ADOPTION AND INTENSIFICATION OF AGRICULTURE IN THE NORTH AMERICAN SOUTHWEST: NOTES TOWARD A QUANTITATIVE APPROACH

David A. Phillips, Jr.

Qualitative models are unable to explain the known variability in the adoption and intensification of agriculture in the prehistoric North American Southwest. Adoption of a quantitative approach (specifically, a model based on marginal costs and benefits) better accounts for that variability.

Los modelos cualitativos no pueden explicar la variabilidad en la agricultura prehistórica del suroeste de Norteamérica. Un modelo cuantiativo, en base a costos y beneficios margenales, parece mejor explicar la variabilidad observada.

One of the perennial issues in the North American Southwest is the adoption and subsequent history of farming. Study of the issue is complicated by the variability in that history. At given moments in the past, people who used elaborate irrigation systems existed along with groups practicing the most rudimentary farming (and with groups who did no farming). Many areas that saw agricultural intensification later saw a reversal of that trend. Models based on qualitative reasoning—for example, claims that the adoption of agriculture was a mechanism for buffering subsistence risk—have great heuristic value. However, by themselves they do not seem able to explain the observed variability across time and space.

Quantitative approaches provide a way to incorporate the gains of previous qualitative models, while circumventing the limits of such reasoning.[1] This suggestion will not be news to scholars who have promoted quantitative approaches to social process (e.g., Earle and Christenson 1980; Jochim 1976; Keene 1981; Read 1990; Read and LeBlanc 2003; Reidhead 1979; Renfrew and Cooke 1979).[2] At the same time, I wish to make the case for quantitative reasoning in a manner accessible to those not trained in such reasoning. My intent is not to take sides in current debates but to illustrate (sometimes literally) a form of reasoning that may help us resolve such debates.

The Challenge: Agriculture Variability in the North American Southwest

Maize—the key cultivar in the Southwest, as in so much of the New World—reached the Southwest by roughly 2000 B.C. (Huber and Van West 2005; Mabry 2005b), so initial regional use of domesticates correlates (at least roughly) with the start of the Late Archaic period. As a consequence, many researchers now instead refer to an Early Agricultural period (Huckell 1995; Huckell 2006). Under either name, maize arrived in the region well before pottery.

We lack consensus on whether maize and other Mesoamerican species arrived with immigrant farmers (Adovasio 2005; Berry 1982; Coltrain et al. 2007; Huckell 1990, 1995; Matson 1991, 2003; see also Hyland et al. 2003:351) or were added to existing foraging strategies (e.g., Cordell 1979:33; Irwin-Williams 1973; Minnis 1992; Simmons 1986; Vierra 2008; Vierra and Ford 2006; Whittlesey and Ciolek-Torillo 1996; Wills 1988b). As Fish and Fish (1994:86) remark, however, "It is doubtful that any single model of [the foraging-to-

David A. Phillips, Jr. ■ Maxwell Museum of Anthropology, University of New Mexico, Albuquerque, NM 87131 (dap@unm.edu)

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farming] transition will prove adequate, given the environmental and probable Archaic cultural diversity of the Southwest." Instead, we need to invoke more complex models (Doolittle and Mabry 2006).[3]

Based on radiocarbon dates, Smiley (1994) argues that cultigens spread quickly once they reached the Southwest. Most archaeologists agree but are left wondering about the lag between the rapid spread of cultigens and the slower development of a heavy reliance on them (e.g., Dean 2005; Minnis 1985, 1992; Simmons 1986; Vierra and Ford 2008; Wills 1988a, 1988b, 1989, 1992). Until recently, many archaeologists perceived a regional lag of at least one millennium between adoption and heavy reliance. Given recent evidence, it may be more accurate to say that in some areas, maize become important over a span of 20 rather than 50 generations—but the lag remains. As Wills (2006:119–120) puts it, the introduction of maize "was followed by a fitful, uneven path to dietary dependence." As this pattern is not unique to the Southwest (e.g., Hastorf 1998a, 1998b; Johannessen 1984; Scarry 1993; Smalley and Blake 2003), models developed for this region have potential applications elsewhere.

One area where dependence came quickly was in southern Arizona, along permanent streams and in marshy areas (Diehl 1997, 2005; Huckell 1995; Huckell et al. 1994; Mabry 2005a; Roth and Wellman 2001). The same pattern extended into (or more accurately, from) Sonora (Carpenter et al. 2002, 2005). In northwest Chihuahua an early reliance on farming is also evident along arable floodplains (Hard and Roney 2004, 2005; Hard et al. 2006; Roney and Hard 2002). On the Colorado Plateau, heavy reliance on maize dates to the Basketmaker II period or En Medio phase, 800 B.C.–A.D. 400 (Chisholm and Matson 1994; Coltrain et al. 2006, 2007; Hard et al. 1996; Matson and Chisholm 1991). Maize also spread into central Utah, but only after another millennium had passed. Thereafter, Fremont culture dependence on agriculture was highly variable over both time and space (Barlow 2002:67–68; Coltrain and Leavitt 2002; Madsen and Simms 1998).

Matson (1991) suggests that the earliest regional agriculture was based on floodwater farming. Only by about A.D. 200–400 did "dry" farming become common in upland portions of the Colorado Plateau. By A.D. 500, some Hohokam were becoming heavily dependent on irrigation, a trend that culminated in the massive systems of the Classic period, A.D. 1200–1450 (e.g., Graybill et al. 1989; Haury 1976). Where irrigation was heavily used, however, it was one of a variety of techniques, among the Hohokam and elsewhere (e.g., Fish and Fish 1984; Fish et al. 1992; Maxwell and Anschuetz 1992; Toll 1995). The maximum diversity of techniques seems to have occurred late—after A.D. 900 (Maxwell 2000:153)—but by the time the Spanish began documenting regional agriculture, some of those techniques were no longer practiced.

