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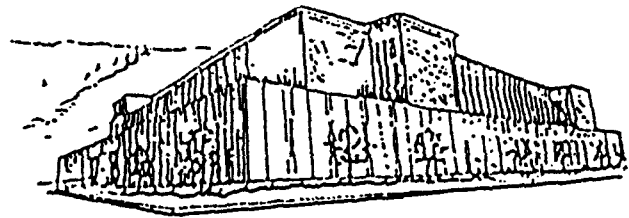
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THE ORIGINS OF AGRICULTURE:
RESOURCE DEPLETION AND PRODUCTIVITY MAXIMIZATION

By

Wanjin Kim

B.S. Seoul National University, 1982

presented in partial fulfillment of the requirements


for the degree of

Master of Arts


The University of Montana

1994

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Anthropology

The Origins of Agriculture: Resource Depletion and Productivity Maximization (62 pp.)

Director: Randall R. Skelton R.S.

Many anthropologists assume that prehistoric hunter-gatherers used optimal foraging strategies. These models are based on the assumption that hunter-gatherers attempted to satisfy their basic needs at the lowest possible cost.

The technological development of prehistoric people permitted a decrease in procurement costs, which caused an increase in productivity, which led to an increase in population density. Continuous increase in population density caused population pressure. One way to avoid the population pressure was out-migration to previously unoccupied territory. However, this solution had limitations.

When population density reached the environmental carrying capacity, surplus population growth led to resource depletion and caused a decrease in the productivity of hunting and gathering. With the climate becoming favorable for agriculture in the early Holocene, the potential productivity of agriculture increased. When the productivity of hunting and gathering eventually became lower than that of food production, people began to adopt agriculture.

Prehistoric people steadily increased agricultural productivity through domestication of wild species and continuous technological development. Continuous growth of population density intensified resource depletion and led to a further decrease in the productivity of hunting and gathering. Thus, once some aspects of agriculture were adopted, people depended more and more on agriculture and less and less on hunting and gathering. Since population in agricultural society tends to increase comparatively rapidly, farmers eventually replaced hunter-gatherers.

My case study of Mesoamerica shows that productivity played a central role in the origins of agriculture in this region.

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CHAPTER I

INTRODUCTION

Perhaps the most momentous change in human history was the transition from a hunting and gathering to an agricultural society. This transition involves much more than simple change of subsistence pattern. It also accelerated the formation of civilizations and complex social structures, and engendered a new relationship with the environment, whereby the ways of human life were totally transformed. What is remarkable is the fact that the transition to food production appears to have taken place separately and independently in a number of different areas between about 10,000 and 5000 years ago (Gebauer et al. 1992:1).

The vast majority of our past was spent as food foragers (Lee et al. 1968:3). Nevertheless, shortly after the end of the Pleistocene, some human groups began to produce food rather than collect it (Gebauer et al. 1992:1). Why should it take so long for food production to begin? Why should the transition happen within such a brief period, within a 5000 year segment of the span of human existence?

The problem of explaining the origin of agriculture has been a major focus of anthropological inquiry through the history of the discipline (Cohen 1977:1), because only when we have this understanding will we be able to fully appreciate the evolution

of human culture. Many causes have been suggested for "the origin of agriculture," such as the oasis hypothesis, technological innovation, population pressure, human-other species symbiosis, "big men" hypotheses, and others (Bender 1975, Gebauer et al. 1992). However, there is no single, accepted general theory for "the origin of the agriculture" despite the large number of studies that have been undertaken since the end of the last century (Gebauer et al. 1992:3).

In this paper, I study the transitions to agriculture in prehistory. I make an effort in this study to address such questions as: Why was hunting and gathering replaced by agriculture? How did the transition proceed? What are the underlying principles of the transition? I propose a conceptual model suggesting that productivity is an essential factor in explaining the transitions to agriculture. In other words, the maximization of productivity in a given circumstance was the driving force behind the transition to agriculture.

CHAPTER II

A MODEL OF HUNTER-GATHERER SUBSISTENCE

Subsistence of Hunter-Gatherers

"Cultural Man has been on earth for some 2,000,000 years; for over 99 per cent of this period he has lived as a hunter-gatherer. Only in the last 10,000 years has man begun to domesticate plants and animals.... Of the estimated 80,000,000,000 men who have ever lived out a life span on earth, over 90 per cent have lived as hunters and gatherers; about 6 per cent have lived by agriculture, and the remaining few per cent have lived in industrial societies. To date, the hunting way of life has been the most successful and persistent adaptation man has ever achieved" (Lee et al. 1968:3).

As this statement by Richard Lee and Irven DeVore suggests, hunting and gathering, "foraging" in more broad term, is the principle mode of subsistence of hunter-gatherer. Foraging refers inclusively to tactics used to obtain non-produced food stuffs or other resources—those not directly cultivated or husbanded by the human population, although they may in some cases be conserved or managed (Feit 1973). Foraging may involve hunting, trapping, netting, snaring, gathering, or other techniques (Winterhalder 1981:16).

Optimal Foraging Strategies

A human group may have many choices of foraging strategies. The decision of which to adopt largely depends upon the efficiencies of the strategies. Many anthropologists assume that hunter-gatherers use optimal foraging strategies (see Keene 1981; Winterhalder 1981). These models are based on the assumption that hunter-gatherers attempt to satisfy their basic needs at the lowest possible cost (Keene 1981:13). Optimal foraging models are based on the neo-Darwinian postulates that natural selection and competition are inevitable outgrowths of heritable reproduction in a finite environment (Pianka 1974:13). Direct and indirect competition for resources place those units best able to acquire materials and energy at a selective advantage over other such units which are inferior at these processes (Pianka 1974:14). In other words, natural selection will favor foraging behaviors which best allow an individual or population to achieve its life goals in a specific environment (Keene 1981:8). In these models foragers are expected to behave so as to obtain a high net rate of energy acquisition while foraging.

Procurement Cost

In a decision-making model concerned with selecting foraging strategies, an obvious concern is the procurement costs of the different strategies available to the population (Earle 1980:5).

A reliable measurement of procurement costs is the key to the quantification of the optimal foraging model. Procurement costs are affected by many environmental and cultural factors, and therefore they must be determined empirically for the specific group being studied (Earle 1980:5). A primary aim of this research, however, is to provide a general methodological and theoretical framework for the study of hunter-gatherer subsistence and causes of its change that are not context specific.

Traditionally, cost has been measured solely in terms of energy expended, because energy has been an attractive "currency" for use in ecological studies for several reasons (Keene 1981:24). First, energy is easily quantifiable, and hence conducive to precise cost-benefit analysis (Keene 1981:25). Second, the use of energy as a currency facilitates the construction of cost-benefit ratios (i.e., in terms of energy captured versus energy expended), that characterizes the efficiency of energy capture (Keene 1981:25). Such cost-benefit ratios, however, do not necessarily consider the amount of time input or the amount of risk involved, both of which may have profound effects on overall decision making patterns (Keene 1981:25).

Time is undoubtedly a major factor in cost calculation, not only because spending time, even in the absence of activity, causes an organism to consume energy for basic metabolism; but also because spending time means spending "opportunity cost"

which might otherwise be used in alternatively productive activities (for opportunity cost see Samuelson 1970:449). Rappaport (1968:256) calculates energy expended from time invested. This method is not always accurate, even though there is some correlation between time elapsed and energy expended. For example, there are apparently different energy-time ratios between two extreme foraging strategies: the "sit-and-wait strategy," in which a predator waits in one place until a moving prey item comes by and then "ambushes" the prey, and the "widely-foraging strategy," in which the predator actively searches out its prey (Pianka 1974:203). Obviously, the second strategy normally requires a greater energy expenditure within a shorter time span than the first one. We should therefore keep energy at least partly separate from time. Some scholars convert time estimates into energy costs by measuring the caloric expenditure per unit time for the different activities (Johnson 1975; Rappaport 1968). However, since time has a different unit and meaning from those of energy, time cannot be converted to calories or vice versa.

Risk is another important factor. It consists of two concepts, stability and safety. In the case of the former, risk can be consolidated into two other factors, energy and time. The latter is not easily quantifiable and hence not conducive to generalization. Thus, risk can only be considered in specific cases. Therefore, I regard energy and time as the major factors for cost-benefit analysis.

The relationships between cost, and energy or time are:

$$C \propto E \qquad C \propto T$$

where C is the procurement cost, E is the energy consumed for the procurement, and T is the time spent for the procurement.

The total procurement cost consists of many partial costs incurred to extract a resource from its environment and transform it into its finished form (Earle 1980:5). Summarized below are seven basic partial costs (see Earle 1980:5; Keene 1981:31)

1. Technological costs involve the energy and time expended in procuring raw materials and manufacturing the tools used in procurement tasks. Because a tool's life often extends over several procurement events, costs must be averaged to determine the specific cost for any one event. For example, a spear may last, with some maintenance, for several hunting trips. The cost of the spear for any one trip would, therefore, be the energy and time spent in manufacture and maintenance divided by the number of trips.
2. Transportation cost is measured as the energy and time expended in reaching the procurement area and in transporting the procured resource back to the base camp.
3. Collection cost is measured as the energy and time expended in actually procuring the resource once the individual or group has reached the gathering area.

