THE EMERGENCE OF AGRICULTURE

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IN SEARCH OF ORIGINS

This fresco by Diego Rivera illustrates the culture of corn and the preparation of corn pancakes. Maize was first cultivated, and ways to prepare it first developed, more than 4500 years ago in what is now Mexico. Biologists and archaeologists seek to gain a better understanding of such processes of domestication, using evidence such as the chipped stone hoes on the facing page, dating to between about A.D. 1000 and A.D. 1100.

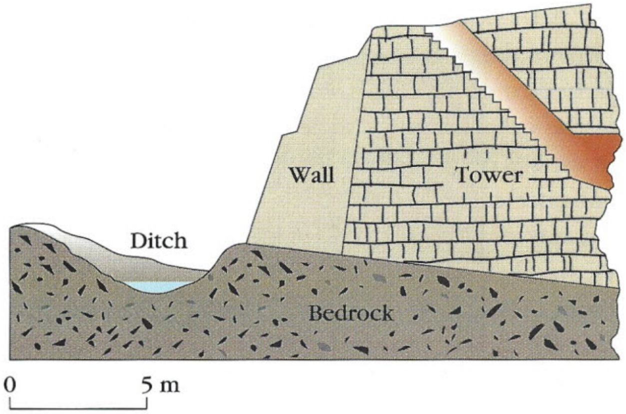
Within the boundary of the modern city of Jericho, in the Jordan Valley, lies the ancient city of Jericho. This older Jericho is a "tell," a large mound built up of the discarded mud bricks of layer upon layer of houses constructed over thousands of years. Near the bottom of this tell, buried beneath more than twenty-five layers of construction, archaeologists have unearthed evidence of a major turning point in human history: a 9000 year old farming village. Underneath this evidence of one of the world's first farming settlements, an earlier settlement was also excavated, where a hunter-gatherer group had camped to take advantage of the spring nearby. Like most camps of hunter-gatherer groups, this settlement

The Jericho Tower. With the formation of permanent villages came a willingness to invest in community building projects such as this 8.5-meter-high circular stone tower. The tower was erected 9000 years ago at the edge of the farming settlement at Jericho, and is shown exposed where two large excavation trenches intersect. Reached by an internal staircase (covered by the square metal grate), the top of the tower would have provided a vantage point for villagers to gaze out on a rapidly changing world.

was likely less than a thousand square meters in size (0.1 hectare); its remnants today consist of a scattering of circular house floors, discarded tools, and the remains of wild plants and animals.

The early farming village, however, found in an overlying layer, was dramatically different from this small hunter-gatherer camp. Covering an area of almost 2.5 hectares (6 acres), this early agricultural settlement contained larger mud-brick houses, and may have had a population of 300 people or more. Its growth was clearly supported by the harvest from nearby fields of cultivated crops like barley. Even more striking than the dramatic population increase, however, were the various signs of a growing organizational complexity. Large-scale construction projects at Jericho attest to the marshaling of considerable manpower. An elaborate system of ditches and walls was built, not for defense, but to divert floodwaters away from the expanding village. A large circular tower of unknown purpose, along with a variety of ritual objects, including plastered human skulls, reflect efforts to organize and unify a settled community of a size far beyond what the world had previously seen.

Ten thousand years ago, at the edge of this spring-fed oasis at Jericho, the world changed forever. The farming community established there foreshadowed the massive process of transformation that was to come. There were a few other small farming communities in the Jordan Valley around Jericho, and several others flourished in similar lake and riverside settings near the present site of Damascus and along the Euphrates. Over the next thousand years in the Near East, domesticated plants and animals would provide new, reliable food sources, shattering the total reliance on wild species that had defined the nature of human existence for millions of years. Created by humans, these new food sources could be stored, on the hoof and in silos, against future need, and had the potential of ever-expanding yields, the limits of which are only now coming into view.



Shown in cross section, the Jericho Tower and staircase, along with an adjacent stone wall and ditch, were once thought to have been built for defense. More recently, Ofer Bar-Yosef of Harvard University has determined that the walls and ditches of Jericho were designed to protect the settlement not from invaders but from floodwaters.

When these new agricultural economies emerged, they didn't just allow human population growth, they also fueled the creation of ever larger and more complex human societies, far beyond what had developed in hunting and gathering times. Large farming villages appeared as people were able to live permanently in higher densities. Such settlements were continuously occupied for thousands of years, and their remains often provide detailed archaeological records of the expanding complexity and scale of agricultural societies. Villages turned into towns, cities and city states gained control of growing agricultural landscapes, and empires emerged as our ancestors became more and more successful at organizing agricultural production and the populations it fed.

Although the Near East and China have yielded some of the earliest evidence of farming villages, the early farmers of Asia were the source of only some of the other farming societies that developed later in various regions of the world. Agriculture emerged not once or twice but many times, as quite different species of plants and animals were domesticated separately and independently in different regions. From each of these separate starting points, the first farming societies and their food-production economies developed along separate pathways up to the present day. Moreover, these early farming societies expanded into adjacent regions, where distinct agricultural landscapes in turn emerged and newly formed farming societies also began their separate historical pathways of development, each responding to changing local challenges and opportunities, both natural and cultural. It is the initial emergence and early expansion of this agricultural way of life, and the transformations in human society they made possible, that will be explored in the pages that follow.

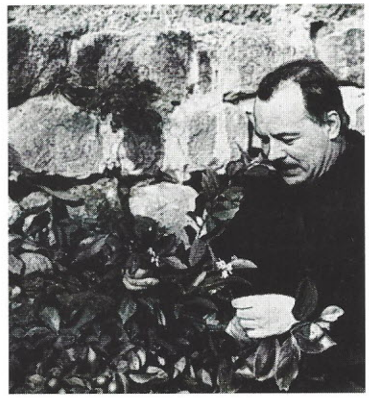
The spread of agricultural landscapes is now approaching an endgame as farmers encroach on zones of marginal productivity and ever-escalating potential costs. Each day, satellites passing over the Amazon rain forest of Brazil record the smoke plumes drifting up from piles of newly cut trees and other vegetation. Most of this land is being deforested so that it can be permanently converted to farmland. Using satellite imagery of these smoke plumes, a team headed by Alberto Setzer of the National Space Research Institute of Brazil estimated that 8 million hectares—about 20 million acres—of forest had been cleared in 1987 alone, at an annual deforestation rate of more than 2 percent. New satellite data have also provided startlingly high estimates of deforestation in India, Cameroon, Myanmar (formerly Burma), and Costa Rica. If these new studies are correct, the world is losing up to 20 million hectares (almost 50 million acres) of tropical forest annually.

