also tend to have a series design in which each component performs a distinct task, but with the disadvantage that if one component fails, the entire system fails. Consequently, maintainable systems must be designed to be easily repaired and brought quickly back into service. The simpler nature of maintainable technologies also means that the user should be capable of fixing damaged components easily and quickly with available tools.

Bleed illustrates his arguments by contrasting the simple portable toolkit carried by !Kung San men and designed to make unscheduled repairs quick and easy, with the reliable technologies of arctic foragers that emphasize reliability due to the restricted time available for seasonal hunting. To increase reliability, the Nunamiut, for instance, rely on redundancy, and transport many well-crafted, specialised tools to the location of intended use, including multiple tools of the same kind. They also cache tools and components at locations around the landscape to reduce the risk of being caught without necessary technologies at critical times.

Bleed further argues that a way to improve the performance of critically important technologies is to add some features of maintainability to reliable technologies, so that "if the worst happens and the system fails when it is needed, it can be rapidly repaired for continued use" (Bleed 1986:740). Torrence (1989) points out that this is exactly what arctic foragers do by incorporating simple and maintainable 'series designed' elements into their tools. Myers (1989:87) also offers the example of the Mesolithic composite weapons comprised of multiple backed artefact components that bring features of both reliability (i.e. redundancy in backed artefact assemblies that enhance performance and mitigate against partial loss or breakage) and maintainability (use of standardised components that can be easily replaced) to the tool, an argument others have also run to explain the adoption of backed technologies in other parts of the world (Bleed 2001; Hiscock 2002; Neeley and Barton 1994).

Technological Investment and Tool Performance. Torrence (1989) argues that risk prone populations should invest heavily in toolkit design and manufacture if this helps dampen the effects of variability and time-stress. Torrence suggests tool specialisation and complexity are the two most obvious signatures of increased investment. The degree to which foragers invest in technology should also be dependent on the costs of failure. Using the same data presented in her earlier paper (Torrence 1983),

Torrence sees a dependence on highly mobile game as a big factor creating the type of short-term risk that foraging technologies can help overcome, and that high latitude foragers that predominantly pursue mobile game are therefore more likely to invest heavily in specialised tools including tended and untended facilities. While the association between latitude and dependence on mobile game (and hence risk) is real, many other populations also experience high levels of stochastic variation and time-limited resource availability, such as foragers in mid-latitude arid environments or those dependant on a highly variable monsoon in tropical regions. Furthermore, any population can be become risk prone if variability is heightened or introduced into the system, such as might result from increased climatic variability.

In risk averse populations, technologies can therefore be expected to be:

1. better designed for high performance and a limited range of functions, as indicated by higher toolkit diversity and complexity
2. made from higher quality raw materials where possible