4. Search cost is measured as the energy and time expended in finding the resource.
5. Pursuit cost is measured as the energy and time expended in killing or capturing the animal resource after finding it.
6. Processing cost is measured as the energy and time expended in preparing a form of the resource suitable for storage and consumption.
7. Storage cost is measured as the energy and time expended in constructing storage facilities (such as granaries or ceramic containers). As with other tools, this cost is averaged to determine the cost for any one event.

Carrying Capacity

Carrying capacity is a major concept in human ecology. However, carrying capacity is used by anthropologists as a label for two different concepts: a measure of environmental productivity, and a description of equilibrium population density (Dewar 1984:601). This duality in the concept of carrying capacity is mainly due to a lack of understanding of the dynamic relationship between environmental and demographic carrying capacity.

Errington (1934) studied the wintering of bob-white quail in Wisconsin and Iowa. He found that each specific territory usually supported a characteristic number of birds. He referred to this

as the "carrying capacity" of the area, and first defined "carrying capacity" as the largest population that a specific environment could be expected to support. His definition of carrying capacity contains some ambiguity. It is not clear whether the equilibrium population is determined only by the limit of the environmental productivity for the birds, or whether the birds' foraging efficiency in the area is a factor. If it is the former case, there is a "maximum carrying capacity" for the birds, no matter how well their foraging efficiency may improve in the future, and this maximum carrying capacity is generally equated with "environmental carrying capacity". Population growth beyond the environmental carrying capacity incurs diminishing returns in terms of the environmental productivity. Consequently, the population will be subjected to Malthusian checks (natural regulation of population tending to keep down the number to the level of the means of subsistence) and hence decrease to a size beneath the carrying capacity (for Malthusian check see Malthus 1798). If, on the other hand, it is the latter case, the carrying capacity may increase with the improvement of the foraging efficiency.

Ecologists generally define "carrying capacity" as the density of organisms at which the net reproductive rate equals unity and the intrinsic rate of increase is zero (Pianka 1974:82). By this definition, carrying capacity is equivalent to equilibrium population density regardless of whether the limit on population density is due to a limit on environmental production

capacity or because of a limit on foraging productivity.

Kirchner and others (1985:45) defined "carrying capacity" as the maximum population of a given species that can be supported indefinitely, allowing for seasonal and random changes, without any degradation of the natural resource base that would diminish this maximum population in the future. By such a definition, carrying capacity means environmental productivity, which can produce subsistence for a certain population size.

Since demographic carrying capacity is confined within the range of environmental carrying capacity, demographic carrying capacity cannot exceed environmental carrying capacity:

$$C_c \geq K$$

where C_c is environmental carrying capacity (after Hayden 1975), and K is Demographic carrying capacity. This relationship tells us that environmental carrying capacity is the maximum possible demographic carrying capacity.

Given these considerations, the concept of human demographic "carrying capacity" of a particular region may be defined as the maximum human population that can be supported at the level of culture possessed by the inhabitants, allowing for seasonal and random changes, without any degradation of the natural resource base that would diminish this maximum population in the future. The term "the level of culture" means "the level of technology," or, in more detail "the level of procurement productivity,"

implies the possibility of the change of carrying capacity according to "the level of culture."

The carrying capacity of a nonhuman species is determined by its diet and foraging habits (Christenson 1980:60), both of which can change only gradually through physical evolution. Human populations differ from those of other organisms in their ability to increase their carrying capacity at a relatively rapid rate through cultural evolution, in which technology plays a central role.

Procurement Productivity

Food resources will be exploited at different rates depending upon several factors, such as biomass (density per unit of area x accessible area); procurement cost, which will be higher for resources that are hard to locate, sparse, isolated, hazardous to harvest, and/or difficult to process for consumption (Hassan 1981:7); and the technology with which the resources are exploited; and other factors. I equate exploitation efficiency with procurement productivity.

Procurement productivity, in general terms, is the measure of how easily (energy) and quickly (time) an individual or group can extract what is needed. In other terms, productivity is the ratio of harvest to cost:

$$P = H / C$$

where P is procurement productivity, H is the amount of harvest, and C is procurement cost.

Procurement productivity is largely dependent upon such factors as environmental productivity, technology, degree of exploitation, population density, and foraging strategy.

Environmental productivity refers to the quantity of resources a given habitat produces for human use in a unit time. Resource quantity can be expressed by energy for the convenience of quantification:

$$E_p = E / T$$

where E_p is environmental productivity, E is the amount of energy (indicated by calories) produced in a given area for human use, and T is unit time (day, month, year, etc.).

Technology may decrease procurement costs, and consequently increase productivity. Baskets, for example, help collection and transportation, thus decreasing collection and transportation costs. Rifles may decrease pursuit cost by offering long shooting range and greater accuracy. The introduction of the horse for transportation may decrease transportation, search, and pursuit cost.

Productivity varies according to the degree of exploitation. When resources are infinitely abundant, search cost bears a linear relationship to production, that is, the unit cost of a specific item is constant, with the total cost of production

increasing at the same increment for each successive item of the same kind added to the production schedule (Keene 1981:30) (Figure 1). In reality, resources are finite, and the unit cost of any resource usually increases, at least marginally, as production continues. That is, the cost of acquiring a second, third, or fourth unit of a given item is successively higher than the preceding one (Keene 1981:30) (Figure 2). As each successive item is extracted from the resource pool, its density decreases and thus cost increases. Furthermore, some species, such as deer, exhibit highly effective avoidance behavior in response to hunting pressure, and this too would serve to increase search costs as exploitation increases (Keene 1981:31). Such an increase in costs leads to a decrease in procurement productivity. The more energy extracted from a given habitat, the more sharply the productivity curve declines (Figure 3).

As long as resources are abundant in comparison with population size, population density will not affect procurement productivity. However, since in reality resources are limited, population growth causes resources to become relatively more scarce. Therefore, both resource density and population density affect the procurement productivity. As a rule, high population density in relation to resource density, leads to low procurement productivity; because with high population density, intensive depletion of the resources may occur and diminishing returns may quickly result (Figure 4).

The efficiency of foraging strategy also has an effect on

procurement productivity, but since I assume that hunter-gatherers use optimal foraging strategies so as to maximize productivity, the efficiency of foraging strategy is not a variable in this discussion.

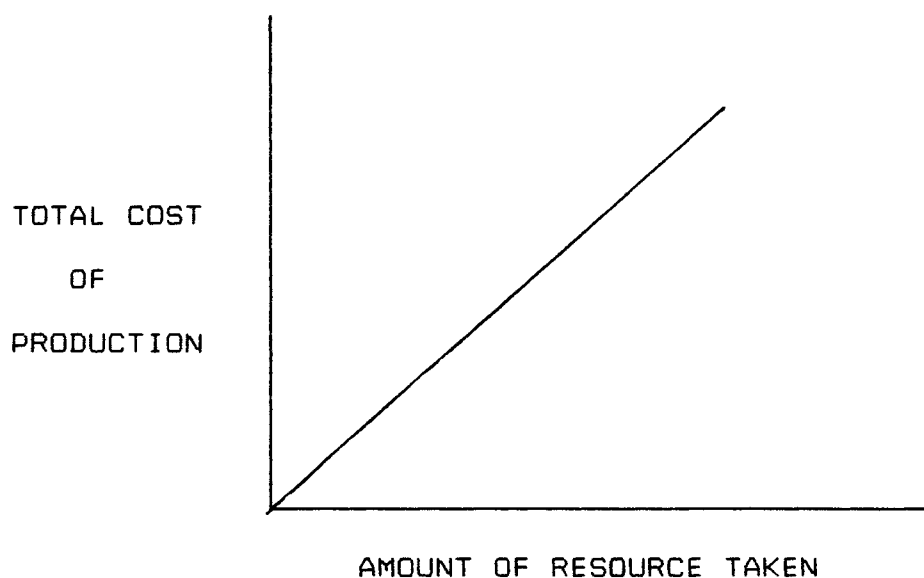


Figure 1. Total cost curve in relation to resource extraction in a area with infinite resource (after keene 1981).