The clearing of tropical rain forests represents just the most recent chapter in the long, complex, and still unfolding history of agricultural expansion. Each year more of the earth's land surface is transformed into cropland or pasture to feed a rapidly growing world population. In the Near East and North Africa 97 percent of the available arable land is now under production, while throughout Asia the agricultural frontier has expanded until now more than 80 percent of the potential cropland is being cultivated. In other regions of the world where land is still available for agricultural expansion, primarily sub-Saharan Africa and Latin America, relatively poor soils hold only limited promise as future farmland.

The increasing mechanization of farming since 1950 has accelerated our approach to the limits of agricultural expansion, but from a longer-term perspective we are seeing the continuation of the process that first began 8000 to 10,000 years ago in Asia and at approximately the same time in the Western Hemisphere, when human societies first domesticated plants and animals.

In view of the importance of the agricultural transformation of the earth, it is not surprising that scholars have long been interested in the origins of agriculture. The questions to be answered are numerous and diverse. How did agriculture begin? In what sequence and in what combinations were different species of plants and animals first domesticated in different parts of the world? Why were certain plants and animals domesticated and not others? What were the wild ancestors of these domesticates? Where, specifically, were certain plants and animals first domesticated? Why did agriculture emerge in some regions and not in others?

Answers to these and other questions are being sought by a broad spectrum of biologists and archaeologists. No one approach can uncover all of the relevant information, so scientists in many areas of biological and archaeological research are engaged in the quest for answers. Each of the various approaches holds the key to some answers, and together they can often produce impressive insights into this major turning point in human history. Two men, Nikolai Vavilov and Robert Braidwood, played central roles in establishing the biological and archaeological approaches to the origins of agriculture.



Nikolai Ivanovich Vavilov, Russian plant geneticist, began the search for agricultural origins through the study of modern plants.

Nikolai Vavilov and the Biological Approach

It may seem surprising to learn that some of the most interesting insights into the origins of agriculture have come not from investigation of archaeological sites, but through research on living organisms. The first concerted attempt to understand agricultural origins through this kind of research was undertaken in the 1930s by Nikolai Ivanovich Vavilov, a Soviet biologist and geneticist. Vavilov's efforts came to an end prematurely when he was imprisoned by Stalinist authorities in 1940 for his defense of genetics and opposition to T. D. Lysenko's teachings on the heritability of acquired characteristics, but before then he had visited fifty-two countries in a search for seeds of crop plants and geographical patterns of genetic diversity. He and other scientists from the All Union Institute of Plant Industry mapped the distribution and degree of genetic diversity of numerous crops throughout the world, and observed that some regions of the world exhibited extremely high levels of variation while others were relatively impoverished. In a small, isolated pocket on the Ethiopian Plateau, for example, Vavilov discovered hundreds of varieties of ancient wheat. He reasoned that since diversity in cultivated forms results from experimentation and deliberate human selection over time, the high degree of diversity in Ethiopian wheats indicated that this crop had been cultivated in the region for a very long time. The longer a crop had been grown, he reasoned, the more uses for it would have developed, and a variety of uses would be reflected in a variety of forms: corn for popping and for roasting, for use in medicine and in ceremonies, for example. More textures and colors could have evolved, as well as greater resistance to more pests and diseases.

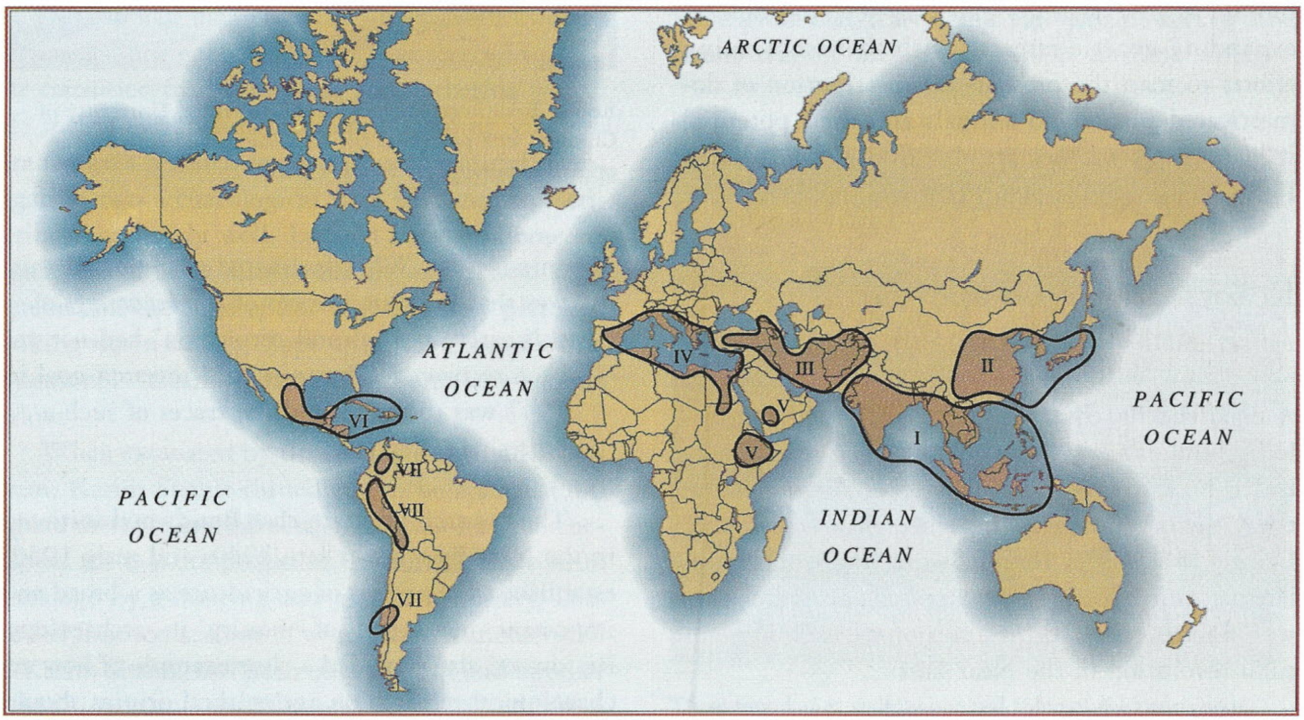
It seemed reasonable, almost inescapable, therefore, that the area where a crop plant had the greatest diversity of forms would also be the place where it was first domesticated. Vavilov proposed that by locating the center of a crop's genetic diversity, one pinpointed its origin. As he mapped the centers of diversity of more and more crops, he found that