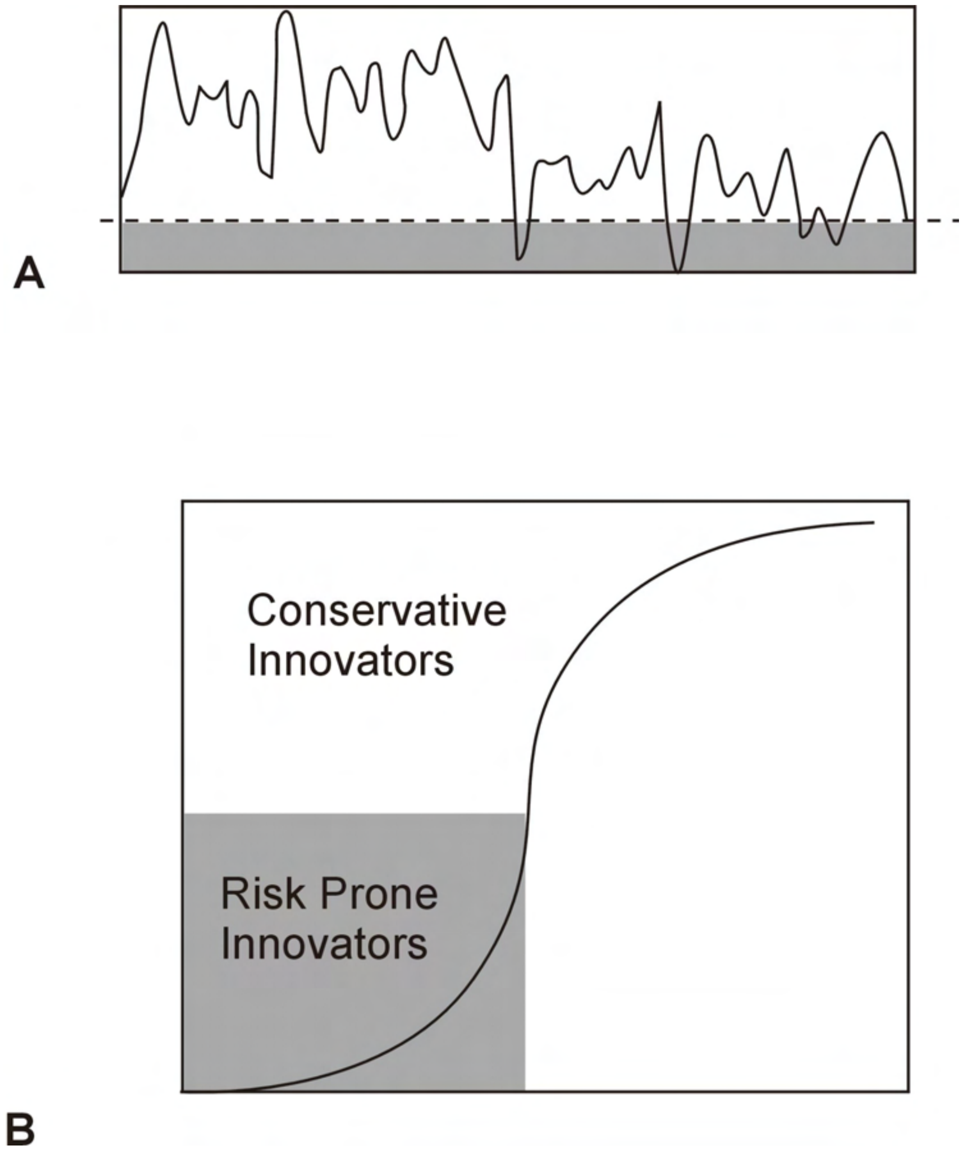
Innovation and Variation. Following Stephens and Charnov (1982), Fitzhugh proposes that as risk sensitive populations begin to experience mean yields below minimum requirements, they should switch from a risk-averse to a risk prone attitude to technological innovation – or the process of constructing and testing new technologies that *might* give higher payoffs than existing ones. Fitzhugh's model is presented in Figure 2.2. In the top graph (A), productivity from foraging is shown over time. In the bottom graph (B), the dynamic feedback between resource productivity and proclivity for risk-taking behaviour is shown as a sigmoidal curve (utility/time). The model predicts that foragers will switch to a risk-prone strategy of technological innovation in the hope of higher payoffs when returns are below the dashed line in A, and return rate falls into the shaded area in B. This model accounts for the way in which new variation may be stimulated once people are able to perceive changes in conditions. Under periods of extreme shortfall then, we might expect to find evidence for experimentation and variation in technologies in the hope that foragers might secure higher returns that at present. Fitzhugh (2001:144) argues that invention and experimentation is most likely to focus first on technologies that may enhance capture rate of larger, high-ranked prey, but as these are driven to decline, inventiveness should gradually turn to hardier, and more reproductively stable r-selected species. Finally, Fitzhugh makes a number of predictions about the circumstances likely to increase risk and lead to greater technological innovation:

1. movement into unfamiliar environments
2. rapid climatic change
3. depletion of high–ranked prey
4. heightened competition between groups

