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Open Field, Common Pot: Harvest Variability and Risk Avoidance in Agricultural and Foraging Societies

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My subject is composed of two disparate pieces with an equation in common. The pieces are separated by geography and culture; time and economic mode of production; and by academic discipline and literature. These differences are manifest and important; the feature that they have in common is somewhat more subtle.

The first piece concerns peoples of the Midlands of England and the Middle Ages of English history, people who engaged in the medieval mode of agricultural production known as the open or common field system, a subject studied mainly by economic and social historians. The second piece focuses on those geographically dispersed populations which gain their subsistence by hunting and gathering, groups studied mainly by anthropologists and archaeologists. The link which unites these dissimilar peoples is the concern of each with subsistence risk, the possibility of harmful shortfalls of harvest induced by unpredictable or stochastic factors in their environment. Climate fluctuations or episodes of pestilence are examples. This similarity and a particular analytical insight are what give the paper a cohesive objective.

I will propose that the same model for risk minimization through the pooling of spatially separated harvests illuminates both of these situations, and that this analytical likeness may provoke insights about the differences between them. The open fields of pre-modern agriculture and the common pot of modern hunter-gatherers may serve the same function, albeit with quite unlike appearances and consequences. The model which captures this

commonality may afford an advantageous perspective from which we can better scrutinize the ways in which food production and food gathering are different.

Hegmon (1987, 1988, n.d.) independently has developed a simulation analysis of inter-household sharing in agricultural societies, with special attention to the advantages of "restricted" sharing, to which the reader is referred.

THE COMMON FIELD SYSTEM AND RISK

In the centuries prior to 1700 the agricultural area to the north and west of London was characterized almost uniformly by the open or common field system of land tenure (my summary is based on McCloskey 1975a, 1975b, 1976, 1986). In the period from 1700 to the mid-19th century, over 5,000 separate Acts of Parliament and equal numbers of private arrangements led to the division and fencing of these once community lands. These Acts of Enclosure were coincident with the early stages of the industrial revolution. They mark a convulsive period in English socio-economic history. Scholars have seen in this painful transformation of the English landscape most of the issues raised by the development of the industrial state and market economy: rationalization of the means of production according to a market model; the clash of class interests; break-down of an allegiance to egalitarianism among the English peasantry; the imperative of technological progress.

Although the variations were numerous, the open field system had a simple general form: the lands of a community were divided into common meadows and wastelands, and three great fields, rotated among wheat, barley (or sometimes corn) and fallow. Every family held land in each of the great fields. A family's tenure within each field was divided into perhaps a dozen or more small, widely separated parcels, laid out in long narrow strips. Seldom were two plots contiguous, but if one takes account of the occasional instances of parcels located in close proximity to one another, the household count of plots reduces to an "effective number" of about eight, still an impressive degree of scattering. Decisions about agricultural scheduling, field boundaries, irrigation, and grazing rights were made and enforced communally. Variants of the open field system have had long histories, not only in central England but throughout northern Europe and much of the third world, where often they have persisted until today.

Explanations by social and economic historians of the origin, maintenance and eventual dissolution of this agricultural system are as diverse as those which adhere to any equally complex and refractory topic studied by anthropologists. They range from the ideological (egalitarian sympathies

on the part of the English peasantry), to the social (partible inheritance) to the "vulgarly materialist" (the large number of oxen required to pull heavy medieval plows). Economists and historians usually have agreed, however, on one point: the open-field system represented excessive, inefficient, and irrational dispersion of agricultural plots. The time required each day to move tools and labor among the numerous miniature parcels is only the first of a long list of economic evils adhering to the system. These include deleterious neighborhood effects, waste of land in balks or sykes, the indirect costs of uniform scheduling and planting practices, lack of correspondence between personal effort and reward, and so on. As stated in a standard preamble to the enclosure acts, the parcels "lie inconveniently dispersed and intermixed, and in their present situation are incapable of improvement" (cited from McCloskey 1975a:82).

Risk management as a rationale for dispersion occasionally has entered the debate on open fields, but it has taken the analytical models and quantitative research of Donald McCloskey (1975a, 1975b, 1976, 1986) to make a convincing case for this interpretation. McCloskey has calculated the cost of scattering to be a 10% drop in the average efficiency of production. This is a disturbing figure in communities which experienced chronic food shortages and occasional starvation. The benefits of field dispersion are a corresponding reduction in the variance of the annual harvests, a result of pooling the output of separated fields. If plots are environmentally distinct (an upland substrate of well-drained soils adjacent to a bottomland with greater water retention capacity), or if spatial separation exposes them to different climatic or pathogenic conditions (the hailstorm that cuts a swath through the north but not the south and west fields), then a harvest which draws from dispersed locales will tend to even out the stochastic factors affecting production.

Because both costs and benefits of dispersion are a function of the number of dispersed parcels, they can be related in an optimization format. When all of the relevant factors are brought together, McCloskey predicted that the optimal number of fields was 8.3, strikingly close to the measured average of 8. McCloskey (1975a:115-116) concludes:

The inefficiencies of the open fields were premiums on an insurance policy in a milieu in which agricultural yields were low and unpredictable, and in which the costs of a shortfall—at best crushing debt or malnutrition and its associated diseases, at worst starvation—were high... The explanation in terms of risk aversion predicts correctly not only that scattering would have existed, but that it would have existed to the approximate degree that, in fact, it did.