Vavilov traveled widely throughout the world collecting seed and plant specimens and searching for centers of plant diversity. His route of travel during a 1930 expedition to North America took him to many regions of the United States and Mexico.

many overlapped. The Near East center of diversity of wheat, for example, overlapped the centers of barley, rye, lentils, peas, flax, and other crops. From 1926 until 1940 Vavilov was continually revising and updating his findings, and in 1940 his last synthesis outlined seven overlapping areas of maximum diversity for a variety of crop plants, and he identified these seven regions as the world's major centers of origin for cultivated plants.

Vavilov's central assumption—that the location where a crop plant was first domesticated is today marked by its geographical center of genetic diversity—has since been shown to have a basic flaw. Domesticates can, and did, originate in one region and then develop much of their diversity in another. Although Vavilov's centers of origin have been subjected to considerable rethinking, his work marks an important beginning in biological research on the origins of agriculture. Vavilov forcefully put forward identification of the centers of origin of the world's crop plants as a goal of biological and genetic research on domesticated plants. In so doing he staked out an area of inquiry that has proved very productive for later generations of plant geneticists and biologists. Vavilov also demonstrated the importance of active field research. Scientists continue to collect seeds and map the geographical ranges of crop plants around the world.

As we will see, later generations of scholars have expanded their mapping to encompass the wild relatives of domesticated crops—species that may have been the progenitors of the first domesticates. If the wild ancestor of a domesticate could be identified, and if it is assumed that the geographical range of the ancestor is the same today as it was at the time the plant was first domesticated, then the present-day range of the wild progenitor should define an outer boundary wherein to look for the area where it was first domesticated. The center of origin of a domesticated plant or animal could thus be established through the seemingly simple and straightforward process of mapping the present-day distribution of its wild progenitor. The value of such an approach of course varies with the size of the geographical range of the suspected wild ancestor. The small geographical ranges of the wild ancestors of domesticated sheep and goats, for example, help to define their areas of initial domestication, but cattle and pigs have such broad distributions that their ranges provide little help in establishing where they were first brought under domestication. In addition, the geographical ranges of wild plants and animals have changed, sometimes substantially, over the past 10,000 years, often as a result of expanding agricultural landscapes. Scientists can address the possibility of such changes over time, however, by



Vavilov's final map, published in 1940, showed seven centers of origin of domesticated plants: I, the tropical south Asiatic center; II, the east Asiatic center; III, the south-western Asiatic center; IV, the Mediterranean center; V, the Abyssinian center; VI, the Central American center; VII, the Andean (South American) center.

establishing the presence of potential ancestor species in archaeological sites of different time periods and at different locations. In this way, they can chart the geographical range of a species in the past.

Another problem is how to identify the wild ancestor of a domesticate. It is seldom easy to establish which of several possible progenitor species actually gave rise to a present-day domesticate, given the long and complex intervening history of genetic manipulation and diversification. Remarkable strides have been made in this area, however, with the development of powerful new procedures for directly comparing the genetic composition of domesticates and their wild relatives. As a result it is possible to identify wild ancestors with confidence. When biological investigators pair this new and rapidly expanding genetic research with their continuing efforts to map the present-day distribution of domesticated plants and animals and their potential wild progenitors, they are able to throw increasing light on the origins of agriculture.

Robert Braidwood of the Oriental Institute, University of Chicago, who pioneered the archaeological search for the origins of agriculture in the 1950s.

Robert Braidwood and the Archaeological Approach

A parallel scholarly tradition of concerted archaeological inquiry into the origins of agriculture can be traced back to the 1940s and Robert Braidwood of the Oriental Institute, the University of Chicago. During World War II, Braidwood began to formulate an interdisciplinary research program that would focus on the beginnings of the early agricultural revolution in the Near East:

> *What would we learn,* we wondered, were we to concentrate on the threshold of cultural change that must have attended the very earliest use of effectively domesticated plants and animals. . . . What fascinated us about all this was that excavated traces of the *beginnings* of this early "agricultural revolution" had not yet been recovered. Thus our field research goal in 1947 was to try to find the traces of such a "threshold."

The research program that Braidwood initiated in the Near East in the late 1940s and early 1950s established the origins of agriculture as a broad and important new field of inquiry in archaeology. Braidwood also provided a clear example of how archaeological research on agricultural origins should be structured and carried out. The basic strategy he used so successfully in the Fertile Crescent was quickly adopted and applied in other regions, and today provides the basic approach employed throughout the world by archaeologists studying agricultural origins.

What were the key elements of Braidwood's approach? First, he reasoned that the best place to attempt to find archaeological evidence of the transition to an agricultural way of life in the Near East was in the "natural habitat zone for all potential domesticates." This reasoning led him in the late 1940s to the remote Chemchemal Valley of northeastern Iraq, near the southern margin of the Zagros Mountains, and well within the geographical range of all the wild ancestors of the seven major Near Eastern domesticates (barley, emmer and einkorn wheat, goats, sheep, pigs, and cattle).

The Chemchemal Valley also clearly contained the second key element required by Braidwood's approach—ancient settlements that seemed to span the transition from a hunting and gathering way of life to the establishment of early farming villages. Braidwood's research team selected for initial investigation two archaeological sites that met this criterion remarkably well. Located only 2 kilometers apart, the sites of Karim Shahir and Jarmo were perched on the edge of flat-topped grassy plateaus, looking down a steep slope onto the Cham-Gawra, a seasonal stream meandering some 40 meters below.

When excavated by Bruce Howe of Braidwood's team, Karim Shahir turned out to be a small (500 square meters) seasonal settlement that had been occupied for a short period of time more than 9000 years ago by a hunting and gathering society. Discarded flint tools, some of which were manufactured at Karim Shahir, had been used to hunt and butcher wild animals, mostly sheep and goats, judging from the animal bone fragments recovered during excavation. Other stone tools attested to the pounding and grinding of seeds and other wild plant materials. A few small fire hearths and cooking pits and a pavement of river cobbles provided the only other evidence of the activities of the small group of hunter-gatherers that briefly lived at Karim Shahir. Their movements tied to the seasons, to the annual ripening of wild wheats and barley at different elevations, and to the corresponding movement of wild herds of sheep and goats to higher pastures as spring turned to summer, hunter-gatherer societies on the margin of the Zagros Mountains would have occupied a number of settlements like Karim Shahir in any given year.