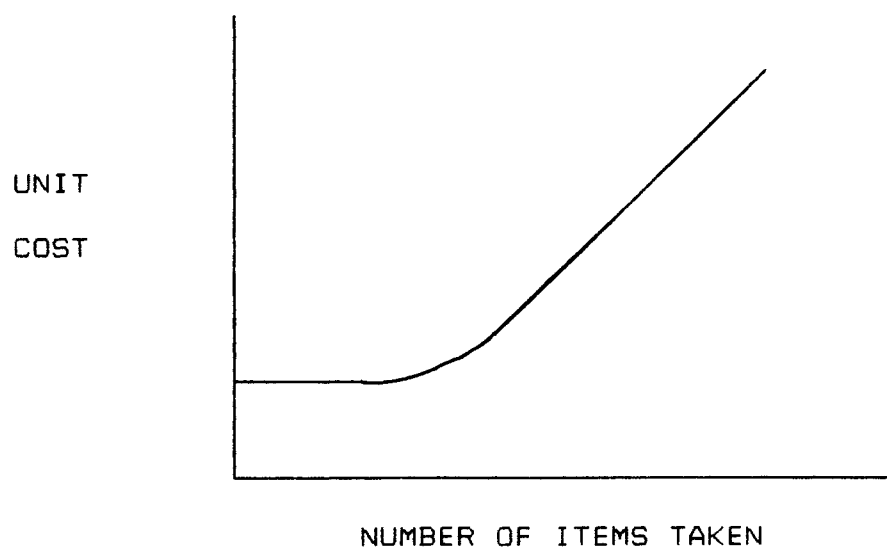


Figure 2. Unit cost curve in relation to resource extraction in a circumscribed area. For most foraging activities, initial costs should be relatively low and independent of the resource extraction. Cost should increase marginally with each successive item taken (after Keene 1981).

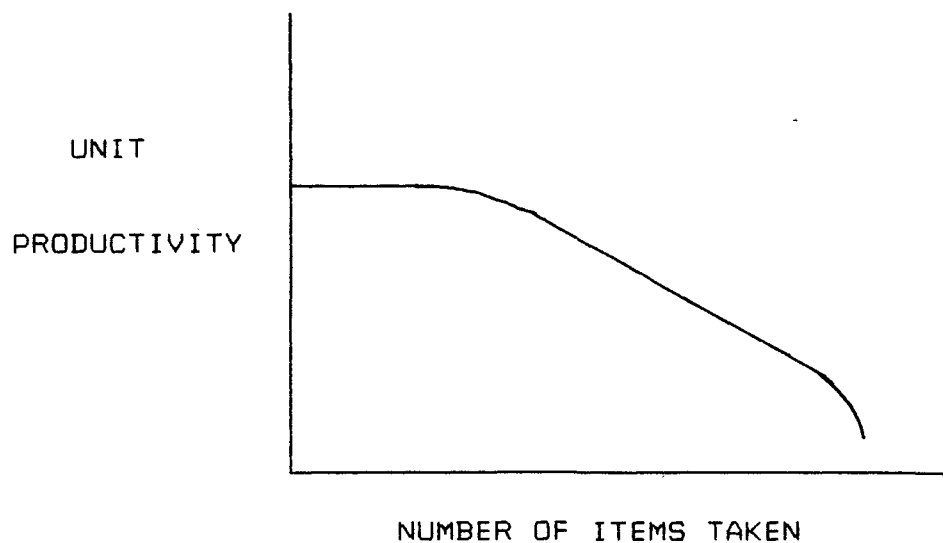


Figure 3. Unit productivity curve in relation to resource extraction in a given area. Start-up productivities are independent of the resource extraction; but as the resources are depleted, productivities will sharply decline.

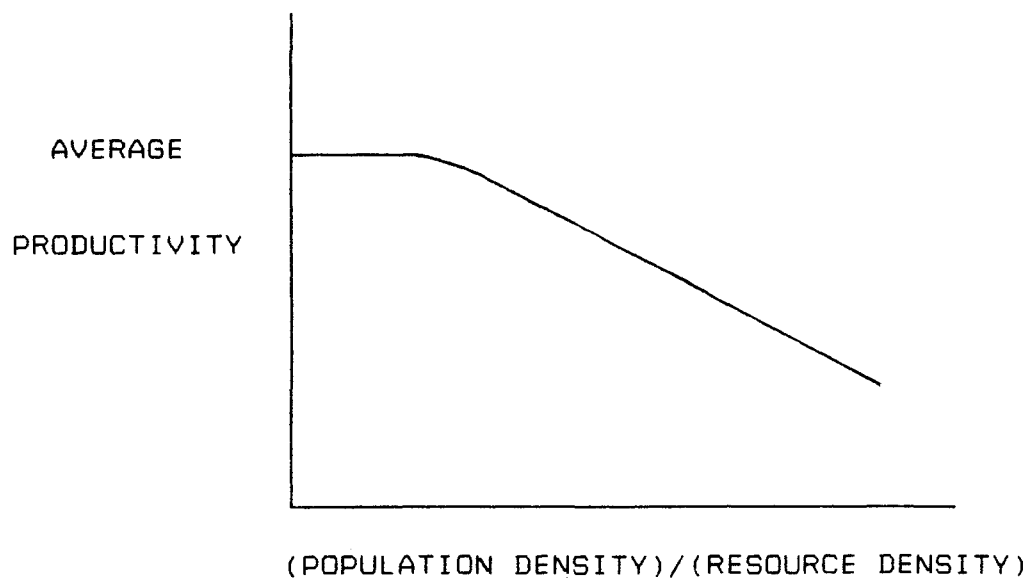


Figure 4. Average foraging productivity curve in relation to the (population density)/(resource density) ratio. The average overall productivities steadily decline when the ratio increases.

CHAPTER III

DYNAMICS OF SUBSISTENCE CHANGE

Technology

Technology has often played a central role in human ecological theories. A wide range of postulated roles have been suggested for the influence of technology on human ecological change. From a systemic ecological viewpoint, technology is a energy-manipulating variable and a limiting factor for the production of goods and services; and thus should be characterized by the types of inputs used, output mix, and the quantitative relationship between inputs and maximum output (Zubrow 1975:33).

The development of technology has increased production in order to satisfy increasing demands, which may either be the result of an increasing population with the same demands, or the same population with increasing demands, or both (see Zubrow 1975:33). As a result, technology has contributed to population growth and, consequently, to the creation of new demands. Thus, technology must continuously develop to increase production in order to meet ever-emerging new demands.

The human species has increased its survivorship through cultural adaptation. The most important element of cultural adaptation is arguably technology. Cultural evolution has occurred primarily through the development of technology.

Technology can permit the human species to increase its survivorship, and hence increase the rate of population growth.

In general, technology is cumulative. In most cases, it develops over a period of time. Technology can increase carrying capacity in two ways. First, it can broaden the resource spectrum and allow people to substitute, to some limited extent, an abundant resource for one that is scarce (Kirchner et al. 1985:47). Second, technology can reduce procurement costs by increasing the procurement efficiency. In both cases technology can increase carrying capacity through increased procurement productivity.

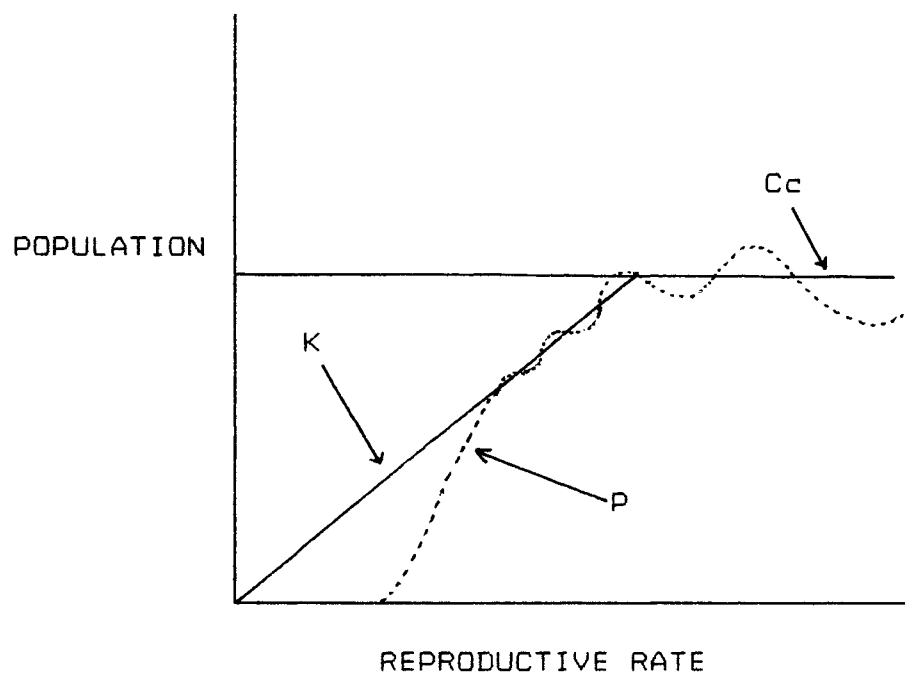
While technological advances can expand the carrying capacity of a region to a considerable extent, theoretically they will ultimately reach diminishing returns, and do not make unlimited population growth possible (Kirchner et al. 1985:48). Technology itself cannot increase either environmental productivity nor environmental carrying capacity.

Population

All populations have a biotic potential, that is the ability to grow (see Zubrow 1975:20). No population, however, can grow infinitely. Population size is regulated mainly by the finiteness of resources. This regulation necessarily leads to density-dependent effects on the growth of a population. The population size usually approaches the demographic carrying capacity. If

the population size is not controlled, it will exceed the carrying capacity owing to its intrinsic tendency to grow. Overly large populations are usually subjected to Malthusian checks, and population size falls below the carrying capacity. Despite Malthusian checks and temporary reduction of population size, the tendency to grow soon reasserts itself and the population again exceeds the carrying capacity. The overextended population size may undergo Malthusian checks again, thus continuing to repeat the cycle.