McCloskey's formula for calculating the effects of field dispersion on the variance of the aggregate harvest is of special interest. It is the unifying axis about which the two parts of this analysis turn. Simplified from finance theory, it takes this form:

$$\sigma = s \left[\frac{1 + (N - 1)R}{N} \right]^{0.5} \quad (4.1)$$

Where:

- σ = c.v. (coefficient of variation) of the net consumption rate (NCR) for a family after pooling the yield of dispersed fields.
- s = c.v. of yield from an individual plot.
- N = number of dispersed plots.
- R = average correlation in yield between any two plots.

Some simple substitutions will show how this equation behaves. In the trivial case of $N = 1$, $\sigma = s$. With a perfect positive correlation among all plots ($R = 1$), then again $\sigma = s$. If all fields fluctuate together, dispersion and pooling cannot reduce variations in the annual harvest. With no inter-plot correlation ($R = 0$), $\sigma = s/\sqrt{N}$. Yield variation falls off, but at a decreasing rate as the number of plots increases. For positive values of R ($\neq 1$ or 0), as N gets large there is an asymptotic limit at ($\sigma = s\sqrt{R}$) to the reductions which can be gained through sharing. Finally, if $R = -1$, then an N of 2 reduces σ to zero. With a perfect inverse correlation in their annual yield, it takes only two plots to eliminate any variation from their aggregate product.

This equation and analysis has an exact analog in the foraging mode of production; we will return to it further along.

HUNTER-GATHERER SHARING AND RISK

Independently of the economic historians, biologists and anthropologists working with foraging theory (Stephens and Krebs 1986; Stephens, this volume; Kaplan and Hill 1985a; Winterhalder 1987; Smith 1983) also have started to examine the effects of risk on subsistence behavior. This group of evolutionary ecologists shares with economists like McCloskey a penchant for formal assumptions and simple analytical models. In this case the models attempt to predict the subsistence behavior of foragers, including what resources they will select, how they will use and move through an environment of spatially differentiated resources, and how ecological conditions will affect the formation of groups and location of settlements. This work

has some theoretical and methodological parallels to micro-economic theory. But it aims to establish a micro-ecological approach to hunter-gatherer production and consumption choices in an ecological setting, whereas the latter addresses producer and consumer behavior in a market setting.

One of the first of these foraging models was the diet breadth model. This model has been used successfully in a variety of field analyses (Smith 1983; Winterhalder 1987; Hill et al. 1987). The environmental parameters incorporated into the model are constants, typically an average of some factor like the density of a prey species. Thus, in the "deterministic" world of the diet breadth model the forager encounters the average density of prey in every kilometer it searches. The assumed goal of the forager is to maximize its net acquisition rate (NAR) of energy or some other food "value" while foraging.

However, using the same concepts and methodology we can ask what is the resulting prediction if we build the same model with environmental parameters that are allowed to vary stochastically, and with the premise that the forager's goal is to avoid the risk of starvation or serious food shortages. That is, what hypotheses would we make about hunter-gatherer diet choice if we assume a risk-minimizing rather than rate-maximizing forager (Winterhalder 1986a, 1986b)?

These questions bring us more directly to the hunter-gatherers who are the topic of anthropological study, the second of my pieces. Although we now move from central England to the Kalahari of Southern Africa or to the neotropical rainforests of Paraguay, the inquiry eventually will take us back to McCloskey's analysis of fields and the equation just described. My route to this closure has three steps:

1. I describe a general means of relating the goal of risk minimization to mean and variation in the food acquisition rate associated with different subsistence choices.
2. I then apply that general method to the question of forager diet choice, using simulation techniques to provide a stochastic analog to the deterministic model of food selection.
3. This exercise leads me to a more general mathematical analysis of foraging and food sharing, using McCloskey's equation.

(1) A GENERAL RISK-AVOIDANCE MODEL

The key to a general risk-minimizing model for hunter-gatherers lies in recognizing that each foraging choice has a mean or "expected value" and a

variation about that mean. Here the choice is which of the resources encountered while foraging to pursue and consume; the value of the resources is measured by the net acquisition rate (NAR) of energy. The variability in NAR is due to fluctuations in prey encounter rate or to other stochastic factors affecting foraging success over time. We can portray this situation by assuming that each choice generates a normal distribution for the NAR, with an expected or mean value (μ) and a standard deviation (σ) (see Figure 1 in McCloskey 1976).

Risk is taken to be the probability of falling below a fixed minimum requirement, defined by m . This minimum threshold might be starvation or some less catastrophic cost to fitness or adaptation. Because we have chosen a normal distribution for our stochastic NAR, we can measure risk with the standard normal deviate (Z). Graphically, the probability of dropping below the minimum requirement is represented by the area beneath the tail of the normal curve and to the left of m . The optimal diet choice is that associated with the distribution which minimizes this area by minimizing the standardized Z -value.

It is evident that risk depends jointly on the mean and the standard deviation of the food capture rate. Both must be considered in assessing risk. This allows us to refine a commonly applied but potentially misleading "rule-of-thumb," to the effect that generalizing the diet by increasing its variety reduces risk. It may, or it may not. Risk reduction may be achieved in some circumstances by specializing strategies (see below). The "rule" seems to be based on the reasonable but implicit proposition that a greater number of food sources reduces the overall variance in their harvest rate. Even if this is the case, it neglects the possibility that greater generalization also reduces the efficiency of food acquisition. The former effect diminishes Z and risk; the latter increases Z and risk; the overall result can be determined only by an appraisal of the two effects taken together. Comparison of normal distributions is a handy means of doing this.