Located 2 kilometers downstream from Karim Shahir, and dating perhaps 500 to 1000 years later, the site of Jarmo hosted a way of life that was worlds apart. Here, in the early 1950s, Braidwood encountered clear and convincing evidence of a very different way of life—a permanent farming village.

These foundation walls supported some of the contiguous rectangular mud-brick houses of the farming village at Jarmo about 8700 to 8000 years ago. This remarkably preserved community plan of an early agricultural settlement was uncovered at a depth of more than 2 meters during Braidwood's excavation.

Excavation down through more than 5 meters of deposits uncovered the history of this agricultural community recorded in a vertical sequence of rectangular mud-brick houses.

The early farming village at Jarmo was likely occupied for anywhere from two to seven centuries somewhere around 8700 to 8000 years ago, and appears to have had, on the average, perhaps twenty-five households and a population of 150 to 200 people. Careful excavation up through the successive building layers at Jarmo provided considerable information about the way of life of these early agriculturalists: what their houses looked like and how they were arranged in a community plan, how large the settlement was and the size of its population, what tools they manufactured and used, how and where they prepared and cooked their food, and what materials they traded for and from where. All this information about the people of Jarmo provided a human, cultural context for considering the central questions of agricultural origins and the initial domestication of plants and animals.

This then brings us to the third key element of Braidwood's research strategy: he included scientists from the biological and earth sciences in a coordinated interdisciplinary approach to the question of the emergence of agriculture. Specialists in their fields were asked to seek evidence of what the climate was like when Jarmo flourished, to reconstruct the environment around the settlement, to identify and analyze the animal bones and plant remains recovered during excavation, and to look for ways to distinguish the wild from the domesticated in the scattered and fragmentary bits of bone and seeds that had survived 8000 years in the ground.

These were not easy tasks in the early 1950s, for little was yet known about how the seeds and bones of domesticates preserved in archaeological sites could be distinguished from those of wild plants and animals. Braidwood's pioneering interdisciplinary approach addressed this critically important challenge, and as we shall see, the analysis of plant and animal materials from archaeological sites has now matured into two well-established disciplines, and clear criteria for identifying domesticated plants and animals have been developed.

In the four decades that have passed since Braidwood's landmark project, the search for agricultural origins in the Near East has expanded to encompass much of the Fertile Crescent. As more sites have been excavated and more information recovered, sites such as Jarmo and Jericho have become part of a much larger and more complex story, as their study has become integrated into that of the entire region. But Braidwood's emphasis on an interdisciplinary approach and on establishing a human, cultural context can be seen today wherever archaeologists search for the beginnings of a farming way of life.

We can see, then, that the archaeological approach to agricultural origins in large measure complements biological research focused on present-day populations of plants and animals. Archaeological research not only offers independent confirmation and an often tighter geographical delineation of the areas of initial domestication; it also provides a date for the origins of agriculture and reveals the pace at which agriculture emerged.

Archaeological excavation of early farming settlements in various regions of the world is the only means of directly observing the economic and cultural context of domestication and the transition to farming. It is this social and economic background that provides a basis for understanding not only when and where plants and animals were domesticated but the process of domestication itself—how and why human societies initiated new relationships with certain wild species and began to intervene actively in their life cycles. What kind of human societies first domesticated plants and animals, and what prompted them to do so? How large and how permanent were these early agrarian settlements? Which species of plants and animals did these people use for food before they began to domesticate some of them? What attributes or characteristics, if any, may have preadapted some wild food sources to human manipulation and domestication? Were different species brought under domestication together as part of an integrated economic strategy? What kinds of changes can be seen in these human societies once they began to invest time and energy in managing domesticates and producing their own food? Did domesticates quickly occupy center stage in rapidly expanding farming economies, or was agriculture slow in developing? Such questions can be answered only through archaeological investigation of human settlements and by careful analysis of the human societies that first developed farming long ago.

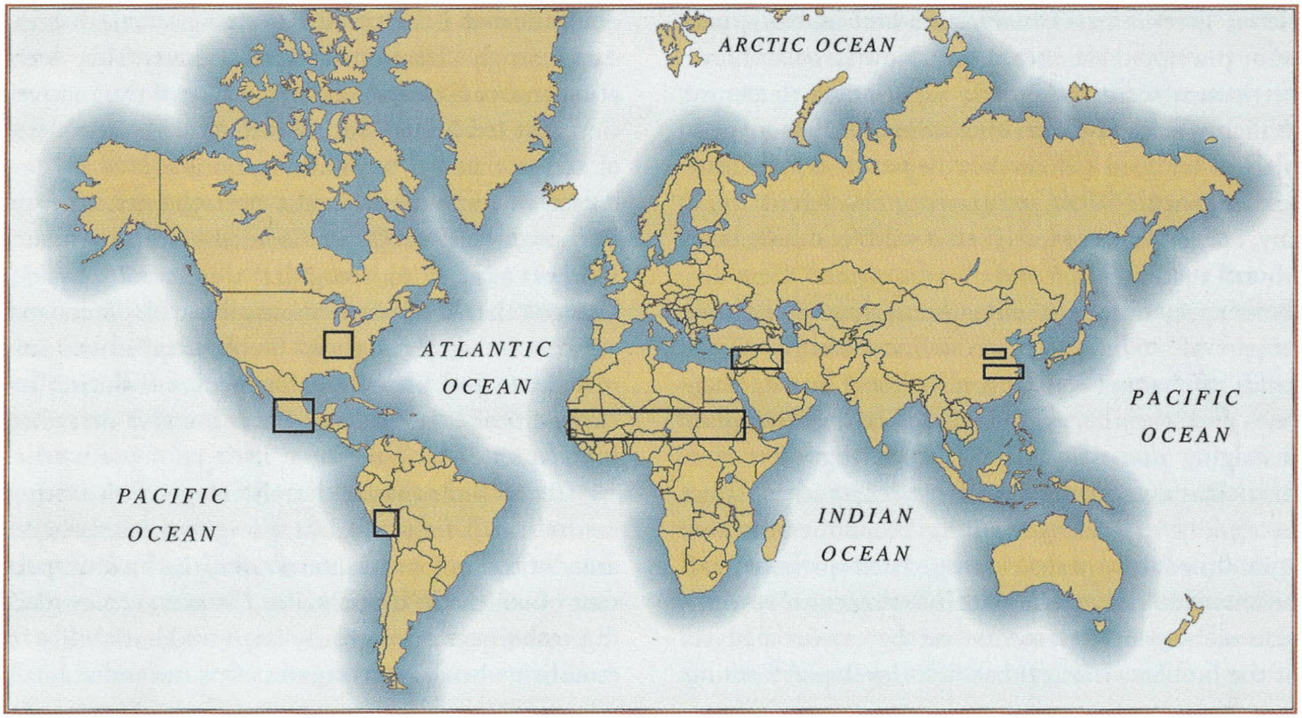
The two parallel scholarly traditions of research on agricultural origins, one focusing on present-day populations of domesticates and their wild relatives, the other directed toward archaeological evidence, thus offer solutions to different parts of what is a large and multifaceted problem. In the decades that have passed since Vavilov and Braidwood laid the foundation for the biological and archaeological approaches to agricultural origins, a number of advances in knowledge and available technology have been made, the most important of them coming in the 1970s.