As technology develops, procurement productivity increases, and so does the demographic carrying capacity. The development of technology tends to increase not only demographic carrying capacity, but also the "reproductive rate" (the number of offspring produced by an individual per unit time) of the population, which permits the population to increase more rapidly than before. This causes the population to exceed the demographic carrying capacity to a greater extent than before, and consequently, population reduction by Malthusian check will be greater. As the reproductive rate increases, the amplitude of population fluctuation becomes larger and larger (see Yodzis 1989)(Figure 5). As technology continues developing, the increasing demographic carrying capacity ultimately reaches the maximum, that is environmental, carrying capacity. From then on, excessive population growth has negative effects on the resource base. Managing such environmental degradation is difficult because the decline of carrying capacity is usually evident only



Cc: Environmental Carrying Capacity
K: Demographic Carrying Capacity
P: Population

Figure 5. Population curve in relation to reproductive rate. Population fluctuates with increasingly greater amplitude along carrying capacity curve with increases in reproductive rate.

some time after the damage has been done, and because over the short term the productivity of the resource has actually increased (Kirchner et al. 1985:46). From this point, additional population growth would begin to cause severe population pressures. In such a situation, if population size is uncontrolled, it will undergo Malthusian check to a greater extent than ever, and the amplitude of population fluctuation also will also be greater than ever (Figure 5). At this level, continuous population pressure becomes a grave human problem and it cannot be settled only through technological advances. Population pressure begins to play a central role in cultural evolution.

Diminution of Carrying Capacity

Population, if not controlled, will usually exceed the carrying capacity because carrying capacity does not immediately regulate population size. There is a time-lag in the population's response to its own density, caused by a time-lag in the response of its resources (Begon et al. 1990:224).

If population size exceeds the carrying capacity without a advance in supporting technology, it will be regulated. If technology develops further, carrying capacity would also increase owing to increase in productivity. When technology develops to the extent that the demographic carrying capacity becomes equal to the environmental carrying capacity, surplus

population that exceeds carrying capacity will degrade its resource base, and from then on the "law of diminishing returns" will come into play. Cohen (1977:48) describes such a phenomenon:

"carrying capacity" concept....implies the existence of fixed population ceilings related to the productive capacity of the environment. According to this mode there is a specific fixed maximum level of consumption of any resource which the environment can tolerate. Consumption at or below this level is compensated for by the regenerative power of the resource. Consumption above this level exceeds the regenerative power of the resource and results in the destruction of the system.

Another, relevant example of this is given by Kirchner et al. (1985:45):

ranchers must assess the carrying capacity of the range and control the grazing herds accordingly. If the herd size exceeds the long-term carrying capacity of the range, immediate starvation (as in the case of the forest deer) is unlikely. Instead, the animal production of the range probably will increase for a brief period. Over the short term, more grass will be converted to meat. Over the long term, however, overgrazing will interfere with the reproduction and growth of the range grass, ultimately causing irreversible damage to soil productivity, thereby reducing the number of animals that the range can feed. Overgrazing boosts animal production briefly, but it does so at the expense of permanently eroding the carrying capacity of the rangeland resource base.... A useful analogy is an interest-bearing bank account. The "carrying capacity" of the bank account is the interest. It is possible to siphon off the interest without impairing the account's ability to produce more interest. However, if money is withdrawn from the account faster than it is being generated (thereby temporarily increasing the "yield" from the account) the process is unsustainable, as the future "carrying capacity" of the account is reduced. Similarly, the carrying capacities of some ecosystems can be exceeded for a while, but they cannot be exceeded sustainably.

As this example illustrates, it is usually possible for population size to exceed the carrying capacity of a given region temporarily. A renewable resource base cannot sustain a population beyond its carrying capacity indefinitely, however,

and will suffer a reduction of its inherent productivity as a result of being overexploited (Kirchner et al. 1985:46). Such overexploitation leads to a decrease in environmental carrying capacity and to more severe population regulation. Thus, environmental carrying capacity is not fixed. It can be lowered by environmental degradation caused by overexploitation. The more severely degraded, the longer it takes to regenerate. Thus, once the population exceeds the environmental carrying capacity, it will cause the environmental carrying capacity to diminish, and as a result, Malthusian check will be more severe.

Migration

We may assume that hunter-gatherers tend to move to more productive areas for foraging. This "primary migration" is mainly aimed at finding an optimal foraging region, and it is one of the optimal foraging strategies. One apparent case is the migration of prehistoric people into higher latitudes, accomplished by virtue of advanced technology, toward the end of the Middle Pleistocene, sometime more than 100,000 years ago. This can be traced from the distribution of Acheulian and contemporary tools, and from the distribution of fossils of the *Homo erectus* type (Cohen 1977:86). Cohen (1977:86) describes this migration as follows:

[*Homo erectus*] now inhabited much of temperate Europe, including southern England, parts of France, and central Europe; the southern portions of the Caspian Sea region; and eastern Asia approximately as far north as Choukoutien, near

Peking, while continuing to occupy Africa and the tropics. In the period between 100,000 and about 40,000 years ago, man further expanded the northern boundary of human settlement, entering for the first time such regions as central Germany, southern Poland, the southern Russian plain, the Iranian plateau, Turkmenia, Uzbekistan. Between about 40,000 B.P. and the end of the Pleistocene, modern man further extended the range to include northern Europe as far as southern Scandinavia, a good deal of Russia, Siberia at least to 61 degrees north latitude. At about the same time populations began to colonize the New World, as well as Japan and Australia.

Although the role of population pressure is rarely considered in this northward expansion of population in the Pleistocene, there would seem to be little question that the movement represents an increase in overall population; and it would seem probable, too, that the motivation for expansion is in some way related to an imbalance between human populations and their selected resource base within their traditional territories (Cohen 1977:87).

Once people reached a region they regarded as optimal, they would settle there. As long as the resources were sufficient for the population density of the region, they would remain; because, as they are already adapted to the environment, migration elsewhere would probably involve significant costs and risks. However, if the population grows, for whatever reasons, and exceeds the environmental carrying capacity, growing population pressure would force them to either control their population size, or undergo Malthusian checks. One way to avoid such population controls is "secondary migration" to marginal regions. Colonization of previously unoccupied territory is an effective way to avoid diminishing productivity caused by high population

density. Despite being marginal, new territory would be more productive owing to less population density. In the new territory, the process of diminishing productivity would repeat itself, and another out-migration would be needed. Thus, we would expect the following sequence of events: first, a population fills up the optimal zone to carrying capacity; later, a second zone fills up to a smaller carrying capacity; then, later, a third zone fills up (Zubrow 1975:29). Presumably, it was by this mechanism that the human species has colonized the entire globe, even to the arctic regions where conditions are very unfavorable for human habitation. Migrations proceed with a long-term tendency toward the development of uniform productivity throughout the world.

Sedentism

Archaeologists tend to connect sedentism with agriculture, and to accept evidence of agriculture as presumptive proof of a relatively sedentary life (Rindos 1984:172). However, some evidence suggests that sedentism and large group aggregations were achieved in many parts of the world without agriculture, and often, in fact, without any evidence of significant new technology (Brown 1985:201; Cohen 1977:37). Sedentism thus is not restricted to agricultural peoples: fishing and foraging peoples have frequently achieved a settled way of life, which means not only that agricultural practices need not be presumed to be the

only route to sedentism, but also that the processes leading to agricultural settlement may be initiated and modified by extrinsic factors (Rindos 1984:173). Similarly, some authors (Sauer 1969; Watson and Watson 1969) have suggested that sedentism was necessary as a precondition for agriculture since it permitted not only familiarity and experimentation with local flora but also long-term observation and investment in vegetable resources (Cohen 1977:9). Several recent authors have even proposed that sedentism is a cause of the origin of agriculture (Rindos 1984:173).

Although the connection between sedentism and agriculture cannot be disputed in most cases, we now have evidence that sedentism is not always a precondition of agricultural development (Cohen 1977:9). Sedentism has apparently preceded developed agricultural systems in certain parts of the world, whereas in other places agricultural systems have become established long before the advent of settled village life (Rindos 1984:173). For example, prehistoric people living in Guitarrero Cave in the Peruvian Andes and the Pawnee Indians engaged in farming while maintaining their mobile lives (see Lynch 1980; Meyer 1977).

It was once thought that since sedentary modes of life were naturally beneficial, when the necessary conditions were present sedentism was adopted by preference (Brown 1985:202). But this idea has been challenged by many archaeologists since the 1960s (Brown 1985:202; Cohen 1985:101; Price et al. 1985:11). These

archaeologists view sedentism as more commonly a consequence of necessity rather than of choice, and believe that it is associated with new problems as many, or more, than with new opportunities (Binford 1983; Cohen 1977; Goodyear 1981; Woodburn 1982). Among the new problems are new parasitic diseases, restriction on the range of dietary sources, and social conflicts.