Stephens and Charnov (1982; Stephens and Paton 1986; Stephens, this volume) give a more elaborate and mathematically formal derivation of the same result, calling it the "z-score model." They also develop a convenient way of depicting the interrelationships among σ , μ , and Z . Basically, the formula for calculating Z ,

$$Z = (m - \mu)/\sigma \quad (4.2)$$

can be rearranged to the format of the linear slope-intercept equation, $y = ax + b$:

$$\mu = m - Z\sigma \quad (4.3)$$

This allows us to depict the three variables of the z-score model on an x - y plane. The minimum intake (m) is the y -intercept, Z is the slope

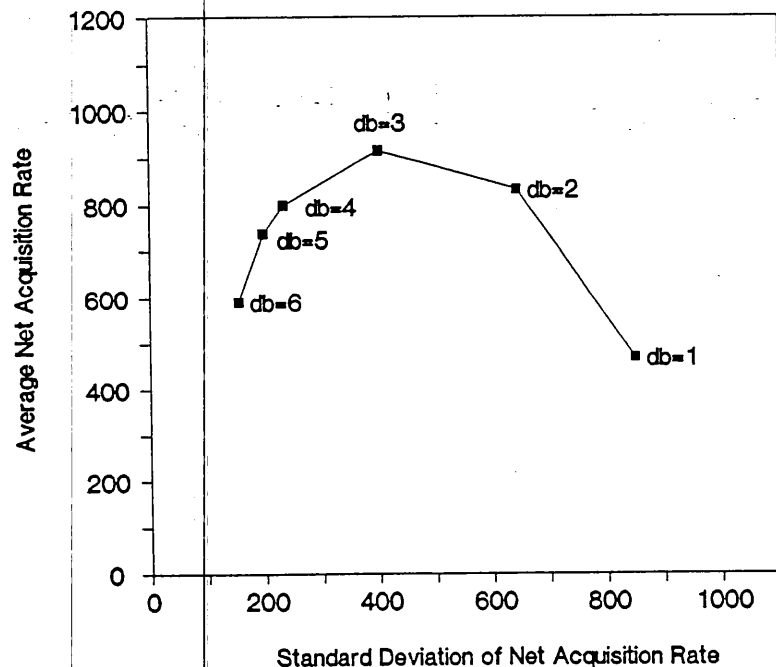


Figure 4.1: Simulated Diet Selections [for a Diet Breadth (db) of 1 to 6 Items] in the Z-Score Format (See Tables 4.1 and 4.2)

of the line. Each (x, y) point in the plane is a s.d./mean combination (σ, μ), representing the food reward distribution associated with a particular subsistence choice (Figure 4.1).

In this graphical format, risk is minimized as the slope of the line in the diagram rotates counter-clockwise. The optimal risk-minimizing choice is that with a s.d./mean pair intersected by the line of greatest slope extending from m . Note that the mean and s.d. fully define a normal distribution, and that each distribution uniquely characterizes what interests us about the associated foraging choice, that is, how well it avoids risk.

(2) DIET CHOICE AND RISK AVOIDANCE

In order to apply this model, we must establish the mean and s.d. of the energy NAR for each of the foraging choices. In the diet selection model two variables can exhibit stochastic properties: prey encounter rate (as determined by relative density) and prey pursuit time. A direct analytical

solution for the stochastic version of the model is mathematically unwieldy, but the same result can be obtained by programming a computer to simulate the solution (Winterhalder 1986a, 1986b). This means iterating calculations of foraging NAR for each potential diet, with the prey densities and pursuit costs for each iteration determined stochastically. A set of these iterations provides the sample for calculating the mean and s.d. of foraging efficiency for the various diet choices.

On the ground, this method envisions a forager moving through a habitat of randomly distributed prey. The density of each prey type encountered per unit area will be a stochastic, poisson variate with a mean equal to the average density per unit area. The time it takes to pursue and capture a prey item is given by a stochastic normal distribution (with a constant coefficient of variation). By use of a random number generator, filtered through the appropriate probability distribution, the computer model creates a partially unpredictable world for the hunter-gatherer. The simulated forager minimizes risk to the extent that its prey selection avoids the chance of a very poor NAR in each of a string of foraging intervals.

Table 4.1 shows the parameters which characterize the six prey types and the forager inhabiting the model. The values assigned to these parameters are scaled so that they are realistic for a hunter-gatherer (see Winterhalder et al., 1988). Table 4.1 also shows the non-stochastic analysis of this situation. Prey types are ranked by their net return rate for pursuit and handling (e/h). E gives the overall foraging efficiency of a diet which begins with CPREY and sequentially adds the ranked types to the group which is pursued when encountered. The optimal diet includes C, D and FPREY, or in the language of evolutionary ecology, a diet breadth (db) of three items. Pursuit of an encountered item ranked below FPREY returns less than 976 kcal/hr, and thus would lower the overall NAR of the food quest.

Table 4.2 shows the stochastic analysis of the same situation and set of choices. Each diet breadth now has a mean and a standard deviation. Note that the average value for stochastic diet breadths of 1 and 2 is significantly below the corresponding values in the non-stochastic case. When prey types are rare, as is the case for CPREY and DPREY, the forager in a stochastic environment will occasionally encounter no prey, and suffers a negative return rate equivalent to the rate of energy expenditure on the unsuccessful search.