Advances in Theory and Technology

Researchers in both the biological and archaeological sciences have dramatically improved our understanding of how plants and animals were actually domesticated—the specific human actions that resulted in the creation of domesticates. They have also come to a clearer understanding of the motivation that led human societies to embark on courses of action that led to domestication, as will be discussed in some depth in the next chapter. In part, they owe their success to remarkable improvements in their ability to recognize the actual physical changes that indicate domestication in plants and animals—changes that can be observed in the animal bones and plant remains recovered during archaeological excavation and that are also described in Chapter 2.

Today biologists and archaeologists also bring to the search for agricultural origins an impressive array of technological innovations, the most important of which are described in Chapter 3. New dating techniques have greatly improved our ability to establish when various species of plants and animals were first domesticated. New methods of excavation have substantially increased the amount of plant and animal remains recovered from archaeological sites. New microscopes have made it possible to identify extremely small markers of domestication in plants. Similarly, an array of new biochemical techniques have made it possible to identify with considerable accuracy the wild populations that gave rise to different species of plants and animals. These tools of the trade have been successfully employed in different parts of the world in the search for the origins of agriculture.

Archaeological and biological research on the emergence of agriculture has not progressed uniformly around the world. In some regions, such as the Near East (discussed in Chapter 4) and eastern North America (Chapter 8), the two approaches have given us a good outline of the transition from hunting and gathering to a farming way of life. The small area of the Near East known as the Fertile



The seven areas of the world where the independent domestication of plants and animals led to the emergence of agriculture.

Crescent witnessed the earliest development of an agricultural economy in the world, about 10,000 years before the present (B.P.). When it was fully formed, about 8000 years ago, this first agricultural economy was remarkable for its inclusion of a large number of both plants and animals that would become important in agricultural economies throughout the world (barley, wheats, lentils, sheep, goats, cattle, pigs). We now have a clear general picture of the domestication of all of these species and the development of agricultural economies in a complex process that spanned 2000 years.

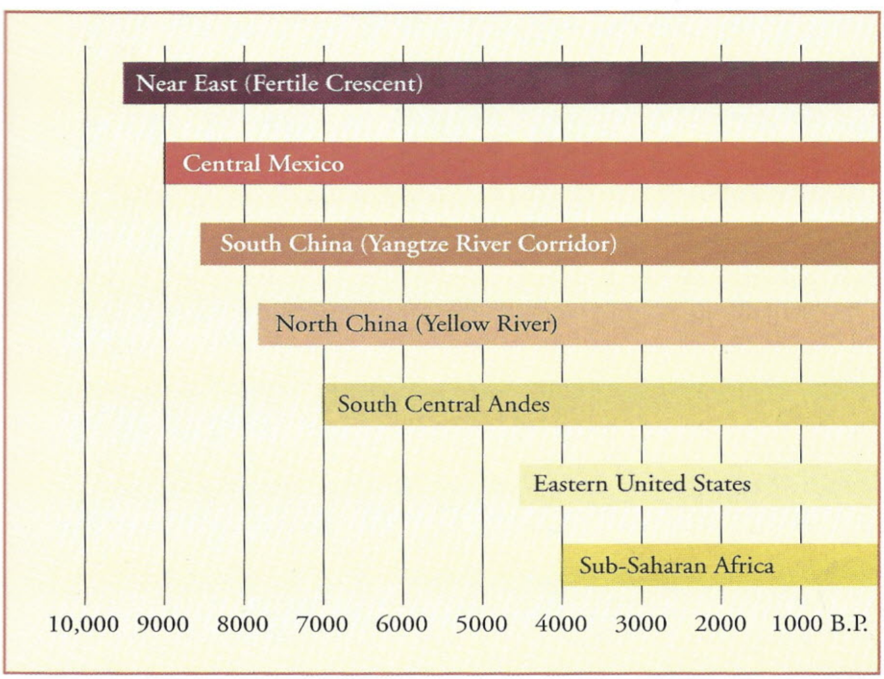
In China (Chapter 6), on the other hand, considerable analysis of plant and animal populations, both past and present day, is still to be done. Moreover, despite the long and detailed archaeological record of agriculture in China, we still lack evidence of the initial transition from a hunting-and-gathering way of life to a farming economy. The earliest known farming settlements, along the Yellow River in the north and the Yangtze in the south, are clearly many centuries past the initial transition to agriculture.

Sub-Saharan Africa (Chapter 5) stands in dramatic contrast to China. Here the archaeological record is rather limited; what is known about the emergence of uniquely African agricultural economies is the result of extensive biological research on modern plant populations, both wild and domesticated. Similarly, in Middle America and South America (Chapter 7), remarkable advances in biological research have dramatically changed the picture of agricultural beginnings in both the central highlands of Mexico and the central Andes of Peru and Bolivia, pointing to the need for archaeologists to focus on new areas and new time periods.