Long after cultigens were part of the landscape, some groups farmed only casually or not at all. In eastern New Mexico, maize was unimportant through the first few centuries A.D. (e.g., Hard et al. 1996). In historical times, groups with a documented "minimalist" approach to farming included the Apache (Minnis 1992:130–131; but see Whittlesey 1997:712–713), Pai (Euler 1958), Yavapai (Gifford 1932, 1936), and Paiute (Euler 1966). Meanwhile, groups that had become dependent on farming retained their original reliance on wild foods. The early farmers of southern Arizona continued to depend on hunting, for example (Dean 2005). Even after building their extensive canal systems, the Hohokam relied on saguaro fruit and other wild foods (e.g., Bohrer 1970; Diehl 1997).

The Piman-speaking farmers who followed the Hohokam also made heavy use of wild food resources. Castetter and Bell (1942) estimated that the most agricultural of these Pimans, along the Gila River, obtained half of their food from farming. Even if this estimate is low (Gasser and Kwiatkowski 1991:419), it is clear that prior to modern times, the most agricultural Native Americans in the region derived a large fraction of their diet from wild foods.

Part of the story of Southwestern agriculture is its geographic limits. Farming spread into portions of California adjacent to Arizona (e.g., Lawton et al. 1976), but not beyond (Minnis 1992:121). Residents of the basins and plains along the eastern flank of the region made limited use of farming or remained foragers. Although environmental factors played a role in this distribution, there were no factors that strictly prohibited agriculture beyond its prehistoric limits.

Perhaps the greatest puzzle is repeated instances of de-intensification. Historical factors (including climate and demographic withdrawal or collapse) undoubtedly triggered these changes. However, some areas—rather than experiencing a simple decrease in agricultural production—saw the loss of carefully developed farming techniques or a complete reversion to foraging. The best-known example of "backward agricultural evolution" (relative to a landscape) is the withdrawal of pueblo-dwellers from southern Nevada, southeastern Utah, southwestern Colorado, and much of northern Arizona and northwest New Mexico (Plog 1976). Other instances abound, including the end of a number of traditions:

- Casas Grandes, centered in northwest Chihuahua (Whalen and Minnis 2001)
- Trincheras, centered in northwest Sonora (McGuire and Villalpando 1993)
- Mogollon occupation of the El Paso area (see Beckett and Corbett 1992)
- Hohokam in southern Arizona (see Ezell 1961)
- Prescott, Sinagua, and Cohonina in west-central and north-central Arizona (Schroeder 1976)
- Fremont of Utah (Coltrain and Leavitt 2002)
- the Mogollon occupations of southeastern New Mexico (Sebastian and Larralde 1989)
- the semi-sedentary hamlets of northeastern New Mexico (Glassow 1980)

Past explanations of Southwestern agricultural practice tend to focus on specific parts of the region, and to cite a single explanation for a single observed pattern. One recurring example of this approach is the attempt to explain why Archaic period foragers became farmers. The most widely accepted answer is that Archaic people used cultigens as a hedge against the unpredictability of wild foods (e.g., Ford 1981; Glassow 1980; Sanders and Webster 1978; Smith 1983:639; Wills 1988b). In a specific application of this concept, Diehl (1997:263) argues that "the occupants of the Tucson Basin valued maize principally because it minimized the risk of resource shortfalls" due to "exclusive reliance on ... wild foods." Wills (1992) has turned the argument inside out, arguing that wild foods buffered the risks associated with the adoption of farming. Such "risk reduction" models contrast with the formerly popular viewpoint that population increase, as an independent variable, drove the acquisition of new foodways to supplement existing ones (Hunter-Anderson 1986). Such explanations fail to explain why farming was transformed from a hedge to an economic mainstay in some instances but not in others, and why it sometimes became less important than it had been. In fact, there is no way for a single qualitative model to explain the observed variation in Southwestern agriculture. We are left with the unpalatable option of coming up with a new model for each new situation.

The next few sections of this essay suggest how models based on quantitative reasoning may better account for the patchwork history of Southwestern agriculture. By assuming the exercise of economic rationality[4] among food producers, we can account for multiple trajectories of agricultural use. It should be kept in mind that what follows is, purposefully, not a detailed model but an illustration of an approach.

Basic Principles: Foraging as a Single-Mode Economy

The basic principles behind the model can be seen using an economy with a single mode of production, namely, foraging for wild foods (the only mode of food production in the Southwest before 2000 B.C.). The term "wild foods" comprises a suite of options but for the sake of argument is treated uniformly. Figure 1 illustrates the relationships between total available food supply, total effort expended in the food quest, and food return.[5] The dashed vertical line represents the limit to food resources gleaned from a given area in a given year—in this case, the limit is arbitrarily set at food for 25 persons. The slanting line represents all points for which the total calories amassed equals calories expended. Any performance above this line leads to hunger. The "curve" approximated by a series of short lines represents a hypothesized group effort: zero effort yields zero food; initial efforts yield more calories than are expended; eventually, more calories are expended than obtained. The ratio next to each segment of the "curve" shows the slope of that segment, and thus the ratio: "(Additional unit of effort) : (Additional units of food)." Some prefer to use a logistical (S) curve to illustrate returns, but for the sake of clarity the curve is simplified. The named values in Figure 1 are as follows:

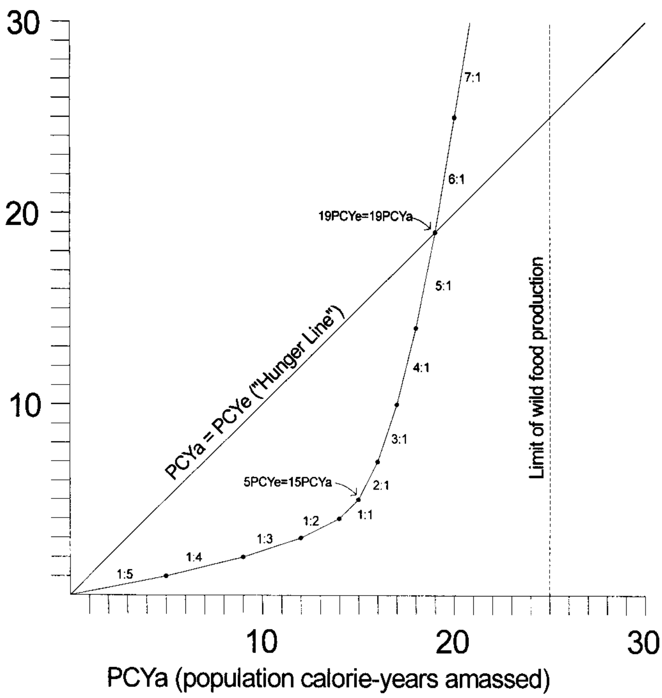

Figure 1. Curve of costs for foraging. This graph reverses the usual axes for independent and dependent variables to ask the question, "If the group varies its return (X axis), what are the cost implications (Y axis)?" Marginal costs for each local secant are shown as ratios of rise to run, equating to the change in effort required for a desired amount of additional food. As one example, "1:5" means that an increase of five units of food requires one additional unit of effort.

- CY equals one Calorie-Year, the amount of calories required by one person in one year;
- P is the initial number of persons in an arbitrary landscape;
- PCYe is the number of calories expended by a population of size *P* in one year; and
- PCYa is the number of calories amassed (as food) by a population of size *P* in one year.

For the purposes of this essay, the terms "calories" and "food" are used interchangeably. Where possible, values are expressed as arbitrary numbers rather than variables. Caloric expenditure (rather than some other measure such as time) was selected to represent effort because of its usefulness in defining a "hunger line." In Figure 1, the line between an adequate food supply and hunger is defined by *n*PCYa = *n*PCYe. The maximum effort that can be made by the initial population—as measured by calories expended—is (one) PCYe.

The shape of the curve can be justified in qualitative terms. When a foraging population is small relative to a landscape, it can live off the most easily obtained resources in that landscape. As the population grows, it must also use resources that require a greater effort.

> For example, as a group increases deer hunting in its territory, the density of deer declines and costs associated with search and capture increase. For hunting and gathering strategies, increased costs reflect the need to travel farther from the base camp (Lee 1969), the need to search longer for a resource, and the need to procure products of smaller size or lower quality. Increased costs in agricultural strategies are a result of the need to travel farther to fields (Chisholm 1970), to use suboptimal fields, and to intensify methods on existing fields (Boserup 1965; Grigg 1976) [Earle 1980:11–12].

Figure 1 assumes that if the initial population wishes to spend all of its efforts foraging, it will obtain a five-year supply of food. Let us assume that for a population size up to 5P, the food production ratio is constant; that is, a day's effort yields an average return of five days' worth of food. In other words, a population of 5P will need to expend only 1PCYe to amass the 5PCYa of food it requires. If the population keeps growing, however, the return for a given foraging effort will diminish. At 2PCYe, the return is (5 + 4)PCYa = 2PCYe, which is an average of 4.5 PCYa per PCYe. At 3PCYe, the return is (5+4+3)PCYa = 3PCYe, or 4PCYa per PCYe. And so on; at 19PCYe the food return is 19PCYa and further effort leads only to hunger.

Some archaeologists may object that Archaic foragers were not trained economists, so were unable to analyze their economic situation as is done here. I admit that people generally do not respond to a total economic picture as graphed in Figure 1. They do, however, respond to the *marginal* costs and returns of their actions. In other words, they ask questions like: "I already have *X* units of this item. If I want *one more unit* of the same item, what will it take to get that additional unit?" (see also Barlow 2006:96; Doolittle 1984). This form of analysis can be done intuitively and is therefore accessible to everyone (including Archaic foragers). It thus circumvents criticisms based on the limited economic perspective of individuals.

The concept of marginal cost is so critical that I will risk belaboring the point. Imagine a valley where ricegrass grows thick on the valley bottom but is more widely scattered on the adjacent hills. If the valley bottom produces a month's supply of ricegrass seed in a week's harvesting, the marginal cost of that grass seed is one week of labor. If the same group must also harvest ricegrass seed from the adjacent hills to get through the winter, and spends two weeks to harvest a second month's supply of seed from those hills, the total cost of the two months' supply of seed is three weeks of labor—but the marginal cost of the hillside seed is two weeks' labor. If only one month's supply of seed is needed, a group that seeks to minimize its efforts will harvest ricegrass seed only from the valley bottom, and ignore the seed available on the adjacent hills.