The results of the simulation are presented in the format of the general z-score model in Figure 4.1. The configuration of the s.d./mean set is parabolic and concave downward. The diet choices from 1 to 6 are positioned around it counter-clockwise. For values of m between about 700 and 1100 kcal/hr, those slightly above to somewhat below the average NAR,

Table 4.1: Forager and Prey Characteristics, and Deterministic Foraging Analysis

CHARACTERISTICS OF THE PREY				
Name	Energy Value (kcal)	Pursuit Time (min)	Pursuit Cost (kcal/min)	Prey Density (#/km ²)
CPREY	10,800	235	6	0.7
DPREY	3,600	95	6	1.5
EPREY	2,800	174	6	5.0
FPREY	1,500	67	6	5.0
GPREY	240	26	6	30.0
HPREY	90	7	6	50.0

CHARACTERISTICS OF THE FORAGER

Velocity:	5.0	km/hr
Search radius:	0.0175	km
Search cost:	4.0	kcal/min

OPTIMAL FORAGING ANALYSIS, NON-STOCHASTIC CASE

Name	Rank (e/h) (kcal/hr)	Foraging NAR (E) (kcal/hr)
CPREY	2397.4	615.1
DPREY	1913.7	899.9
FPREY	983.3	928.2
..... Boundary of the Optimal Diet		
EPREY	605.5	776.9
HPREY	411.4	718.9
GPREY	193.8	581.7

Table 4.2: Stochastic Foraging Analysis (all parameter values as in Table 4.1)

Prey Type	Foraging NAR	
	Mean	s.d.
CPREY	468.9	849.5
DPREY	832.6	642.4
FPREY	916.9	400.4
EPREY	800.0	233.3
HPREY	737.0	198.0
GPREY	591.9	154.9

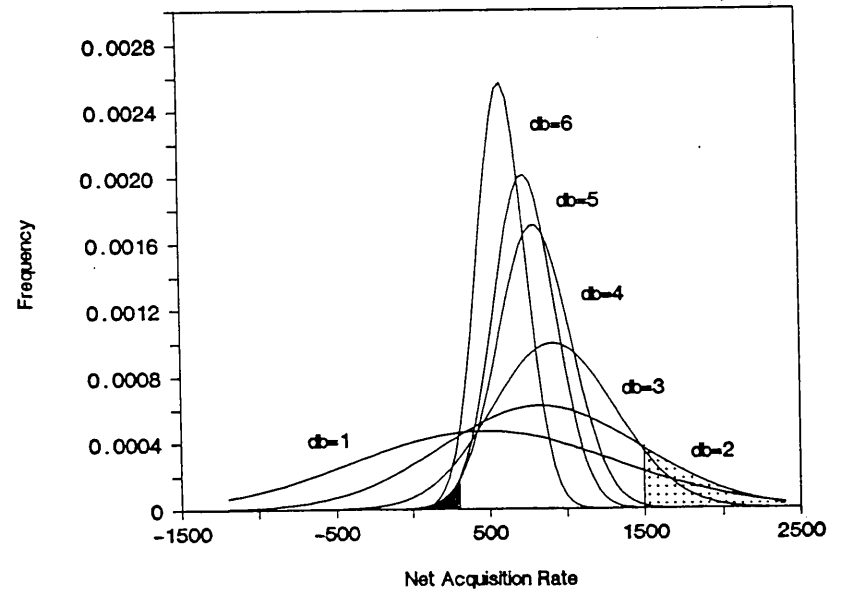


Figure 4.2: Simulated Diet Selections Represented as Normal Curves (See Figure 4.1, and Tables 4.1 and 4.2), Using the Mean and Standard Deviation of the Z-Score Model

the optimal risk-minimizing diet choice converges with the rate-maximizing choice of three prey types. If the forager's minimum requirement is a fair degree below what it can expect on average, say < 600 kcal/hr, the risk-minimizing diet expands to 4, 5 or 6 prey types. The forager sacrifices efficiency for reduced variance. Conversely, if for some reason the organism requires more energy than it can expect on average, say $m > 1100$, the model predicts that it will contract its diet breadth and take only the top two prey types. In this latter circumstance, the forager's best choice is to trade a small loss of expected efficiency for high variance (Hawkes, this volume, offers another situation in which foragers might prefer a high-variance strategy).

The z-score model is simply a handy way of representing and comparing the normal distributions which comprise our risk-minimization model. The curves themselves are shown in Figure 4.2, for the same data as portrayed in Figure 4.1. The peak (central tendency, or average value) of the distributions increases up to $db = 3$, then diminishes; their width, (or variance) steadily diminishes from $db = 1$ to $db = 6$. Two points are worth empha-

sizing. First, a few “what if” experiments with these curves will affirm a point made earlier: generalizing the diet by increasing the variety of prey consumed does reduce variance in the NAR, but its effect on risk depends on the expected value of each alternative (μ), and on the threshold, m . Secondly, in some instances we can use the curves themselves to determine the optimal risk-minimizing diet. Thus if $m = 300$, a $db = 5$ offers the lowest probability of failure (dark shading). Conversely, if $m = 1500$, then a $db = 2$ offers the greatest chance of success (light shading). However, for many values of m , the best choice is not immediately evident from this thicket of curves. These instances allow us to appreciate the utility and elegance of the z -score format used in Figure 4.1 (Stephens and Charnov 1982).