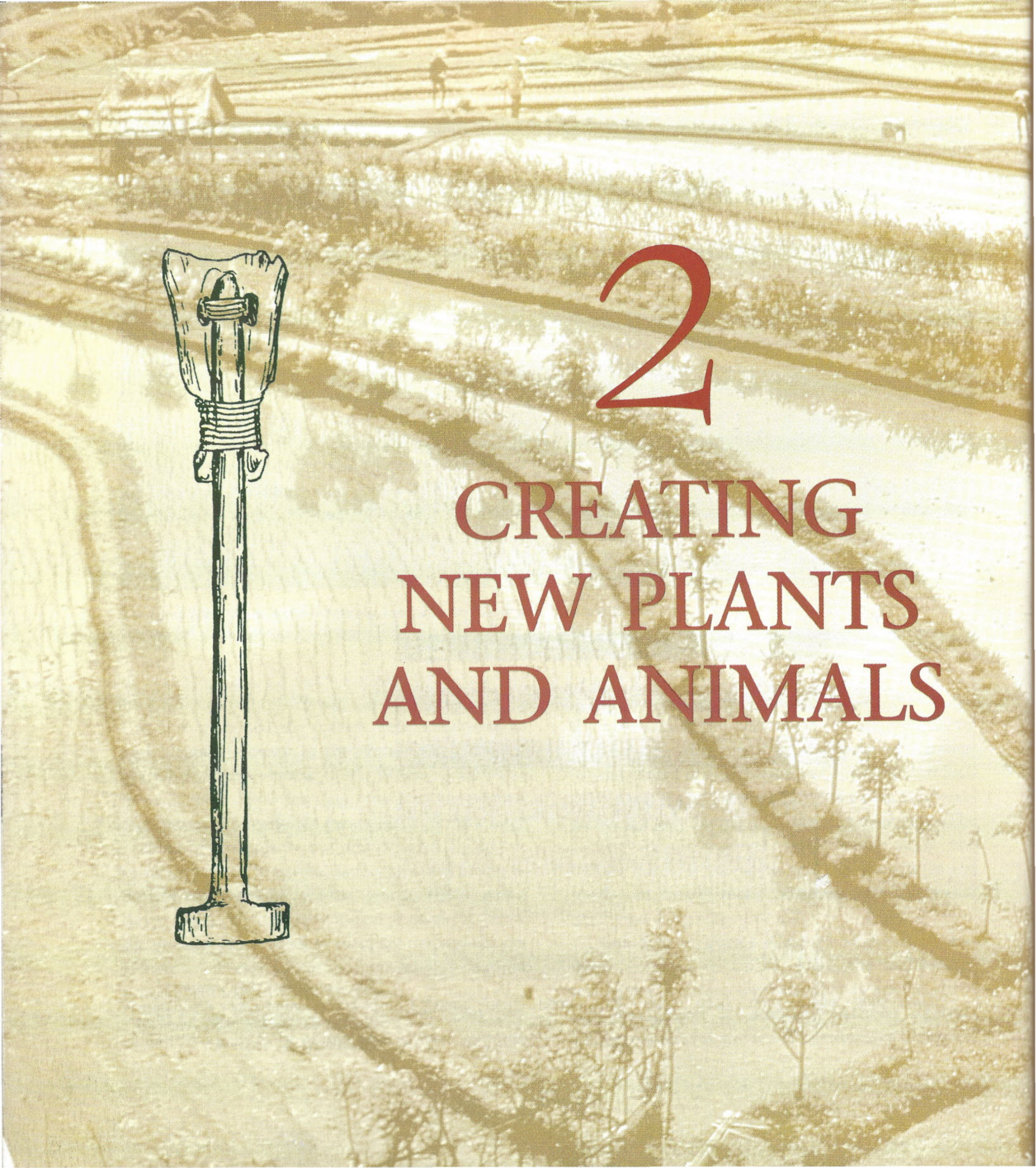
Very little is yet known about the early history of food production in either Southeast Asia (Chapter 6) or the lowland rain forests of South America (Chapter 7), although there is considerable speculation regarding the great age of root-crop agriculture in the tropics.

To a considerable extent, then, this book has been shaped by the level of success of archaeological and biological research carried out in different regions. Its emphasis is on those regions of the world—China, the Fertile Crescent, central Mexico, the central Andes, sub-Saharan Africa, and eastern North America—where wild species were independently domesticated and distinctive agricultural economies emerged, and on the two regions where agricultural expansion is best documented: Europe (Chapter 5) and the southwestern United States (Chapter 8).

Before agriculture came to these various parts of the world, all were inhabited by groups of hunter-gatherers who relied on the hunting of animals and the collecting of wild plants. How did these groups transform themselves into tillers of the earth and husbanders of animals? Part of the answer rests in an understanding of how efforts leading to the domestication of wild species could have emerged out of a wider class of human behavior common to all hunter-gatherers.



The approximate time periods when plants and animals were first domesticated in the seven primary centers of agricultural development.



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CREATING NEW PLANTS AND ANIMALS

An old man with a donkey cart, China. Created by human societies in different places at different times over the past 10,000 years, domesticated plants and animals have provided a reliable source of food, clothing, and pulling power. Artifacts such as the 6400-year-old spade on the facing page, excavated at the Ho-mu-tu site in China, provide evidence of early rice farming economies.

The changes brought over the past 10,000 years as agricultural landscapes replaced wild plant and animal communities, while not so abrupt as those caused by the impact of an asteroid at the Cretaceous-Tertiary boundary some 65 million years ago or so massive as those caused by advancing glacial ice in the Pleistocene, are nonetheless comparable to these other forces of global change.

Though the "agricultural revolution" exhibits some basic similarities to the major "natural" forces of global change, it differs dramatically in being a uniquely human creation, and, unlike these natural changes, it cannot be traced to a single causal event or process. The agricultural transformation had a series of isolated, independent beginnings involving different peoples, different areas of the world, different time periods, and different animals and plants. All of these separate beginnings, however, seem to have come about in generally similar ways, in response to a similar motivation.