Applying such an approach, if the initial foraging population (of size P) wishes only to replenish its food supply, it can get by with spending only one-fifth of its time foraging. The group's remaining time can be spent on appeasing the gods, socializing, taking naps, and otherwise doing things with little or no "practical" return.[6] Because everyone loves a good meal, leisure-time activities can include the collection and preparation of foods that, economically speaking, are luxuries (e.g., Johnson and Behrens 1982).

Moreover, at population size P it is easy to increase the food supply. If certain leisure-time activities lead to a larger population, the immediate consequences are minimal. By the time the local population reaches 5P, it is still spending roughly one-fifth of its time foraging to replenish its food supply.

As the population increases further, however, the increase in the marginal cost of foraging becomes more pronounced. Individuals become conscious that they are working harder and harder to obtain the same incremental result. At some point it becomes obvious that another day's effort no longer yields another day's food, even though more food is available in the landscape. At that point populations will begin seeking alternatives to increasing total food amassed (for example, by emigrating to a less crowded area).

Because of marginal costs, prehistoric human populations in a stable environment are unlikely to exceed their available food supply. Figure 1 shows the theoretically most intensive foraging strategy at 19PCYe = 19PCYa, but each additional effort yields less than that amount of food energy beyond 5PCYe = 15PCYa. Beyond 15P—well before the theoretical food-based limit of 25P—it becomes depressingly obvious that additional foraging is not worth the effort.

The rising marginal costs of a food quest may be imperfectly perceived, and people are not prevented from making "wrong" (i.e., calorically expensive) decisions. Still, there is a price to pay for those decisions, and a group that pushes its food quest too far will flirt with starvation—something that is difficult to ignore. Thus, to the extent that marginal costs can be perceived, catastrophic outcomes are avoidable (see also Charnov 1976).

Choosing between Strategies

The explanatory potential of the approach emerges when prehistoric subsistence is modeled in terms of competing strategies (Figure 2). The question asked by our hypothetical population becomes, "If we wish to obtain a certain supply of food, what is

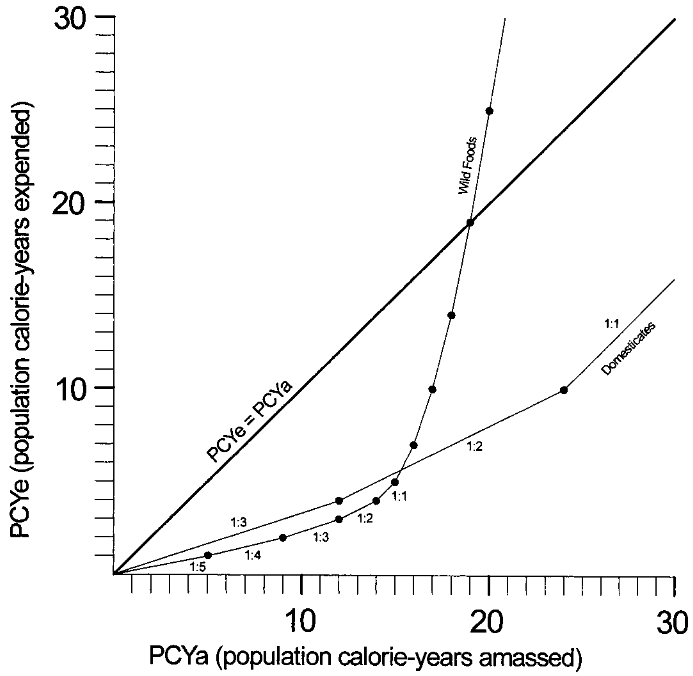

Figure 2. Curves of costs for foraging versus farming.

the best combination of wild and domesticated food to obtain that food?" Having examined the concept of marginal costs in the preceding section, we can proceed directly to those costs. We will add the following notation:

(W) meaning "from wild foods" and
(D) meaning "from domesticates" (based on methods other than irrigation, which will be considered later in the essay).

Figure 2 again greatly simplifies matters. The marginal costs of foraging are the same as in Figure 1. Farming is modeled as less efficient than foraging (i.e., it requires more labor to obtain that first PCYa of food), requiring .33PCYe to yield the first PCYa(D). The marginal cost of farming increases more slowly, however. The steep portion of the farming curve is assumed to exist, but lies to the right of 30PCYa.

Foraging versus Farming, or Foraging and Farming?

Under the conditions graphed in Figure 2, what is the most sensible way to get food? Initially the answer is through foraging. Even if farming is an option, it requires greater effort to achieve the same amount of food. As long as population is below 9P (i.e., less than 9PCYa of food is needed), there is no rational reason to develop farming. If cultigens are available they may be grown, but as a luxury item rather than staples. At this range of subsistence intensity, efficient solutions to the food equation range from

PCYa = PCYa(W) + 0PCYa(D)
to
9PCYa = 9PCYa(W) + 0PCYa(D).

Beyond a population of 9P, the situation changes. In Figure 2 the initial marginal cost of farming matches the marginal cost of foraging for the 10th, 11th, and 12th PCYa(W). At this point, it makes as much sense to do some farming as it does to increase foraging efforts. For example, multiple solutions are equally efficient for the following food need:

12PCYa = 12PCYa(W) + 0PCYa(D),
12PCYa = 11PCYa(W) + PCYa(D),

12PCYa = 10PCYa(W) + 2PCYa(D), and
12PCYa = 9PCYa(W) + 3PCYa(D).[7]

The four solutions listed above all equate to the notion that under the circumstances, the most efficient strategy is "foraging plus some farming" (see also Harris 1996:Table 1.1; Smith 2001). Why not switch over entirely to farming? Even though beyond the accumulation of 9PCYa(W) foraging is no more efficient than farming, foraging for the *initial* 9PCYa(W) remains more efficient than farming for even the first PCYa(D). As a consequence, people at this level of subsistence intensity will wish to retain their core strategy of foraging, and add foraging-plus-farming to that core.