(3) A GENERAL MODEL OF SHARING AND RISK REDUCTION

We have identified the “best choice” diet, but it is also important to know if that choice is good enough. How well can our optimal risk-minimizing forager avoid a shortfall by adjusting his or her selection of resources? How dangerous is the peak of the z -score curve and how much safety is gained by moving off the peak to a selection which trades high NAR for the advantages of greater or lesser variance?

If we assume a minimum requirement of 500 kcal/hr and the optimal choice of 4 prey types ($\mu = 800$; $\sigma = 233.3$; Table 4.2), then reference to a cumulative normal distribution table shows that 10% of the foraging intervals will fall short of the threshold [$Z = (500 - 800)/233 = -1.28$; $G(Z) = 0.10$]. In fact, of the 100 foraging intervals actually simulated, 8 had values below the minimum of 500 kcal/hr. The best choice may not be a good one, or even good enough. This will be especially true for organisms like humans with a long life span relative to the frequency with which they must procure something to eat. The problem is this: for the case in which $m < E$, the forager which moves away from the rate-maximizing diet in order to reduce variance, also forfeits average foraging efficiency. Even as the threatening tail of the curve gets tucked in toward the mean, the whole curve shifts in the direction of danger. The converse problem arises if $m > E$. To minimize risk by varying prey choice, even optimally, is not always to avoid the untoward outcome.

The shortcomings of diet selection as a means of avoiding risk return us to McCloskey's analysis. Pooling and division of the catch of separate foragers is an effective way of circumventing this limitation. This can be demonstrated by adapting McCloskey's equation to the circumstances of foragers. For year-to-year variability in yield of an agricultural plot, we

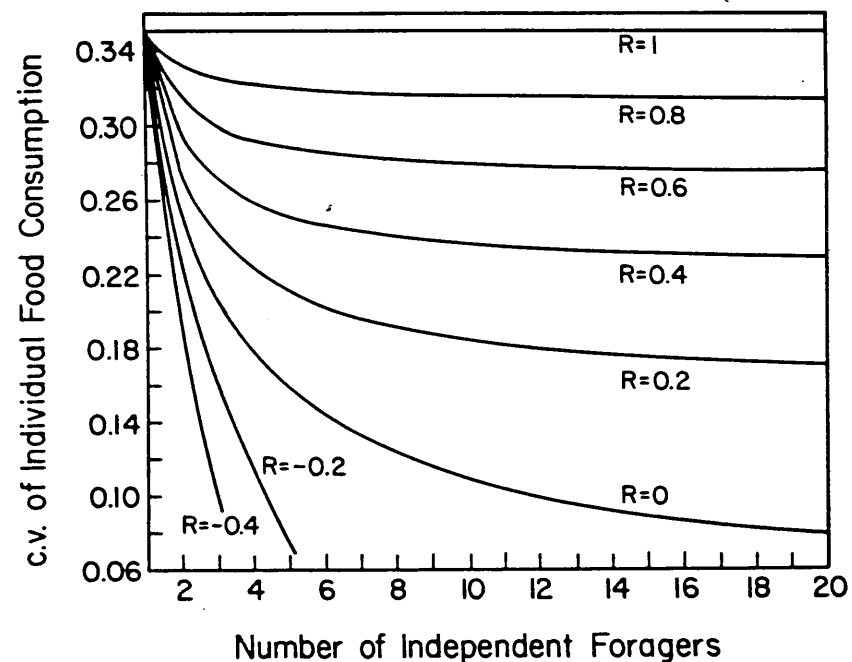


Figure 4.3: Reduction in Net Consumption Rate (NCR) Coefficient of Variation (σ) as a Function of Inter-Forager Correlation (R) and the Number of Sharing Foragers (N). (Winterhalder 1986b, used with permission of Academic Press.)

substitute a forager with trip-to-trip variability in his or her harvest (s); for the correlation between dispersed parcels of land, we substitute the daily correlation among the results of separate foraging expeditions (R); for the family larder, wherein the product of numerous parcels of land are pooled, we substitute the cooking pots of a band, wherein the proceeds from the day's food quest are combined and shared. In this new circumstance, N is the number of independent foragers who contribute to the sharing, rather than the number of dispersed plots. The objective is to determine how variation in the net consumption rate (NCR) of sharing foragers is affected by: (i) day-to-day variation in the NAR of one forager; (ii) average inter-forager correlation of NAR in each foraging interval; and, (iii) number of foragers participating in the sharing group.

Figure 4.3 graphs equation 4.1 for different group sizes ($n = 1, \dots, 20$) and a range of negative and positive inter-forager correlations ($R = -0.4$ to $+1.0$). s , the NAR c.v., is 0.35, roughly that experienced by the risk-

minimizing forager simulated earlier (Tables 4.1 and 4.2). For $0 \leq R < 1$, there is a continuous decrease in the NCR variation as group size grows. The major gains in risk reduction occur for relatively small values of N . At $R = 0.2$, for instance, 80% of the potential risk reduction from pooling and division can be gained by only 6 cooperating foragers. For modestly negative values of R , even smaller numbers of individuals (e.g., 3–5 foragers) can achieve dramatic reductions in the variation of their pooled catch.