Sedentism has been assumed to reduce procurement costs, such as transport and search cost, and biological stresses, particularly the burden on mothers carrying children in their arms or in utero (Cohen 1977:36). Certainly, there are some advantages to sedentism. However, the only advantages that I can identify associated with the sedentism of hunter-gatherers, are simply those related to the liberation of individuals from the burden of setting up a new camp and from carrying their food storage and processing appliances each time they move. I know of no evidence showing that sedentism reduces the overall procurement costs of hunter-gatherers, except for ones living in areas with abundant resources. The transportation cost for the food procurement by sedentary hunter-gatherers often exceeds that of mobile hunter-gatherers, because the sedentists have to travel farther in their quests for food as a result of the depletion of resources in the surrounding areas, and they have to transport procured items greater distances to their villages. Even though sedentism reduces some transportation costs in some cases, it cannot offset the increased cost of the intensification of

exploitation.

Moreover, some ethnographic evidence suggests that some hunting and gathering groups actually do not move all that much, and the stresses of mobility, even those associated with bearing children, have probably been overestimated significantly (Hassan 1973:535). Lee (1968:35) has shown that Bushmen do not frequently engage in long distance movements; they move their camps five or six times a year, and rarely more than ten or twelve miles from the home waterhole.

In addition, there is considerable evidence that hunting and gathering groups did not perceive any advantage in settling down, and hence much of the advantage that we perceive in sedentism may be a function of hindsight, or more importantly, may result from our own accustomed dependence on the capital goods that sedentism permits (Cohen 1977:37). The crux of my argument is that people usually adopt sedentism not because of the benefits of sedentism, but because of a reduction of the benefits provided by mobility.

Some basic causal arguments for sedentism have been identified by archaeologists, including shrinkage of the resource base; abundance or concentration of resources, often accompanied by a broadened food spectrum; and population growth (see Brown 1985:202). Whatever the cause may be, it is associated with the reduction of productivity advantages provided by mobility. In other words, sedentism emerges when the benefits of mobility, in terms of productivity, no longer exist. More specifically, shrinkage of the resource base reduces the benefits of mobility.

That is, mobility cannot contribute to increased foraging productivity in a situation where the resource base is spatially limited. On the other hand, an abundance or concentration of resources does not necessitate mobility, because people can maintain a high level of productivity without being mobile. As for Population growth, it makes mobility impractical because of the effect of social circumscription, that is, the surrounding units restrict the mobility of each other (for social circumscription see Chagnon 1968).

In brief, sedentism is a consequence of the process of intensification of either hunting and gathering or farming, and the feasibility of intensification depends on local food supply mainly determined by procurement productivity.

Pressure for Subsistence Change

To summarize, my theoretical position thus far is as follows. Prehistoric hunter-gatherers steadily increased their procurement productivity and, consequently, their carrying capacity through the intensification of exploitation of the resource base and/or through the development of technology. When their population size reached the environmental carrying capacity, a further rise in population density would have resulted in the overexploitation of their resource base in order to feed a continuously growing population. Overexploitation of the resource base usually results in a reduction of carrying

capacity, because overexploitation is necessarily followed by diminishing environmental productivity and the resource base needs rest and time to regenerate. The people would now face a Malthusian check caused by the reduction of carrying capacity. To avoid this check, three choices are possible: population control, out-migration to a new region previously unoccupied, and new subsistence modes which better accommodate the surplus population.

The ability to solve this problem through out-migration is limited due to geographical circumscription or, ultimately, the finiteness of global territory. Yet, if migration is restricted, and population growth is not controlled by other means, population size would eventually exceed the environmental carrying capacity. Subsequently, environmental productivity would decline geometrically, and population size would be regulated by Malthusian checks. From that point on, if not before, people will attempt to halt the decrease in their carrying capacity by any and all means. For example, they may try to broaden their food spectrum, even though such an attempt is not novel. Broadening of the food spectrum helps increase the carrying capacity to some extent, but has obvious limitations as a long-term solution.

The only long-term way to increase the carrying capacity is to undergo the subsistence change to food production. Although food production initially has low productivity, due to unfamiliarity, its productivity can be increased continuously by technological development. Moreover, it has a greater potential

for increase in production volume and is thus more responsive to population growth than food foraging. Food production virtually demolished the ceiling of carrying capacity.

CHAPTER IV

TRANSITION TO FOOD PRODUCTION

Prerequisites for Food Production

Both environmental and technical conditions must be right for the transition to agriculture to occur. The environmental conditions include climate, rain fall, soil qualities, and various ecological relationships. Environmental conditions favorable for agriculture had existed at least since the end of the last ice age (Wright 1977). Considering that food foraging seems to be a natural, innate and instinctive activity of every animal, and that there is no example of a nonhuman mammal engaged in farming, agriculture presumably requires the evolution of such conditions as intelligence, manual dexterity, and a certain level of technology. I assume that the human species already possessed the physical characteristics requisite for agriculture by 10,000 years ago, when it was adopted. As for technology, prehistoric people had considerably advanced technology for foraging and other activities. I have no reason to assume that these technologies were not useful within the context of agriculture. Thus, both the environmental and technical conditions suitable for agriculture existed at the time of agriculture's origins.

Diffusion or Independent Origins of Agriculture

Some scholars (see Carter 1977; Caldwell 1977) have tended to perceive agriculture as a single invention that diffused throughout the world. Many other anthropologists, on the other hand, have tended to assume that the knowledge required for agriculture is universal, and that what needs to be explained is not the availability of new knowledge but rather the process leading to the implementation of techniques which had previously been available (Cohen 1977:18). There is a fairly widespread consensus now among anthropologists that the basics of agriculture are universal knowledge. For example, Cohen (1977:19) states:

the knowledge that plants grow from seed is probably universal among hunters and gatherers and that this knowledge has probably been available to human groups since very early times, long predating its application in full fledged agricultural economies.

Similarly, according to Flannery (1968:68):

We know of no human group on earth so primitive that they are ignorant of the connection between the plants and the seeds from which those plants grow.

In many regions, moreover, there is evidence of a significant delay between the earliest evidence of cultivation and dependence on agriculture as a way of life (see Cohen 1977:26).

If it is conceded that most hunting and gathering populations knew about plant reproduction, why did people not adopt, or delayed the adoption of this system, when they were fully capable of implementing it?

Agricultural productivity was initially low when compared with hunting and gathering, because prehistoric hunter-gatherers were not familiar with farming, and the productivity of hunting and gathering, under optimal conditions, was relatively high. However, continuous increase in population density caused diminishing productivity of hunting and gathering, and when it fell below the level of productivity of agriculture, people should have been more willing to adopt agriculture in preference to hunting and gathering (Figure 6). While hunting and gathering is an extremely successful mode of adaptation for small human groups, it is not so successful for large or dense human populations (Cohen 1977:14).

On the other hand, an introduction of new foraging technology may suddenly increase hunting and gathering productivity. In such cases, farmers are likely to convert back into hunter-gatherers. For example, The introduction of rifle and horse in the great Plains in North America caused many farming tribes to change into the buffalo hunters.

Another point worth noting is that the timings and rate of the adoption of agriculture varied from region to region. This difference is due to variation in environmental conditions in each region. Other things being equal, hunter-gatherers living in an environment more favorable for agriculture than for hunting and gathering, are more likely to adopt agriculture earlier and more rapidly than a similar group living under the opposite conditions.

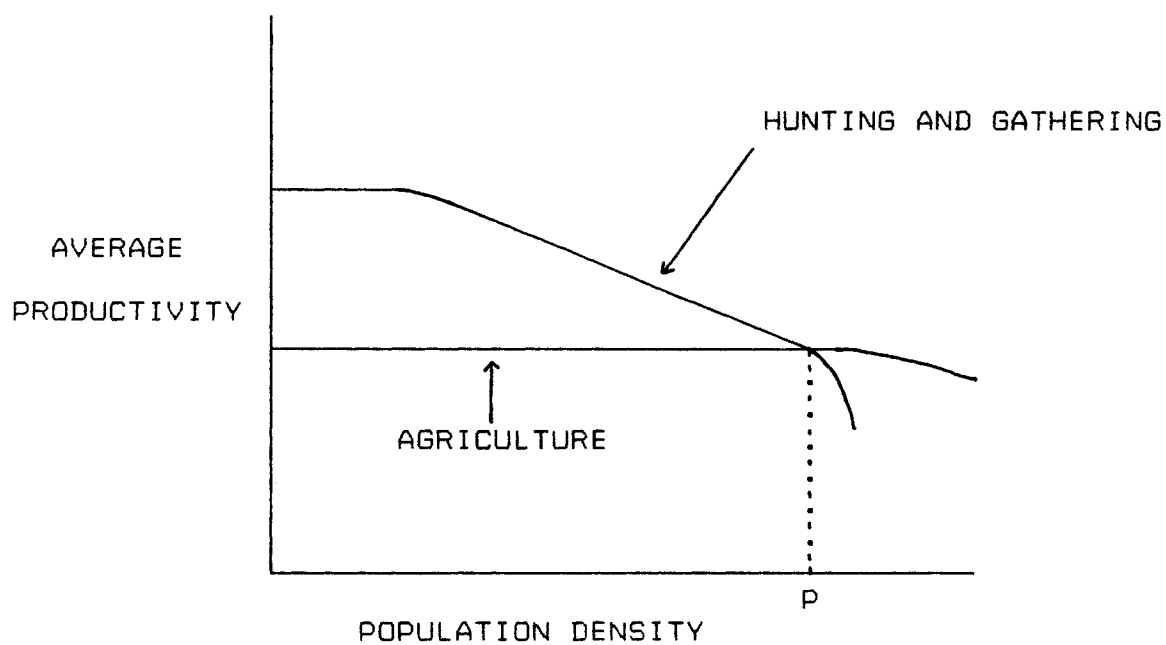


Figure 6. Average productivity curves for hunting and gathering and agriculture in relation to population density. The average overall productivity of hunting and gathering decline more sharply than does that of agriculture, with increased population density. P is the point at which the productivity of hunting and gathering and that of agriculture are equal. Around this point, people begin to adopt agriculture.