When the population expands beyond 12P, the situation changes again. At this point, the marginal cost of adding a single PCYa from foraging rises to .5PCYe, while the marginal cost of adding that same PCYa from farming continues to be .33PCYe. As modeled in Figure 2, the optimal solution requires intensification of foraging to cease, while intensification of farming continues, to

24PCYa = 12PCYa(W) + 12PCYa(D).

If we continue intensification to include all returns of 2PCYa per PCYe, the solution for maximum intensification becomes

36PCYa = 12PCYa(W) + 24PCY(D).

To recap: within a landscape, the most rational solution to the food quest depends on food demand (Earle 1980:21; see also Netting 1990). As modeled in Figure 2, when total demand for food is low, the food quest will emphasize wild foods even when cultigens are an option. As subsistence efforts are intensified, the rising marginal costs of foraging will eventually match the initial marginal costs of farming and the latter will become a competitive approach to *adding to* the food supply. The easiest way to obtain food is, however, to continue to exploit the original wild food sources, which are supplemented with a mix of additional wild foods and cultigens. The latter do not replace the former. With further intensification of subsistence, a point is reached where expansion of foraging efforts ceases, while expansion of farming efforts continues. Nonetheless, marginal costs preclude abandonment of one strategy in favor of the other. In a landscape where only foraging and farming are possible, the most intensive food quest imaginable involves both.

Irrigation, Farming, and Foraging

It is time to further complicate the picture by making canal irrigation an option (Figure 3). Canal irrigation is modeled as even less efficient, initially, than farming without irrigation—it requires even more labor to grow the first PCYa of food—but because it greatly bumps up total agricultural productivity, its curve is much flatter than those for foraging or non-irrigation farming. Figure 3 tells us that an early Southwestern population would have little reason to build irrigation systems. Instead, canal irrigation would take place only at the few springs, and along the few streams, where it was as easy as it was productive—conditions ignored here.[8] Applying the most efficient solutions, and adding the variable descriptor I for "Irrigation," the most efficient solution (up to 24PCYa) involves no canal irrigation:

24PCYa = 12PCYa(W) + 12PCYa(D) + 0PCYa(I).

That is, a population even 24 times the initial foraging population would be working harder than necessary if it began canal irrigation. Thereafter, however, any intensification of the subsistence economy could include canal irrigation in addition to (but not instead of) the prior emphasis on mixed foraging and dry farming. Intensification of foraging ceases to be efficient (compared to irrigation) at a total yield of 14PCYa(W), however, and intensification of dry farming ceases to be efficient at a total yield of 24PCYa(D). Thus, once the subset of non-irrigation strategies is intensified to

38PCYa = 14PCYa(W) + 24PCYa(D)

any further intensification of the food quest will involve only additional canal irrigation. In this case as well, the most efficient solution does not involve switching from one mode of production to another, but rather a mix of strategies.

Is irrigation always more labor intensive than other methods? In Polynesia, according to Kirch (1994:9–10), "it was not irrigation but short-fallow dryland systems that were the most demanding of labor inputs." If we limit ourselves to qualitative reasoning, Kirch's assertion falsifies any model crafted in the U.S. Southwest. If we adopt quanti-

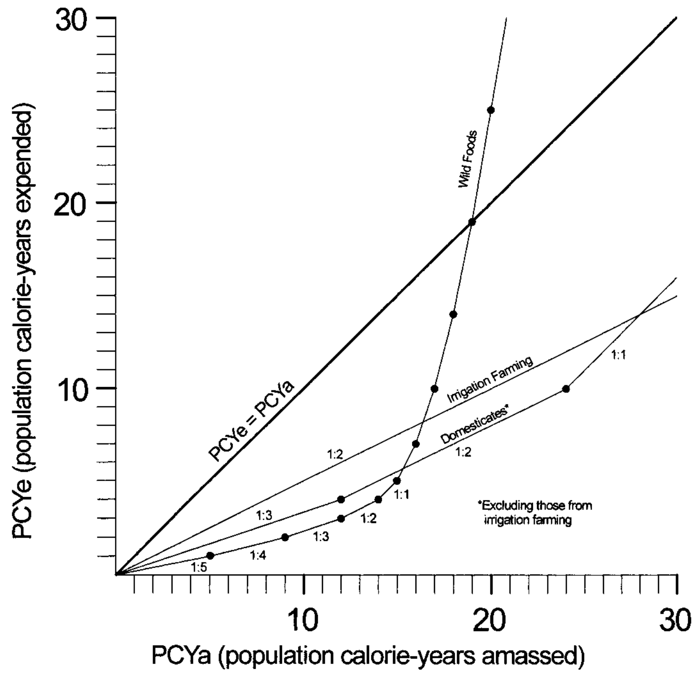

Figure 3. Curves of costs for multiple strategies.

tative reasoning, the challenge becomes to develop a single model that can be applied (with different constants) to both regions.

Agricultural De-intensification

Beginning about A.D. 1100, multiple areas in the Southwest saw less intensive farming or the abandonment of farming as a subsistence option. The most spectacular reversal took place among the Hohokam of the Gila River watershed. Prior to A.D. 1300, the Hohokam canal systems required huge amounts of labor to build and maintain, and irrigated hundreds of square kilometers of desert. When first contacted by the Spanish, the local residents farmed only the bottomlands (Ezell 1961).