There is a simple and yet more general way of demonstrating the effectiveness of sharing in small groups. As the sharing unit grows in numbers, the marginal amount that each new member reduces NCR variation diminishes rapidly, due to the asymptotic form of the curves. The third forager to join the sharing group brings a clear reduction in NCR variance, the fifteenth does not. At some point the *disadvantages* to increasing group size (e.g., more rapid localized depletion of prey) will offset the small marginal benefits gained by sharing. We might ask, then, what number of pooling foragers is necessary to obtain some fixed proportion of the potential gains to be achieved by sharing? Posing the question in this form has a handy mathematical consequence—it eliminates both σ and s from equation 4.1, allowing expression of N as a direct function of R (see Winterhalder 1986b).

The graph produced by this exercise (Figure 4.4) has four curves, depicting a 50% to an 80% reduction ($k = 0.5$ to 0.8) in the NAR c.v. Each curve spans R values from -1.0 to $+1.0$, the full range of environmental possibilities for inter-forager correlation. Although there is a sharp narrow peak in N as R approaches zero, it is striking that small and relatively invariant numbers of sharing foragers can achieve a large proportion of the potential reduction in NCR variance. For example, six or fewer sharing foragers can achieve 60% of the potential benefit, whatever the inter-forager correlation (R). This means that the conclusion about small group size is relatively insensitive to R .

To the extent then that pooling and division of independently acquired resources can reduce consumption variance, it can do so with quite limited numbers of participants. For negative or low to medium positive values of inter-forager correlation (R), small group sharing is very effective at reducing NCR variance. For high positive values of R over the group's foraging range, it is much less effective and foragers must rely on other means of risk mitigation. An important one is reciprocal access (Smith, this volume) through group movement or trade to areas which because of distance or ecological dissimilarities are not positively correlated to a high degree.

Observe, however, that somewhat the same result is available to one forager able to store and carry over the surplus from above-average days. The sharing group consumes a pooled average; the provident individual

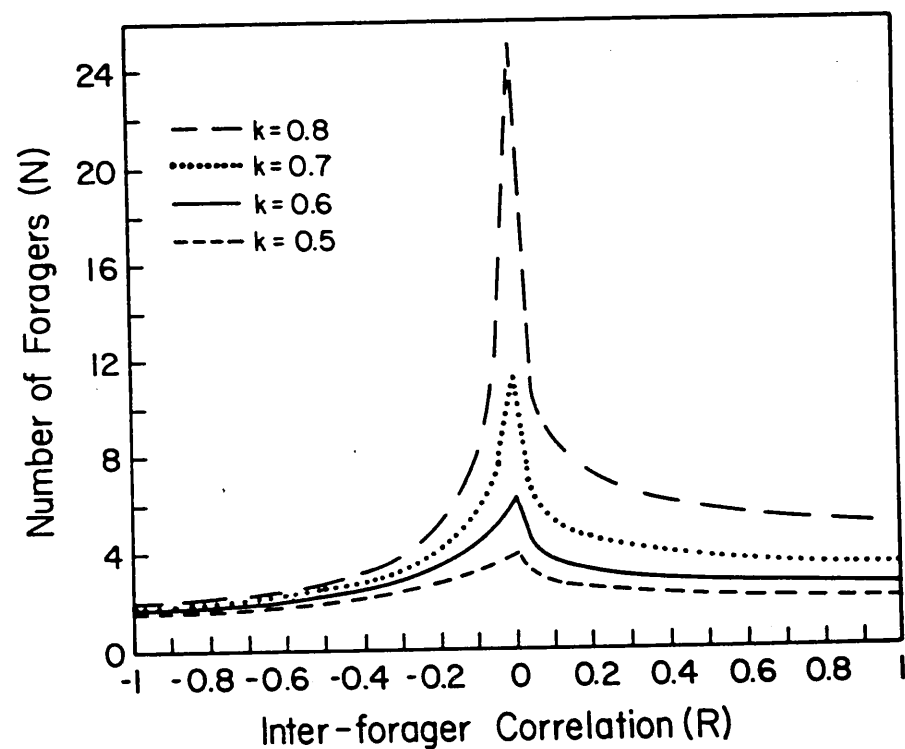


Figure 4.4: Number of Sharing Foragers (N) Required to Attain a Fixed Proportion ($k = 0.5$ to $k = 0.8$) of the Potential Reduction in NCR Variation, as a Function of the Inter-Forager Correlation (R). (Winterhalder 1986b, used with permission of Academic Press.)

consumes a running average. But these are not exactly equivalent because of the factor of time. The individual practicing sequential pooling may not be able or willing to tolerate the accumulated effects of a run of several bad intervals, whatever the statistician's reassurances about the "long term." Because a sharing group averages within time intervals, the benefits of such statistical reassurance are gained more quickly. Further, group pooling still allows for carry-over when surpluses are available.

Two observations will lead me to a discussion of these results. First, although the size of local foraging bands varies greatly, there is a close correspondence between the average number of members that would be predicted from a simple risk-minimization argument and that observed by anthropologists. Local bands appear to converge on an average size of about 25-30 individuals (Hassan 1981:61), a group of the right magnitude to provide the 6 to 8 productive foragers ideal for risk minimization. Second, it now is apparent that the match between the predicted and observed degree of field dispersion is more general than McCloskey's empirical analysis of Midlands records might suggest. By applying a marginal analysis to equation 4.1, we can predict an effective number of about 8 dispersed fields, even if unsure of the environmental details affecting inter-plot correlations and intra-plot fluctuations. If I may summarize the hunter-gatherer result by paraphrasing McCloskey, an evolutionary ecology approach to foraging efficiency and risk reduction not only predicts that intra-band sharing would exist, but that it would exist in bands of the approximate size that, in fact, it does.