Dispersals of Agriculture

When the productivity of hunting and gathering drops to a point equal to or below the level of agricultural productivity, people should be willing to adopt agriculture, at least partially. In the beginning, ~~people would have adopted a limited set of food items and techniques of production, the productivities of which were higher than some aspects of hunting and gathering.~~ In other words, they would adopt only those food products more productive than those of wild foods, and they would invest time and energy in food production only to the degree that overall productivity was not lower than that of hunting and gathering in a given region at a given time.

For example, about 12,000 years ago, small groups of hunter-gatherers living in Guitarrero Cave in the Peruvian Andes grew beans in small gardens close to a nearby river, leaving the plants to fend for themselves while they hunted and foraged elsewhere (Fagan 1992:391). This pattern of early plant tending persisted in the Andes for many centuries. Other plants were probably grown and, like beans, served both as a supplementary food and as a means of expanding into marginal areas. Several thousands of years elapsed before these plants became economic staples (see Lynch 1980).

Some North American Plains tribes, such as the Pawnees, also often left their cornfields unattended through most of the summer while they hunted buffalo (Meyer 1977:64). For another example,

American Indians in the Southwest accepted maize and squash as a means of enhancing resource security or predictability, the potential productivity of which was much greater than that of the relatively unreliable wild resources in pinyon-juniper woodlands (Wills 1988:5). Thus, hunter-gatherers in transition to becoming farmers, tended to selectively adopt items and techniques of agriculture in ways that maximized the productivity of their foraging activities overall.

The productivity of agriculture persistently increases with the progressive development of agricultural techniques and technology regardless of the growth of population density, because an agricultural economies can absorb the population of higher density than hunting and gathering can. When the increase in agricultural productivity leads to increase in population density and the increased population density leads to depletion of resources, the productivity of hunting and gathering decreases more and more. Through such processes, the overall productivity of agriculture ultimately comes to exceed the productivity of hunting and gathering. Agriculture may thus seen as offering significant and obvious economic advantages to human populations in a situation with diminishing resources that once the appropriate level of technique was achieved dependence on the new economy would be inevitable. Thus, once some aspects of agriculture were adopted, people would depend more and more on agriculture, and less and less on hunting and gathering.

Despite the advantages discussed, people need not

necessarily adopt agriculture. Some groups of hunter-gatherers adhere rather persistently to a hunting and gathering way of life by maintaining a steady demographic state by internal mechanisms that limit numbers of offspring at the generational replacement level (a system termed a "closed population system", see Binford 1968:328). Binford (1968:326) describes a system of this type as follows:

functional relationships between the normal birth rate and other requirements...favor the cultural regulation of fertility through such practices as infanticide, abortion, lactation taboos, etc. these practices have the effect of homeostatically keeping population size below the point at which diminishing returns from the local habitat would come into play....These data suggest that while hunting-gathering populations may vary in density between different habitats in direct proportion to the relative size of the standing food crop, nevertheless within any given habitat the population is homeostatically regulated below the level of depletion of the local food supply.

If some hunter-gatherers thus avoid adopting agricultural systems even when they are fully available, then there must be some disadvantages to adopting it.

Prior to 1960, hunting and gathering groups were commonly pictured as existing near starvation, struggling constantly to find adequate food resources (Cohen 1977:27). An increasing number of anthropologists studying contemporary hunting and gathering populations, however, have challenge these traditional assumptions (Cohen 1977:27; Diamond 1987). For example, Cohen (1977:27) states:

a good deal of evidence is accumulating which suggests rather uniformly that the diet of hunting and gathering populations (outside the Arctic) may be calorically quite adequate, and at the same time richer in food variety, vitamins, minerals, and above all protein, than that of

agriculturalists. These recent studies suggest also that hunting and gathering involves activities widely preferred to those of agriculture and provide foods widely preferred for consumption to the main agricultural staples-grains and tubers; that the food supply of hunters gatherers may be reliable than that provided by agriculture; and that it may be obtained with as little, or even significantly less, labor than is necessary for agricultural production.

Diamond (1987) also states:

so-called primitive people, like the Kalahari Bushmen.... have plenty of leisure time, sleep a good deal, and work less hard than their farming neighbors. For instance, average time devoted each week to obtaining food is only 12 to 19 hours for one group of Bushmen, 14 hours or less for the Hadza nomads of Tanzania. One Bushman, when asked why he hadn't emulated neighboring tribes by adopting agriculture, replied, "why should we, when there are so many mongongo nuts in the world?"

According to a preponderance of ethnographic sources, hunting and gathering is by no means a inferior mode of life. For example, according to Diamond (1987), skeletons from Greece and Turkey show that while the average height of hunter-gatherers toward the end of the ice age was a generous 5'9" for men and 5'5" for women; height declined with the adoption of agriculture, and by 3000 B.C. had reached a low of only 5'3" for men and 5' for women. Even modern Greeks and Turks have still not regained the average height of their distant ancestors. For another example, the Bushmen are healthy, suffering less from kwashiorkor, the most common nutritional disease affecting the children of African agricultural societies, than neighboring agricultural peoples (Lee 1968:37). The Bushmen are also relatively long-lived, having a proportion of adults over sixty years of age of nearly 10 percent, which compares favorably to the percentage of elderly in industrialized populations (Lee

1968:36). In addition, the Bushman subsistence base is surprisingly dependable and predictable—so much so that Bushman life was not affected by a severe three year droughts in Southern Africa, while neighboring pastoralists and agriculturalists suffered so severely from famine that they were forced to depend on a famine relief program from the United Nations (Lee 1968:39).

While these advantages of hunting and gathering over agricultural systems lead some hunter-gatherers to maintain this subsistence mode by choice, other hunter-gatherers, like the native Americans at Dickson Mounds, abandoned hunting and gathering and took up farming not by choice, but from necessity in order to feed their constantly growing numbers (Diamond 1987).

Why, then, were the majority of hunting and gathering societies replaced by agriculturalists, even though many hunter-gatherers prefer hunting and gathering to agricultural systems?

Natural selection seems to have been at work in this replacement. Agricultural systems may be described as having greater fitness than hunting and gathering in that people in agricultural system leave more offspring, than do hunter-gatherers. This difference in reproductive rates between these two types of societies is mainly due to the fact that while hunter-gatherers control their population to avoid diminishing returns, farmers do not, since food production can accommodate population growth more flexibly.

One consequence of population growth under conditions of food production is an increase in the relative importance of

emigration as a mechanism for maintaining the local group within limits of optimal size and density (Binford 1968:332). Therefore, where there is a marked contrast in the degree of utilization of food production between two sociocultural units, there would be a tension zone where expanding colonies from the group depending more on food production would periodically disrupt the density equilibrium balances of the group depending less on food production. Under these conditions there would be strong selective pressures favoring the development of more effective means of food production for both groups within this zone of tension (Binford 1968:332).

Thus, a population "frontier" would be expected between regions which differed widely in the degree of food production practiced by the resident groups. For example, the expansion of the Bandkeramik complex, an early European farming culture between 6500 and 6300 B.P., created a "frontier" in many parts of Europe between farming communities and Mesolithic groups (Dennell 1983:173). They knew of one another's presence, traded with one another, and interacted through an intricate web of contacts that were beneficial to both sides; the Mesolithic peoples were undoubtedly well aware of cereal crops and domesticated animals; but in many cases, they saw no advantage in adopting a new way of life that involved a great deal more work with few significant changes in the diet (Fagan 1992:337).