In some cases, an existing agricultural regime may have become unsustainable (Minnis 1985). Even so, why did Southwestern populations not do less of each technique, as total food production decreased? The model developed in this paper is able to explain specific patterns of agricultural de-intensification, simply by putting itself into reverse (see also Brookfield 1972:35). Again turning to Figure 3, but substituting floodwater farming for "non-irrigation" farming to reflect local conditions, we have a series of curves that sketch out the Hohokam food quest.

As before, foraging was the preferred initial food production strategy of the Archaic occupants of the area. As needs increased, floodwater farming became a second source of food. As those needs continued to increase, irrigation farming was adopted. Even under intense population growth, however, the most rational approach was a mixed economic strategy, not irrigation monoculture. This appears to have been the actual pattern among the Hohokam; indeed, they added a fourth strategy, the growing of agave, a slow-maturing plant whose roasted hearts were a highly prized food (Doolittle and Neely 2004; Fish et al. 1985; Fish et al. 1992; Gasser and Kwiatkowski 1991). As Hohokam society (and therefore food needs) collapsed after A.D. 1300, irrigation agriculture shrank drastically and the growing of agave came to a halt, but foraging and floodwater farming continued. Which practices were lost, and which were retained, appear to reflect marginal costs. The same approach allows us to predict that if the population of the Gila River watershed had dropped even further, agriculture would have become unimportant. The resident populations never reached such a nadir, but in other parts of the Southwest farmers gave way to foragers. In such cases it is tempting to find some reason why farming became impossible; instead, it may be necessary to understand that while farming was still possible, it no longer made sense.

Do such reversions actually occur? Bellwood (2005:37–39) cites numerous candidates. According to Wills (2006),

> Such alternation is well-known ethnographically and is described by Netting (1990) as "ecological fine-tuning." Many modern hunter-gatherer societies may, in fact, be recent reversions from agricultural adaptations (Wilmsen 1989; Oota et al. 2005). In an evolutionary framework, this sort of alternating indicates that the underlying economies of foragers and farmers were fundamentally similar, or at least not very dissimilar, allowing tactical adjustments rather than strategic change [124].

Another way to visualize foraging and farming strategies as "fundamentally similar" is to view particular strategies as falling on continua of costs and returns.[9]

Non-intensification

In the 1960s and 1970s, when many archaeologists viewed cultures as homeostatic systems, it was possible to argue that populations tended to stabilize relative to their environment (e.g., Binford 1968; Harris 1977). With the abandonment of the systems approach, and in the face of the continued rise in human population, it is tempting to return to a Malthusian viewpoint. Nonetheless, the concept of marginal costs can also help us understand why, in some cases, local groups did not continue to grow as they reached the limits of existing strategies. In Figures 1 through 3 the curves for food production strategies were rigged to create a steady progression from less to more intensive methods. What happens, however, when nature doesn't cooperate?

In Figure 4, foraging remains the easiest way to obtain an additional day's supply of food, but beyond 15PCYa of wild food (derived from 5 PCYa of effort), one day's attempt to intensify foraging yields less food than is consumed on that particular day. Irrigation farming is possible but requires a substantial initial effort, and thus is a losing proposition until used to obtain 6PCYa of food (after which the rate of return is increasingly positive). For a foraging group seeking to increase its total food supply from 15PCYa to 16PCYa, the increase in effort jumps from 5PCYe to a little over 10PCYe. Doubling one's effort, in exchange for a minor increase in food supply, is a powerful disincentive. With no continuous path from foraging to farming, the only way to go from one to the other is a radical change, which is not possible except through processes such as conquest and political assimilation. Instead, the clear choice under a marginal analysis is to *stop requiring more food.*

This conclusion is based on the privileged perspective of the analyst—to which readers may, again, rightly object. The individual (i.e., marginal) perspective is of the increasing difficulty of feeding a family. Faced with rationing, families also face a choice between hunger and controlling demand for the available food (e.g., through emigration or restriction of family size). If enough similar choices are made at the family level, the emergent pattern is a halt to local population growth. Under the specific conditions just modeled, the end result is more likely to be population stability rather than intensification of food production. Consideration of marginal costs leads us to an understanding of why demographic increase acts like an independent variable in many instances but not in all of them (see also Kirch 1994:312; Brumfiel 1992:556).

Discussion

Were prehistoric people the equivalent of MBAs, calculating optimum food-yield strategies? Of course not. It is far easier to see past (and present) human beings as "imperfect decision-makers" (VanPool and VanPool 2003:99; see also Brumfiel 1992:559; Mithen 1989, 1990) than as *Homo economicus*. Nonetheless, by experiencing marginal costs and returns humans can devise solutions without seeing an entire economic picture. Moreover, because of the constraints imposed by those marginal costs, households in the North American Southwest were selective about their subsistence