Toward a Synthesis

So far a great many subsistence and technological strategies have been listed that foragers could employ to increase energetic efficiency, reduce risk and thereby increase the chances of success in subsistence and other aspects of life. Combining these individual strategies into a synthetic model that places causal factors in their proper order (i.e. resource availability and structure, then subsistence organisation and then technology) is not easy, especially if we are to heed Torrence's warning about the hopeless inadequacy of rigid settlement/subsistence typologies. Most formulations appear to begin with a series of propositions about technological problems that need solving, without stipulating the conditions giving rise to these problems (e.g. Hayden *et al*. 1996). No simplified model is ever completely satisfactory, and there are many points of potential overlap and ambiguity in any system. For instance, similar aspects of technological organisation (such as embedded procurement and advance manufacture) could equally stem from changing levels of mobility or the need for risk reduction, even though in one context the goal is to reduce travel costs and in the other it is to buffer against future uncertainty by ensuring tools are made well in advance of need.

Figure 2.2. Illustration of the relationship between stochastic variation and risk sensitivity, after Fitzhugh (2001). A: hypothetical return rate from foraging over time, B: sigmoid curve representing utility / time (gain rate) for foraging.



One model that has made significant progress in uniting the various themes in technology and subsistence touched upon in this chapter is Kuhn's (1995) system of technological provisioning. With some additional specification for the situations in which different provisioning strategies are likely to obtain, this model would seem to be a convenient and powerful tool for studying subsistence and technological change in the archaeological record.

Kuhn's Provisioning Model

Kuhn has portrayed the strategies employed to balance subsistence against technological costs as a range of alternatives involving planning for the nature, timing and location of use. To be most successful, technological planning must take into account temporal and spatial fluctuations in the frequency, predictability and range of residential moves, functional requirements for exploiting different kinds of resources, time-stress and urgency of use, opportunities for maintenance, the richness and diversity of foraging opportunities and the availability of replacement raw materials; in other words, the range of factors outlined above. As we have seen, different variable states, as well as variation in these over time, should elicit different responses in terms of the way raw materials are provisioned and the specific design of the toolkits themselves. Kuhn describes two provisioning

strategies that represent solutions to the problem of maintaining a constant supply of effective tools under conditions where mobility, and access to and predictability of resources varies. These strategies are called the *provisioning of individuals*, and the *provisioning of places* and subsume the more common and problematic concepts of 'curated' and 'expedient' technologies (Kuhn 1995:22).

Individual Provisioning

Individual provisioning represents a response to situations where future contingencies must be planned long in advance with little certainty over where or when extractive and maintenance tasks will take place (Binford and Binford 1966). This strategy can be linked to situations of high logistical mobility in variable/patchy environments, to high residential mobility where foraging opportunities may not coincide well with opportunities to reprovision with raw materials, and where down-time cannot be scheduled with any certainty. Individual provisioning might be expected to arise as a result of increasing resource depression leading to longer travel times to more distant patches, fewer and more time-limited encounters with high-ranked mobile prey, and increased climatic variability creating greater stochastic variation in resource availability. Longer travel times should also give rise to greater pre-processing of resources to increase utility per unit load (Beck *et al*. 2002; Bettinger *et al*. 1997; Jones and Madsen 1989; Metcalfe and Barlow 1992).

Individual provisioning cross-cuts the categories of mobility, risk reduction, and time-stress discussed above. In keeping with the principles of optimal design for each of these situations, toolkits designed for individual provisioning will tend to be portable, versatile, flexible, maintainable and reliable (i.e. with features of both), and will be made well in advance of use, and hence, be on-hand when and where they are needed.