Manipulating the Environment to Reduce Risk

I think that the motivations that eventually led our ancestors to domesticate plants and animals can comfortably be included in a much broader class of behavior: efforts by hunter-gatherer societies to increase both the economic contribution and the reliability of one or more of the wild species they depended on for survival, and thus reduce risk and uncertainty. Hunter-gatherer societies that survive today attempt to reduce risk in a variety of ways, from storing food against hard times to maintaining far-reaching kinship networks. These networks serve as a kind of insurance policy that enables family groups to survive lean years by temporarily moving in with distant relatives in regions where food is more plentiful. More interesting for our purposes, present-day hunter-gatherer societies also reduce

In Australia, hunter-gatherer societies "domesticate" the landscape, burning off vegetation to encourage the growth of valued plant species.

risk both by deliberately manipulating the habitats of plants and animals they rely on for food and by actively intervening in the life cycles of those species. Both these types of activities are undertaken to increase the yield and dependability of wild food sources. Together such activities represent a deliberate effort to modify the environment and make it more to the liking of these species—in a way to domesticate it.

In Australia, for example, where hunting-and-gathering groups have lived without agriculture for at least 20,000 years, Aborigine societies burn vegetation to encourage some species of grasses they depend on for food at the expense of other plants that do not fare so well in the burned-over areas. They also increase the yield of some food plants by intervening directly in their life cycles. After they dig out the tubers of the wild yam *Dioscorea,* for example, Aborigine foragers replace the stem-attached top of the tubers so that more yams will grow to be dug up another time.

The Kumeyaay Indians, a hunter-gatherer society of southern California, made even more extensive efforts to reduce risk by "domesticating" the landscape. By interviewing Kumeyaay elders and studying historical documents, Florence Shipek, a historian at the University of Wisconsin at Parkside, has been able to document a range of activities that encouraged the growth of desirable wild plants.

Straddling the border with Mexico, the coastal valley area of the Kumeyaay was not naturally rich in plant foods, and was subject to frequent droughts and floods, along with considerable variation in rainfall and temperature from year to year. Yet when the Spanish entered coastal California in 1769, they encountered relatively large Kumeyaay populations, which they described as subsisting not on agriculture but on wild seeds and other foods. The Kumeyaay thrived in this erratic and inhospitable environment as a result of very intense and far-reaching experiments in transplanting food plants across the full range of micro-habitat zones.

From coastal sandbars and marshes up through floodplains, valleys, and foothills, to high mountain deserts, the Kumeyaay had made experimental plantings of a variety of food and medicinal plants. They created groves of wild oaks and pines producing edible nuts at higher elevations and established plantings of high-desert species such as desert palm and mesquite along the coast. They planted agave, yucca, and wild grapes in various micro-habitats. They also planted cuttings of cacti and other succulents near their villages. They carefully burned many of the groves and other plantings of wild species to keep yields high, and by regularly burning off chaparral they improved the browse for deer. In early summer they harvested large stands of a wild grain-grass, now extinct, by hand stripping seeds from the stalk. Then they burned off the stands and broadcast a portion of the harvested seed across the burned areas. This highly modified and carefully "domesticated" landscape of the Kumeyaay, a complex mosaic of manipulated wild plants, disappeared with the coming of European settlers and their crops, and survives today only in the memories of Kumeyaay elders, in early Spanish documents, and in Shipek's writings.

Thus hunter-gatherer societies of the past and present, to varying degrees and in a wide variety of ways, have reshaped their environments to make them more to their liking. Across the full course of human history, societies dependent on wild plants and animals for their survival should not be seen as passive participants in the ecosystem who simply conform their lives to a rigid, unyielding natural environment. These societies have actively and continually experimented with manipulation of plant and animal communities to reduce risk in their own lives.

It is from such efforts that domesticated animals and plants were initially created. The likelihood that any plant or animal will actually be domesticated, however, is not the same in all situations. The opportunities for experimentation that could lead to domesticates varied widely. Many habitats and many species of animals and plants held only limited potential for manipulation, while others held great promise. Such promising species can be considered as preadapted to domestication. And just as some species are more likely candidates for domestication than others, some types of human intervention in the life cycles of species are more likely pathways to domestication than others.

What Is Domestication?

Scholars have been providing definitions and descriptions of "domestication" from various perspectives for more than a hundred years. Debate continues today on the fine points, but there is considerable agreement on a good starting definition: domestication is the human creation of a new form of plant or animal—one that is identifiably different from its wild ancestors and extant wild relatives.

Differentiation within wild species—the emergence of new forms of plants and animals—has of course occurred innumerable times in the earth's history without any human assistance at all. One of the most common ways in which such "natural" episodes of differentiation occur parallels the process by which humans create domesticates. First, a physical barrier of some sort separates a species into distinct reproductive groups within its geographical range. Over successive generations the groups on the two sides of the barrier begin to diverge as they respond to different sets of environmental forces or Darwinian selective pressures (differences in climate, habitat, predators and competitors, and so on).

Domestication is similar to this natural process, except that human societies set up the physical barrier and determine the selective pressures. A new set of selective pressures comes into play when humans intervene in key aspects of the life cycle of the now "captive" population, creating new rules for survival and reproductive success. Only those individuals able to survive and produce offspring under the new rules contribute genetic information to the next generation.

Over generations, in response to the new rules for survival, the captive populations change in a number of ways, some deliberately caused by the domesticators, others incidental and automatic. Taken together, all of the adaptations or adjustments made by a captive population can be collectively described as that species' "adaptive syndrome of domestication."

Many of the changes that occur as part of the adaptive syndrome of domestication are "phenotypic," or observable (larger seeds on a food plant, say, or smaller size in a herd animal), and it is such observable changes that often enable us to determine that the species has been domesticated. Associated with these observable changes, of course, are changes at the molecular level, in the genes themselves. The ratio of female to male, or young to old, in a population of domesticates may also serve to distinguish them from wild populations. Defining domestication in terms of either phenotypic or genotypic changes in individual animals, or changes in the composition of their populations, while certainly appropriate, is at the same time somewhat misleading. Although such measurable changes are often

Seeds of wild and domesticated marsh elder (top), sunflower (center), and squash (bottom) differ considerably in size, allowing archaeologists to recognize the presence of domesticates in ancient settlements. The wild marsh elder seed is modern; the domesticated marsh elder seed is from the Turner site, in southeast Missouri, which has been dated to A.D. 1300. The wild and domesticated sunflower and squash seeds are from the Cloudsplitter rock shelter in eastern Kentucky, and are more than 2000 years old.

the goal of domestication, they are at the same time symptomatic of an underlying change in the relationship between human societies and plant and animal communities. Domestication is not simply an observable end product—physical changes in plants and animals. It also reflects a revolutionary change in the relationship between human societies and the species they have domesticated.