Continuous population growth in agricultural societies demands more arable lands. This tendency forces them to expand

into the territories of hunter-gatherers, and eventually, the former replaces the latter. For example, the farmers of prehistoric southern Scandinavia moved into and settled hunter-gatherer territory in competition for land with the indigenous residents (Zvelebil et al. 1986). Such competitions were usually accompanied by conflicts between the two groups. The evidence of these conflicts resides in the substantial fortifications found in early Bandkeramik settlements in Belgium (Keeley et al. 1989), which may have been erected for short-term protection against local hunter-gatherer bands trying to recover territory taken from them by the farmers (Fagan 1992:339). As time went on, food production became extensive and widespread, with farmers eventually displacing the hunter-gatherers, and the frontier finally vanishing (Fagan 1992:338).

Despite the expansion of farming populations, a few hunting and gathering societies continue to exist by virtue of geographical isolation; or, more commonly, because their marginal environment is of little interest to their farming neighbors (Cohen 1977:37).

CHAPTER V

THE ARCHAEOLOGICAL MEASUREMENT OF PRODUCTIVITY DIMINUTION

The absolute procurement productivity of a society can be measured using such data as foraging technology, environmental conditions, demographic conditions, and food items consumed. In the case of a prehistoric society, the problem is complicated because of the fact that our standard methods for reconstructing these overall economic conditions are fairly crude. However, we can find some clues for measuring relative productivity even for a prehistoric society. The most clues might come from the catchment areas foraged or the items consumed. Cohen (1977) suggests a number of types of evidence for prehistoric population pressure. These offer lots of hints as to evidence which might be used to measure prehistoric diminution of productivity as well. The list, mostly constructed from his suggestions, is as follows:

1. It is possible to estimate transportation costs by comparing the transporting technology in the society with the distance between the base camp and catchment areas, or from catchment areas to consumption areas. Longer travel distances undoubtedly entail more costs than shorter ones. Therefore, if it is shown that travel distance for the food quest is increasing in the absence of an corresponding advance in transporting

technology, we may reasonably assume that the population is encountering a diminished foraging productivity near its home base.

2. Other factors being equal, the search and pursuit costs of foraging in an optimal zone is less than that of foraging in a more marginal zone. When a group expands into more marginal, previously unoccupied territories, this expansion may indicate a diminution in foraging productivity within the home territory.

3. Large mammals are a highly favored food in most cultures. When a group shifts from eating large mammals to eating smaller mammals, birds, and reptiles, a depletion of the resource or diminution in productivity of the large mammal hunting may be assumed.

4. When a group shifts from the consumption of organisms at high trophic levels to those at lower trophic levels (in particular, when it shifts from meat to plant foods), this shift may indicate a diminution in hunting productivity, resulting from the depletion of animals.

5. When a shift occurs from the consumption of foods previously requiring small procurement costs to foods requiring larger procurement costs, this shift may indicate a diminution of the former's productivity.

6. Broadening of the food spectrum may indicate diminution of overall productivity of preferred food items.

7. When the size or quality of individuals exploited from a particular species shows a steady decline through time (when, for

example, the size of molluscs in middens decreases), this decline may indicate diminishing productivity of the species, resulting from overexploitation.

8. When a population shows an increase over time in skeletal evidence of malnutrition, such as Harris lines and the reduction of height, we may assume that the population is encountering depletion of food resources.

9. The adoption of food production per se indicates a diminution of overall productivity of hunting and gathering.

CHAPTER VI

CASE STUDY: MESOAMERICA

The Beginning of Agriculture

One of the most important regions of the New World with respect to the development of early agriculture is Mexico, or the Mesoamerican region in general. This region has contributed by far the largest proportion of the native North American cultigens, and this area, on the basis of present evidence, appears to be the home of the three most important native food-crop plants: maize, beans, and squash (Cohen 1977:211). Mexico also has the longest archaeological record of domestication in the New World, and it is the one portion of the continent where a clear case can be made for the independent, indigenous development of agricultural technology, a case reasonably unclouded by controversies about the diffusion of crops from other regions, or even about the possibility of stimulus diffusion (Cohen 1977:211).

Archaeologists have intensively studied domestication in three localities of Mexico: the Tehuacan valley in the south central region, the state of Tamaulipas in the northeast, and the Valley of Oaxaca in the south.

Flannery (1973:287) outlines the beginning of agriculture in

this region as follows:

Sometime between the close of the Pleistocene and the start of the fifth millennium B.C., the Indians of Mexico first began the cultivation of a series of native plants which would later become the staple foods of ancient Mesoamerican civilization. For centuries these prehistoric inhabitants of the semiarid basins and valleys of Mexico, Puebla, Oaxaca, Morelos, Guerrero, and Hidalgo had lived off the land, learning the secrets of the wild vegetation—how to roast Agave to make it edible, how to make wooden tongs for picking the spiny fruit of the organ cactus, how to extract syrup from the pod of the mesquite, how to leach tannic acid from the acorn, how to find wild bean and wild onion flowers in the dense underbrush, and how to predict when they would be ready to harvest. They survived on the basis of collecting strategy with many alternate moves and alternate food sources, depending on whether the rains came too soon or too late, the spring was too cool or too hot, the deer were in the valleys or up in the forest, the pinyon nut crop was heavy or meager. Finally, by 5000 B.C., one of their ultimate strategies became the artificial increase of certain edible plants by selection and planting. Beans, squashes, pumpkins, amaranths, chiles, tomatoes, avocados came under cultivation not long after this date. But the most important of these was maize or Indian corn, which they so modified that these prehistoric Indians can be credited with having produced the greatest morphological change of any cultivated plant and with having adapted corn to the widest geographical change of any major crop plant.

It is remarkable that although early experiments in cultivation began in a context of broad-spectrum exploitation approximately 7000 to 8000 years ago, agriculture appears to have developed very slowly as an economic strategy; so that it is only by 4000 B.P. or later that sedentary populations make extensive use of domestic crops (Cohen 1977:212). Why did it take so long for the incipient cultivation to become full-time agriculture?

The late Pleistocene occupants of this region possibly experienced a decline in hunting resources and began to depend on plant foods, eventually adopting part-time cultivation as a supplementary subsistence strategy. The early cultivation of wild

plants undoubtedly had low productivity, but continuous domestication gradually increased the productivity to the extent necessary for full-time agriculture.

Climate

Significant late Pleistocene and early Holocene environmental changes took place in Mexico not long before cultivation began (Flannery 1986:9). The late Pleistocene climate was so cold and dry as to severely reduce the potential for wild cereals. With the post-Pleistocene climatic change about 11,000 years ago, there was an enormous expansion of the thorn-scrub-cactus forest, and a new suite of plants immigrated into the region, including the wild cereal grains (Wright 1977:297). Thus, the early Holocene saw the establishment of environment types in which so many of the wild ancestors of the early domesticates grew (Flannery 1986:10). I assume that these climatic changes played a role of increasing the potential productivity of agriculture, and consequently promoting the beginning of agriculture.

According to one model, the late Pleistocene occupants of Mexico lived primarily by hunting large game such as mammoth, mastodon, or horse, but with the extinction (or northward migration) of many large species at the end of the Pleistocene, hunter-gatherers were forced to rely increasingly on small game and plant foods (Flannery 1986:9). If this is the case, the

extinction of big game animals obviously became a cause of the decrease in the productivity of hunting. The increased dependence of the occupants on plant foods probably led them to acquire the knowledge and techniques needed to increase agricultural productivity through familiarity with the wild species.

Demographic Context

The population density in the Tehuacan-Oaxaca region is estimated to have ranged from a maximum that seldom exceeds one person per 5 square miles to one person per 50 or more square miles (Flannery 1986:39). This population density is not absolutely high, and lies within the range of other hunter-gatherers listed by Steward (1955:125). In this context, neither Cohen's population pressure model nor Binford's density equilibrium model explain why agriculture began so much earlier in this region than in other parts of North America. Flannery, who applied Binford's density equilibrium model to the development of agriculture in the Near East (Flannery 1969), is reluctant to apply the same model to Mesoamerica on the grounds that, prior to 5000 B.C., human population densities in those parts of Mesoamerica which he has surveyed are very low. Additionally, there is no area where he can document a population expanding so fast that it might have affected the density equilibrium of adjacent regions (Flannery 1973:296).

Major Cultigens

Maize (Zea mays)

There are two conflicting views on the origin of maize, Mesoamerica's most important economic plant (Galinat 1971:447; Flannery 1973:290). The traditional theory is that of Paul Mangelsdorf (1947), who believed that cultivated maize arose from a now extinct form of wild pod maize. His hypothesis provided grounds for a good deal of speculation about where in Mesoamerica (or in South America or even in the Old World) such a wild species might have existed and where and how many times it might have been domesticated (Cohen 1977:213). The modern theory, which was vigorously propounded in the early 1970's by a growing number of botanists, such as Walton Galinat (1971:447) and George Beadle (1972), holds that maize may be descended from its closest living relative, teosinte (Zea mexicana), or from an ancestor common to both. If this scenario is correct, the fact that teosinte is a native annual grass of the semiarid, subtropical zones of Mexico and Guatemala, from Southern Chihuahua to near the Guatemalan-Honduran border, provides a clue as to the approximate location of early centers of domestication (Cohen 1977:213). According to Flannery (1973:290), teosinte is a "short-day" plant which likes no more than 12 hours of sunlight a day, combined with warm temperatures. The teosinte fruit has seeds enclosed in very hard cupulate fruit cases which shatter naturally, and is hence very difficult to harvest efficiently. Nevertheless, it is used by

some Mexican Indians as a "starvation food." In addition, because of its brittle rachis and short period of peak maturation, it is most efficiently harvested by large work gangs, or "macrobands." Small "microbands" or individual families would take too long to harvest the whole crop before it shattered.