Kuhn argues that this strategy has direct consequences for the production and design of toolkits. For instance, the significant transport costs entailed in high mobility are likely to select for light-weight stone tools of smallish size (Shott 1989). Frequency of mobility is also likely to constrict the diversity of tool-kits, with a focus on versatile, multi-functional tools, as opposed to a number of tools each designed for specific tasks (Shott, 1986). High logistical mobility should create a trend toward the opposite extreme - that of specialised and diverse toolkit manufacture - with each tool better suited to a limited range of functions. Because access to replacement material may be unpredictable, tool use-life should be extended (Hiscock 2005; Macgregor 2005), or tools should have the capacity for recycling so that unscheduled tasks can be performed (Dibble 1995; Kuhn 1995). Because they are small, these portable toolkits are also more likely to be employed as components in composite, hafted tools (Keeley 1982; Odell 1989). To meet the requirements of maintainability they may be designed as interchangeable tool bits to fit pre-fabricated hafts, thus requiring a degree of standardization in their morphology. To offset the risk of breakage at times of critical need they may also be manufactured from higher quality raw materials (Goodyear 1989), or form one of a number of multiple redundant components (Bleed 1986; Myers 1989).

This set of features is not exhaustive and additional designs are conceivable. The point is that the provisioning of individuals should have predictable archaeological correlates.

Place Provisioning

The provisioning of places is a more favourable strategy when the location and timing of activities to be performed in the future is predictable and mobility is low. This strategy would tend to be employed at locations where the diversity or richness of subsistence opportunities is greater, such as when high-ranked or stable resources are abundant and close by, variance in foraging returns is low, and resources are patchy and suited to exploitation from a central place of low residential mobility. Provisioning of places promotes the transport of raw material, or 'tool making potential' in Kuhn's words, to a site of relatively longer-term residence, where the type of equipment needed can be predicted and where the range and quantity of extractive tasks may be greater, and hence greater flexibility in tool form may be desirable. Since this provisioning strategy is best adopted under conditions of low mobility and relatively short range logistical foraging, material can be expected to

be transported to the central place over relatively short distances, and therefore not to have been pre-processed to any significant degree. Raw material stockpiling should therefore be a common feature of place provisioning (Parry and Kelly 1987), and might include such strategies as the provisioning of large blocks and cores that offer maximum flexibility in terms of the creation of fresh sharp edges of a range of shapes and sizes with minimal processing required. The supply of raw material to provisioned sites need not digress completely from broad patterns of raw material supply, however, and distance decay relationships should still be expected. This is because procurement will still reflect patch use, while the degree and rate of consumption will reflect time since procurement and the anticipated time until the next procurement.

While each of these strategies is portrayed as an alternative to a given set of economic and/or ecological constraints, in reality both forms may co-exist to differing degrees within different segments of the total land use system. It should be possible therefore to find elements of individual provisioning within a predominantly place provisioned landscape, and vice versa, depending on the levels of mobility required to exploit resources in each patch and the levels of variance experienced in each.

Kuhn's model is elegant and contains most of the ingredients required to deduce changing patterns of land use, mobility and risk, and from these infer likely changes in resource availability and subsistence organisation. As a useful heuristic, it can also be broken apart more easily than the highly ambiguous and often confused concepts of curation and expedience.

Conclusion

Human foragers must make complex decisions about the world in order to survive, reproduce and compete with their conspecifics. Optimality models help us understand the sorts of decision foragers *should* make in given situations and their likely effects on fitness differentials, even if no one ever really acts like this all of the time or even cognizes problems in this way. That these models appear to explain even some human behaviour, let alone accounting for many situations with pleasing accuracy (Smith 1983), attests to their utility in anthropology and their ongoing importance in helping explain human evolution and cultural variability. The focus on two kinds of models – utility increase and risk reduction – allows many of the day-to-day decisions facing foragers to be modelled and particular responses and coping strategies predicted. Placing subsistence concerns first, rather than relegating them to a shadowy background as many technological models have done, provides us with a set of statements about the likely factors giving rise to particular technological problem solving strategies. For the most part these seem to be aimed either at maximising energetic efficiency under different constraints or maximising or minimising variation in returns when environmental conditions are variable and minimal requirements are at stake. The various models presented form a complex set of entangled problems and solutions that are not easily synthesized into a single interpretive scheme. Kuhn's provisioning model, however, takes us at least some way toward that goal by providing a coherent account of the likely relationship between subsistence concerns and technological problem solving strategies. With this interpretive scheme in place, it is now possible to explore in more detail the methods by which we can detect changes in provisioning in the archaeological record.