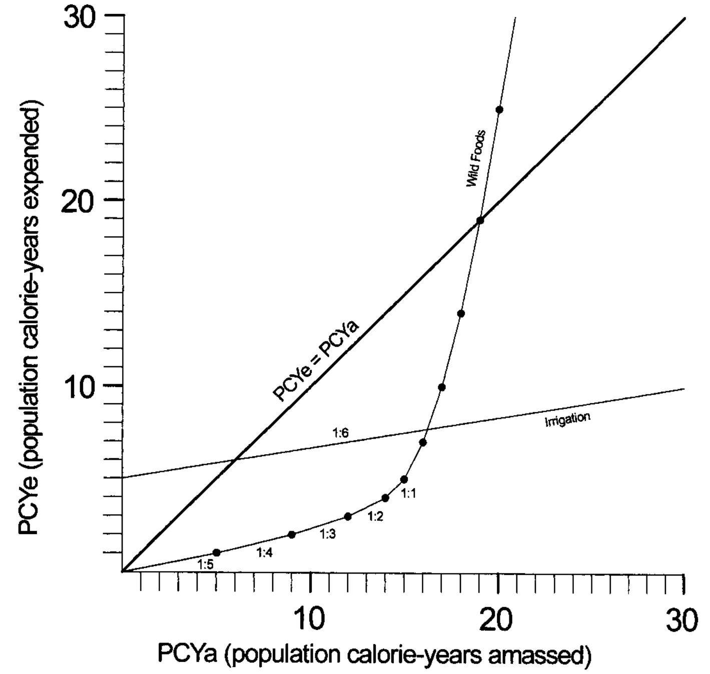

Figure 4. Conditions leading to the deliberate non-adoption of agriculture.

practices. By understanding the marginal costs and returns for specific approaches, as developed through trial and error, and by basing decisions on that understanding (i.e., "schema" [Gell-Mann 1992]), prehistoric households made choices in the face of cultural and natural constraints. And, by making the choices they did, prehistoric people actively shaped the content of their culture.

Proving these assertions is beyond the scope of this paper. Nonetheless, the broad patterns of Southwestern subsistence history seem better accounted for by a marginal analysis—even one merely sketched out—than by other models proposed to date. Southwestern groups continued to rely exclusively on wild foods well after domesticated foods were available from Mesoamerica, and thereafter farming spread unevenly. Given the speed with which maize first spread through the U.S. Southwest, versus how long it took to become a staple, it is likely that some groups started cultivating maize as a ritual food or a special treat (see Farrington and Urry 1985; Hastorf 1998a, 1998b; Smalley and Blake 2003). For certain groups, it was never anything more. When and where maize did become a staple, foraging was first supplemented by less labor intensive forms of agriculture, and only later by more labor intensive practices. If a local population diminished, the more labor intensive foodways were dropped. The most parsimonious explanation of this highly varied agricultural experience is that it reflects the marginal costs and returns of subsistence strategies in particular places and times.

If we assume, just for the moment, that the model is correct, what else does it tell us about prehistory? The model asserts that the intensity and variety of a local food quest were direct products of the demographic pressure on local landscape—and thus that observable attributes of the food quest serve as a proxy measure of demographic pressure. If so, the immense variation in prehistoric Southwestern food quests signals equally large variations in local demographic pressure. Turning to a concrete example, irrigation began early and lasted many centuries in parts of the Gila River watershed, even as farming was based on less intensive approaches (or was nonexistent) elsewhere in the region.

The roots of this variation do not appear to lie in the relative costs of wild foods or non-irrigation farming. The Sonoran Desert easily competes with the Southwest's higher-elevation areas as a source of wild food, in terms of both productivity and reliability (consider saguaro fruit versus piñon nuts, which are famously a mast crop). Direct rainfall farming is possible at higher elevations, but the Sonoran Desert combines opportunities for floodwater farming with fewer risks of killing frosts. Thus the observed pattern, as viewed through the model, suggests that prehistoric demographic pressure on landscapes was more uneven than natural conditions can explain. Moreover, it is difficult to imagine social barriers that account for this unevenness, given the growing evidence of migration within the region (e.g., Clark et al. 2008).

This conclusion is at odds with notions of demographic pressure borrowed from ecology. In such notions, the effects of increased population pressure in one place ripple through the greater landscape, through emigration or by displacement of one group by another, until a barrier is encountered. Thus, for example, Binford (1968) looked at demographic pressure on optimal versus marginal habitats, and Carneiro (1970) argued that when a landscape was "circumscribed," so that demographic pressure could not bleed off, the result was social hierarchy. It instead appears that "pull" factors can outweigh the "push" of demographic pressure, leading to demographic peaks and troughs not reducible to ecological factors.

The model thus points down a path already illuminated by a different set of studies. In the North American Southwest, the late prehistoric period is best known for the process of village formation that resulted in the modern Pueblo world (e.g., Adler et al. 2006; Cordell et al. 1994). An equally striking change is progressively uneven land use at the regional level (Center for Desert Archaeology 2009; Clark et al. 2008; Wilcox 2007). In locations that underwent depopulation, fewer people remained behind than changing conditions required. In the Mesa Verde region, for example, everyone left, even though the area could have supported a reduced population (Van West 1994). While the causes of late prehistoric demographic clustering are complex, there seems to be no way to derive those patterns except by concluding that humans do, in some circumstances, swim against the flow of demographic pressure. *If* the current model is correct, this tendency began early and was pervasive and long-lasting. In other words, regional human populations repeatedly behaved in ways that make no sense from a narrowly ecological point of view.

The next logical step in this approach would be to identify purely social factors that made the regional human population so inherently uneven, relative to its landscape. These would necessarily go beyond "social circumscription" (Carneiro 1970; Chagnon 1968), in which other populations serve as a barrier to free demographic movement, to identify sources of demographic compression *in the absence of* barriers to emigration. Thus, the model's greatest heuristic value may not lie in what it explains, but in what it does not explain—therefore forcing us to consider new factors in our modeling of prehistoric human adaptation.