Teosinte seeds have been found in archaeological layers dated to about 7000 B.P. at Tlapacoya in the Valley of Mexico (Cohen 1977:214). The oldest known archaeological maize cobs from Tehuacan, Mexico that also date to about 7000 years in age have been assumed to be those of wild maize, and can be interpreted as being in the early stages of transformation from teosinte to maize through human selection (Flannery 1973:294). Had this primitive maize been domesticated directly from the teosinte, the history of maize would become a good deal simpler, and it would no longer be necessary to postulate the complete extinction of its ancestor (Flannery 1973:295).

Since there is no evidence that teosinte grew at any time in the Tehuacan sequence when the earliest corncobs were found, it would appear that maize arrived in Tehuacan from another region where it was already under cultivation (Cohen 1977:214). The question of where maize was originally domesticated is still unsolved.

According to Flannery (1973:291), teosinte is a weedy, pioneer plant which colonizes natural scars in the landscape: When cornfields are abandoned today, they are rapidly invaded by teosinte. If a group of hunter-gatherers cleared a campsite, the

following year they would return to find their former campsite a teosinte field. Moreover, wild runner beans and wild squash also occur naturally in such fields, with the beans twining around the teosinte. The Zea-bean-squash triumvirate appears thus not to be an innovation of the native population -nature provided the model.

Beans (Phaseolus)

The archaeological record of beans (Phaseolus) is somewhat easier to interpret because the wild ancestry of the domesticated species is more clearly defined and criteria for distinguishing wild and domesticated forms are relatively well established (Cohen 1977:215). Three species of beans, common beans (Phaseolus vulgaris), runner beans (Phaseolus coccineus), and tepary beans (Phaseolus acutifolius), have wild ancestors in Mexico. The oldest beans archaeologically documented are wild runner beans from Daxaca (8700-6700 B.C.) and from caves in Ocampo, Tamaulipas (7000-5500 B.C.) (Flannery 1973:300; Cohen 1977:215). Those from Daxaca belong to a species which was never domesticated, while the Ocampo runner beans are wild Phaseolus coccineus that appear to have been domesticated gradually (Flanery 1973:300; Cohen 1977:215). The common beans and tepary beans are known archaeologically in domesticated forms. Common beans occur in Tamaulipas between 4000 and 2300 B.C. and at approximately the same time in Tehuacan (Kaplan 1967:205). Tepary beans occur in Tehuacan about 3000 B.C. (Kaplan 1967:208).

The domestication of the common bean was accompanied by three critical changes: an increase in seed permeability, so that the beans did not need to be soaked in water as long; a change from corkscrew-twisted pods (which shatter when ripe) to limp, straight, nonshattering pods; and, in some case, a shift from perennial to annual growth patterns (Flannery 1973:300). Because beans are intimately associated with maize, both in the wild and in the diet of ancient Mesoamerica, it is also worth noting that beans are rich in the amino acid lysine, and since maize is deficient in lysine, the combination of beans and corn makes for a more complete plant protein (Kaplan 1965:360; Flannery 1973:300).

Squash (Cucurbita)

The archaeo-botanical history of the Mesoamerican squashes (Cucurbita) is difficult to unravel because in most cases the wild-squash ancestors are not known for certain (Flannery 1973:300; Cohen 1977:214). Three domesticated squash species (Cucurbita pepo, Cucurbita mixta, and Cucurbita moschata) can be ascribed considerable antiquity in Mexico, but apparently the interrelationships between the wild and cultivated squashes are not known well enough at present (Cohen 1977:214). Squash seeds occur as far back as 8000-7000 B.C. in caves in Oaxaca and Tamaulipas. These earliest specimens are probably all wild forms, or "weedy camp followers" (Flannery 1973:301).

It was the seeds that were originally important in wild

squashes, because they, for the most part, have flesh which is either so bitter or so thin and dry (like a gourd) that it cannot be eaten, while the edible flesh is a product of domestication (Flannery 1973:301). According to some archaeologists (Cutler et al. 1967:216), squashes tend to be "weedy camp followers" which do well on disturbed soils, such as the talus slopes of an occupied cave. Their wild forms resemble the bottle gourd which is one of the plants with the longest documented history of human use. They may have been originally domesticated by foragers who already knew and cultivated the bottle gourd and who therefore instantly recognized the squashes as potentially useful. At any rate, they are one of the oldest Mesoamerican plants whose human use can be documented, from Oaxaca to Tamaulipas.

Other Cultigens

The avocado was one of the four most common cultivated genera found throughout Mesoamerica at 1300 B.C. (Flannery 1973:299). Maize provided the carbohydrate, beans and squash seeds provided essential amino acids, and avocados provided fats and oils (Flannery 1973:300). According to Cohen (1977:216), avocados (Persea americana) occur probably as early as 7200 B.C. in Tehuacan. The seeds show clear signs of morphological domestication by 1500 B.C. Chili peppers (Capsicum annum), apparently wild, are found in Tehuacan layers dated to as early as 6500 B.C. The domestication of chili peppers is first documented in Tehuacan at about 4000 B.C. (Smith 1967). Amaranth

(Amaranthus sp.) is found by 4500 B.C. (and possibly earlier) in Tehuacan, but the dates for the beginnings of cultivation there are uncertain.

Productivity of Early Cultivation

Supposing that teosinte was ancestral to maize, why would such a plant have been domesticated in the first place?

Highland Mesoamerica, like the Southwest, has great contrasts in wild productivity between wet and dry years, and the cultivation of maize might have arisen as an attempt to even out the difference between these extremes by increasing the range of weedy, pioneer annuals (Flannery 1973:296). Whatever the cause, the origins of maize cultivation amount to a deliberate increase in the productivity of a "starvation food" which finally became a staple.

Foxtail grass (Setaria sp.) and teosinte are two of the grasses which grow in the tributary barranca of the semiarid valleys of the central and southern Mexican highlands. In a wet year, food collectors could count on a good Setaria harvest; in a dry year, on the other hand, the barranca zone harvest could only be raised to its usual level by augmentation with teosinte (Flannery 1973:296). It may be that the productivity of Setaria was far lower than that of teosinte and could not be much increased by the repetition of selecting and planting. Whereas, teosinte if it is the ancestor of maize, responded to cultivation

and selection with a series of favorable genetic changes which moved it in the direction of the much more productive species, maize. This may have tipped the balance in favor of increased attention to maize on the part of these prehistoric people.

Field studies in Oaxaca show that Zapotec Indian farmers do not consider cultivation and land clearance to be worthwhile unless a yield of at least 200 to 250 kg (shelled maize) per hectare can be expected (Kirkby 1973). This tendency apparently shows that productivity is a key factor in determining subsistence strategy. On the road from early cultivation to full-time agriculture, the productivity of maize increased. The earliest cobs (5000 B.C.) from Tehuacan suggest a yield of only 60-80 kg per hectare; later preceramic cobs (ca. 3000 B.C.) suggest yields of 90-120 kg per hectare; the yield of maize did not cross the critical threshold of 200-250 kg per hectare until sometime between 2000 and 1500 B.C. when permanent villages on good alluvial agricultural land became the dominant type of settlement in Mesoamerica (Kirkby 1973; Flannery 1973). It is a remarkable coincidence that the level of the productivity considered acceptable by modern farmers corresponds to the productivity at the time when prehistoric full-time farming first began in this region.

CHAPTER VII

SUMMARY AND CONCLUSION

In summary, there seems to be sufficient evidence to conclude that one mechanism which led to the origin of food production operated as follows: technological development led to increased procurement productivity, which led to population growth, which led to the depletion of resources; which, in turn, led to a decline in hunting and gathering productivity. When the climate became favorable for agriculture in the early Holocene, and as the productivity of hunting and gathering became lower than that of food production, people began to adopt agriculture, and developed this mode of subsistence as their economic base.

The origin of agriculture was not an event but a cultural process through which people coped with the changing natural and cultural environment. This process appears to have had a direction, that is, toward maximizing productivity within a given culture. In conclusion, the cause (or at least proximate cause) of the origins of agriculture is the maximization of productivity.

In this paper, I have explained the origins of agriculture in terms of productivity. Perhaps productivity is the dominant determinant of human decision-making behaviors, especially for economic concerns. Most forms of physical and cultural evolution

appears to be closely concerned with productivity. It is probable that all organisms and their behaviors evolve in the direction of maximizing their productivity. In the same manner, all cultural systems develop in the direction which maximize the productivity of their members. The higher the productivity of an individual or a group, the more fitness it has in terms of natural selection.

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