SUMMARY

Hunter-gatherers typically live in small groups which share food. Their environment presumably is unpredictable to some degree (Low, this volume); subsistence risk-minimization may have been an important factor in their foraging decisions. There appears to be a rough convergence between rate-maximizing diet choices predicted by deterministic models, and the most effective, risk-minimizing choices revealed by their stochastic analogs. Thus, if we could give a forager only one piece of very general advice on risk it might be this: doing well by the averages often is an excellent way to avoid the rare instance of doing very poorly.

To continue in the pedagogical mode, we could make our advice somewhat more reliable by giving our forager a z-score model and apprising him or her of the trade-offs between the mean and variance of the available diet choices. This will improve the odds of avoiding a shortfall, but even the best risk-minimizing diet choice available to the individual organism may not avoid critical shortages over the long term. The forager who both captures and consumes food independently may be able to reduce its

subsistence risk to only a limited extent by adjusting prey selection.

Our best advice would be to pool and divide the harvest of a small group of foragers. But of course it appears that foragers found this out long ago. Band-level sharing is observed to be a regular feature of the hunter-gatherer societies studied by anthropologists (summary and references in Kaplan and Hill 1985a; Kaplan et al., this volume). In fact, based on these ecological models we can suggest a fundamental division in the economy of hunter-gatherers: production decisions will emphasize high harvest rate whereas distribution will emphasize sharing in order to achieve low consumption variance.

DISCUSSION

Temporal fluctuations in food intake can be dramatically mitigated if the diet is drawn from dispersed and imperfectly correlated sources, be those separated fields or independent foragers. In either case, a risk-minimization hypothesis predicts that the sources will number roughly 6-8. In this respect, the open fields of the English Midlands and the common pot of extant foragers may be adaptive analogs, different manifestations of a similar ecological function. The correspondence itself is interesting, an analytical nugget to be found in both of the disparate pieces with which we began. However, it may be more instructive to use this similarity to raise, from a fresh perspective, questions about the vast differences between these two situations.

One question is this: Why don't farming communities, such as occurred in the Midlands, pool and divide as do foragers, with each family unit sharing their harvest with other local households? It appears that were they to do so, they could effectively reduce risk *and* avoid all of the inefficiencies associated with field dispersion. What constraints or costs might have prevented this from occurring? Or conversely, why do foragers seem to find it necessary or advantageous to manage risk by pooling among, rather than by applying some tactic within, productive units? In effect, why is intra-group sharing rather than some other form of self-insurance the norm among human foragers?

We might gain some initial purchase on this question by considering the set of possibilities represented in a 2 X 2 table (Figure 4.5), forager and farmer set against the possibility of risk management within or among the family production units. The regular ethnographic association of foraging with intra-group sharing locates hunter-gatherers in the lower left cell. To the extent that analogs of the common field system were widespread in early Europe and are so in third world regions today, then we can place pre-modern farmers in the upper right cell, a categorization which may

		Mode of Production	
		Forager	Farmer
Means of Risk Management	Within Family Units	cell 1 ?	cell 2 Common Field System
	Among Family Units	cell 3 Hunter-Gatherers	cell 4 ?

Figure 4.5: Risk Management within and among Family Production Units of Foragers and Food Producers

not apply if political or market institutions provide some other type of insurance.

The questions now can be reformulated: Why are the lower right and upper left cells empty? What factors account for the fairly tight association between production mode and form of risk management? Some provisional hypotheses may be elicited by comparing forager and farmer with respect to the parameters of the risk-minimization formula, temporal and spatial scale, structural constraints, and costs and benefits. Of course, this casting of the problem imposes a rude, dichotomous typology on the evidence, and it blurs the issue of what constitutes a family or household in the two cases, but a general inquiry requires some abstraction. The particulars will not be damaged by their temporary exile.

In McCloskey's formula (eq. 4.1), s gives the variation of yield. Comparative evidence on the size of this variable in foraging and farming societies sorely is needed (Hames, this volume, discusses differences in variance associated with the foraging, fishing and horticultural activities within a particular group). Still, it seems unlikely that there will emerge a consistent and clear dichotomy in the magnitude of the vagaries affecting foragers and pre-modern food producers. Further, while s affects the need for some

kind of risk-minimization, it appears not to determine the form of the solution. Temporal variance of yield, however large or small, does not in itself direct us toward toward intra- or inter-family pooling.

We can take the argument further by noting that s is important only as it affects Z ; s measures yield variance, but Z measures risk. This directs attention to μ and m , or more precisely, to $(\mu - m)$. It might be the case that foragers and food producers are dissimilar in terms of this measure of the difference between expected NAR and a disastrous NAR. Recent studies (e.g., Hill 1982) have shown foragers to have a fairly high food capture rate relative to minimum requirements. In contrast, McCloskey's investigation of 18th Century agriculture indicates that m was as high as 0.5μ . Pre-modern agriculturalists may be more sensitive to yield variation than are foragers because their margin is much smaller. This is a point worth investigation, but not one holding insights for the immediate question. A given degree of yield variance may be riskier for farmers than for foragers, but our inquiry begins with the assumption of significant risk in both cases. Neither the value of s nor its impact on Z tells us which form of risk management to predict.