These speculations aside, my goal has been to present a sketch of a model. As proposed here, the model ignores the role of environmental variation (including that caused by humans) in Southwestern prehistory (e.g., Graybill et al. 1989; Redman et al. 2004; Van West 1994; Van West and Altschul 1997). It describes all wild food collection as a single strategy, which was never the case (e.g., Hawkes et al. 1982; Munro 2004). Risk is ignored (see Hegmon 1989), as are age, gender, and other internal social divisions (see Brumfiel 1992). As Brookfield (1972), Hastorf (1998b), Kirch (1994), Plog (1990), and many others have made clear, social as well as natural factors define what an "economic" decision is. Readers should be suspicious of any model that relies on the interplay of variables along two dimensions (in this case, a fixed environment versus total population) to account for changes in actual subsistence economies over several thousand years.

I will therefore cheerfully abandon the model presented here when faced with an alternative, incorporating other factors, which better accounts for the regional archaeological record. Meanwhile, quantitative reasoning appears to provide a way to propose, evaluate, and ultimately discard models of change that reach beyond what is possible through qualitative reasoning alone. If this essay serves to encourage more widespread use of such reasoning, it will have done its job.

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Notes

1. This essay may remind readers of optimal foraging theory and its close intellectual cousins (e.g., Boone and Smith 1998; Johnson 1975; Keegan 1986; Kelly 1995; Smith 1983; Smith and Winterhalder 1992; Winterhalder and Smith 1992). Among their other achievements, such approaches have yielded data on the costs and returns of specific strategies (including in the Southwest [Barlow 2002, 2006]). I confess to greater sympathy with archaeologists who build, in one way or another, on the concept of "agency" (e.g., Brumfiel 1992; Dobres and Robb 2000; Gumerman and Gell-Mann 1994; Kantner 1996, 2003; Kohler and Gumerman 2000; see also Hegmon 2003:219–222; VanPool and VanPool 2003).

2. Currently, Southwesternists often turn to computer-based simulations (e.g., Axtell et al. 2002; Dean et al. 2000; Hegmon 1989; Kohler et al. 2000; Van West 1994), which obviate many problems arising from more traditional forms of quantification. It is not a huge leap from the concepts illustrated here to a working computer model. For the purpose of illustrating the concepts, however, certain earlier approaches seem to work best (see especially Earle 1980).

3. In examining the Colorado Plateau, for example, Matson (1991, 2003) argues that eastern Basketmaker II foraging-plus-farming developed in situ while western Basketmaker II represents agricultural immigrants. His arguments dovetail with Hill's (2002, 2003, 2006) reading of the linguistic evidence. Combining the two models, Uto-Aztecan farmers spread up the west coast of Mexico and into the U.S. Southwest, becoming various archaeological groups including the western Basketmakers. Resident speakers of Kiowa-Tanoan, Zuni, and Keresan (among them, the eastern Basketmakers) then adopted farming from the immigrants.

4. The capitalist belief system often asserts that rationality requires a marketplace. I assume that at any given moment, social forms present arbitrary challenges to individuals, and that "rationality" consists of the sum of those individuals' attempts to survive within, or prevail over, those forms (see also Rapaport 1960:107–108).

5. The curves are designed for ease of argument rather than accuracy. Except in Figure 4, I ignore initial costs. Also, I depict marginal cost through slope values for the secants used to approximate a curve. The only advantage of that approach is that readers need not know calculus to grasp the relationship between total cost and marginal cost. Finally, diminishing returns can occur without limits to a food supply but such limits provide an intuitive basis for the concept of diminishing returns. For more realistic examples of curve-based arguments see Brookfield (1984), Earle (1980), Kirch (1984, 1994, 2007), Morrison (1994), and Sachs (1966).

6. This approach specifically rejects the notion of maximization (see also Earle 1980:14–15; Foley 1985; Kantner 2003; Mithen 1989). Reports of foraging economies' low labor inputs (Harlan 1967; Lee 1969; Lee and DeVore 1968) led Marshall Sahlins (1968, 1972) to refer to foragers as the "original affluent society." While this formulation has been criticized repeatedly (e.g., Bird-David 1992, Kaplan 2000, Kelly 1995:19–23) the fact remains that most foragers have more free time than most members of agricultural or industrial societies (Kaplan 2000:313). More to the point, it is not necessary for foragers to have lower labor inputs than farmers. If the reverse is true, the model yields different predictions.

7. When continuous curves are used, the zones of equal efficiency are reduced to points, but as those points are approached the output differences among strategies approach zero. The practical effect is the same.

8. In any practical application of the approach, such a simplification is highly unrealistic: canal irrigation was sometimes practiced early on (e.g., Damp et al. 2002; Mabry 2002, 2005a; ZCRE 2000). This fact goes to the larger point of the essay, however. When canal irrigation and rainfall-based farming are contrasted qualitatively, it is difficult to explain why irrigation was sometimes ignored, sometimes adopted, early in the region's Formative period. When specific strategies are viewed quantitatively, one can explore the variable use of those strategies (see also Vierra 2008).

9. An anonymous reviewer pointed out one additional implication of Figures 1–4. Once the population exceeds 19P, the commitment to farming is, in practical terms, permanent—any complete reversion to wild foods would lead to starvation. It is also possible to envision a scenario in which local agriculture becomes less cost-effective than it was—so that a different area, whose efficiencies of farming once made it less desirable, becomes more so. Here we begin to see how changes in productivity relative to effort (something not considered as part of Figures 1–4) might lead to emigration or even regional abandonment, in the absence of catastrophic change. Instead, gradual factors such as wood and game depletion, or small changes in climate, might be sufficient to trigger the decision to leave.

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