The scale of the temporal variation relevant to foragers and food producers is more promising. A foraging trip is relatively short; it occurs over hours or days. Measured from initial effort to potential yield, the duration of the forager's *production interval* is less than or at most about equal to the starvation interval, the time a hunter-gatherer can survive and function on endogenous reserves. In contrast, the production interval of food producers dependent on annual crops is much longer than the capacity to persist unfed. Here the measure is months or a year for annual crops. The hunter-gatherer will survive two days of unsuccessful foraging trips; the food producer will not survive two years of no yield.

I see two lessons in this difference of scale. First, carry-over averaging (above and Winterhalder 1986b) which may entail food-processing and storage will be more effective for foragers than for food producers. I refer here to food stores accumulated because of production risk, and not those meant to even out predictable seasonal changes in food availability. The forager can average over 6 to 8 foraging trips more easily than the agriculturalist can average over the 6 to 8 annual cycles it would take to get a substantial amount of variance reduction. In addition, food producers must be able to preserve their surplus for much longer periods and in larger amounts, and must defend these attractive stores from the depredations of landlords, tax men and vermin.

Second, any insurance scheme based on averaging among units entails the cost of potential shirking by the participating individuals. Is Ben slackening off because his livelihood is secured by the more dedicated efforts of

his neighbors? Is the poor yield of his crops due to avoidable or unavoidable failures? Dispersing responsibility for production may dissipate the incentive of each to be a devoted producer. Of course this affects both foragers and agriculturalists, but hunter-gatherers may find it easier to control potential laggards. Not only is the group smaller and more isolated, but the short production interval allows for quick assessment, sanction and correction. Action can be taken before the imbalances grow and resentments harden. In fact, ethnographic studies show that hunter-gatherers devote considerable social energy to the maintenance of sharing and a relatively egalitarian ethic (Cashdan 1980). In contrast, social control may be less effective when the production interval is measured in years, and the perceived imbalances are of greater and longer significance. Ben's neighbors will have to provide months of subsidy and wait many annual cycles to amass a sample large enough to separate his failures from nature's vagaries.

To summarize, the values of s , μ and m determine the degree of risk and hence whether a case enters our inquiry about the form of the risk management. But these variables do not in themselves allow us to predict whether intra- or inter-family pooling will be the most effective response. More promising are the different temporal scales of the production interval affecting foragers and farmers. Because of their short production interval, it is easier for foragers to practice carry-over averaging, although this alternative is not so attractive as to move foragers into cell 1 (other things being equal, carry-over averaging will never be as effective as sharing for the simple reason that hunger is not as patient as a statistician; see discussion above). And, because of their long production interval, it is difficult for food-producers to control shirking, as would be necessary if they were to pool and average among households.

R , the correlation among sources of yield, is the second variable of interest. While data on R in different environments and modes of production will be of great interest, it is not likely to be potent in this inquiry. R determines the effectiveness of pooling and division, but not whether the result is best achieved within or among family units.

However, scale again might provide some clues. The roughly eighty families of an open-field community exploited an area of about 5 km²; the eight families of a foraging band might exploit a range of 500 km². Measured as density this is a rough thousand-fold difference. Hunter-gatherers must cover a much larger area to find their keep. This imposes on the forager high travel costs and the need to maintain knowledge of a large region in order to search for resources which are evasive and already well dispersed.

Although foragers cover a wide range, their use of space is subject to a peculiarly local constraint. Typically, hunter-gatherers can realize the opportunities of a location in the environment only when there. Prey are

mobile and elusive and must actively be located and caught in person. Except as male and female may go different ways, the foraging family can't simultaneously multiply itself over the landscape like the farmer can multiply dispersed fields. This is a structural constraint that partially closes one opportunity to envision foragers with intra-family pooling (cell 1).

I used the qualifier "partially" for the reason that traps and gathered vegetable foods allow for a degree of simultaneous dispersal. With a trap a forager can multiply his or her capture opportunities as a predator. However, a trap is unlikely to be as effective as the real thing, so it might take many of them to duplicate the forager even once. Still, we might hypothesize less frequent or more restricted sharing in foraging societies in which traps are a prominent part of the foraging technology. Gathered vegetable foods, if they are a more predictable, localized and concentrated source of energy, may act more like dispersed fields, offering opportunities for intra-family insurance.

N , the third variable of the equation, would be significant for our inquiry if the number of foragers or farmers' fields needed to achieve significant risk-minimization were greater than could be accommodated in local groups in either mode of production. In fact, I have made the argument that the expected number is equal to or smaller than the feasible number of foragers in a band or farmers in a medieval community. N appears to offer little opportunity for our explorations.

The analysis presented in this paper makes it fairly clear why foragers might find it advantageous to share (cell 3), despite the costs to individual production incentives. McCloskey's analyses make it evident how open field farmers benefited by field dispersion (cell 2), despite the losses associated with extra travel and other costs. The attempt to explain the empty cells (1 and 4) is more selective and provisional, but it points in several directions. The actual values of s , μ , m , R , and N may be of secondary importance at this level of generality. More important are the temporal and spatial scale at which these variables are expressed. The long duration of the farmer's production interval mitigates against an approach like that of foragers, using pooling among family production units. The large spatial scale of hunting and gathering and the limited ability of foragers to concurrently disperse their capture options inhibits them from controlling risk as do the agriculturalists, by pooling within the family production unit.

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