When we take into consideration this new relationship between humans and other species, we have to expand our earlier definition of domesticates as human-modified plants and animals to include this essential attribute: they have been changed so much that they have lost the ability to survive in the wild. Corn (*Zea mays*), for example, is by almost any measure one of the most successful plants in the history of the world, occupying as it does vast areas of the earth's land surface. Yet any cornfield left untended will simply cease to exist within a few years. Long-term human selection has produced in *Zea mays* a plant incapable of dispersing seed that can survive to the next growing season, germinate, and successfully compete with the variety of aggressive intruders likely to invade any uncultivated cornfield. Human societies long ago intervened in the life cycle of teosinte, the wild ancestor of *Zea mays,* and selected for plants with reduced ability to disperse their kernels, and these kernels themselves were less able to delay sprouting until the following spring. At the same time humans took over responsibility for the dispersal and germination of seeds by harvesting and storing kernels and then planting them in cultivated fields at the start of the next growing season. Human beings have similarly intervened in the life cycles of many plants and animals, so that after thousands of years of selection and sheltered existence, these organisms have been transformed into a rich variety of domesticated species that are highly successful in agricultural landscapes and at the same time incapable of surviving without human help. In the same way, the survival of human societies has come to depend on domesticated food sources.

How do such relationships of increasing mutual dependence get started? Within the general pool of hunter-gatherers' efforts to manipulate their habitats, what particular types of intervention in the life cycles of target species precede and precipitate domestication? And why are some species and not others drawn into such revolutionary relationships?

Researchers have identified a logical sequence of human activities that give us ever-increasing levels of control over wild plants and animals, culminating in the specific actions that result in domestication. Some scholars have proposed that these increasing levels of intervention represent a continuous and gradual developmental pathway leading up to domestication. Let's look at possible pathways to the domestication, first of seed plants, then of animals.

The Domestication of Seed Plants

Most of the major crop plants grown today are seed plants. The pathway leading to the domestication of seed plants might have begun with the encouragement of wild plants that grew outside of any human-made environment. While such human efforts as the Australian Aborigine's burning of the landscape can increase the number and size of wild stands, and hence their yields, even intensive harvesting will have no appreciable genetic effect on the wild plants in that stand, because it is the seeds that *escape the harvester* and are exposed to the full set of natural selective pressures that become the next generation of plants.

Another form of human intervention, however, does represent a step toward domestication: the disturbance of the soil and associated disruption of existing plant communities that accompany a wide range of human activities, particularly around settlements. People disturb plant communities by clearing away vegetation, building houses, excavating pits for storage and cooking, and piling up refuse. These activities have little lasting impact on plant communities if the people move on fairly soon. Hunter-gatherer populations that move their settlements frequently produce a series of temporarily disturbed patches that soon return to the original vegetation cover after the people have left. When people maintain their settlements over a number of years, though, a new human-created plant habitat becomes more permanently established.

Such relatively permanent disturbed habitats have three important characteristics. First, being comparatively clear of preexisting vegetation, they are open to colonization, particularly by pioneer plants and other plants adapted to any similar naturally disturbed habitats that may exist in the wild. Second, they are in close proximity to human settlements, where hunter-gatherers could accidentally drop seeds they had harvested from wild stands and thus inadvertently introduce colonizers. Third, these disturbed habitats bear some resemblance to the broken ground of seedbeds prepared for cultivated plants. Thus by producing habitats where soil was disturbed, sedentary hunter-gatherers inadvertently created experimental quasi-garden plots that a variety of wild plants, some of economic importance, had an opportunity to invade and colonize.

Plants that are successful in such disturbed habitats, particularly those created by human action, are usually called "weeds." As Edgar Anderson, a botanist and director of the Missouri Botanical Garden, pointed out in the 1950s, some natural forces—most notably rivers, which constantly rework floodplain soils—create zones of permanently disturbed soil that typically are inhabited by a range of weeds, long adapted to the open floodplain. Anderson argued that the weeds of natural open habitats were preadapted to colonizing human-created open habitats, and in this respect were excellent candidates for eventual domestication. Representing in many respects a new niche, the patches of soil that people inadvertently disturbed around their settlements not only offered excellent opportunities for weeds to invade from their natural habitats but also provided a place where weedy adaptations by other colonizing wild plants, particularly those of economic importance, could develop.

The attitude of hunter-gatherers toward the weedy plants that colonized the ground they had disturbed could have ranged from dislike and active eradication, through simple toleration, to various degrees of encouragement and use. Those weedy colonizers with a history of having been harvested as wild food sources were the most likely to be actively encouraged, perhaps by people removing competing plants or expanding the disturbed soil area.

In sum, disturbed soil settings close to human settlements were similar in some respects to the prepared seedbeds of garden plots. They were open to colonization by weedy species preadapted to growing in such settings and offered opportunities for first attempts to encourage and control weedy "camp follower" plant species. As a result, they may well have provided the context for a logical next step that led directly to plant domestication: the deliberate planting of stored seed stock.

No matter where they were carried out, the first experiments with planting could well have consisted simply of efforts to enlarge stands of wild or camp follower food plants by broadcasting some of the harvested seed over a wider area, as the Kumeyaay did. The hunter-gatherers could have later elaborated the process by minimally preparing the soil to receive the wild seeds and then "weeding." These initial experiments with planting, seen as a logical extension of hunter-gatherers' efforts to increase the yield and dependability of wild and weedy species, would not lead to true domestication, however, unless people isolated the plants in question and intervened in their reproduction. They could have done so easily enough. All they needed to do was set aside some seeds of target species after they had harvested them, and then plant those stored seeds the following year in a prepared area, or "seedbed." When sown with part of the previous year's harvest, such planting areas would have provided substantial genetic isolation from populations of wild relatives.

Over time, the practice of planting stored seed stock would produce domesticated plants—plants that had responded and adapted to the newly created human environment, and in doing so had undergone a series of changes in their "morphology," or outward shape and form. At first glance, planting might seem a simple and logical extension of hunter-gatherers' manipulation of food plants. In fact, however, it marks an essential change in the relationship of human societies to their environment.

Unintended Benefits: The Consequences of Seedbed Competition and Human Harvesting

By storing and planting harvested seed, hunter-gatherers assumed control of the life cycles of the now isolated target plants, shielding them in many ways from the competition and pressure of the natural environment. But at the same time that this protective relationship released the plants from one set of selective pressures, it subjected them to another. As the now "protected" plants adjusted to this new set of selective forces, their morphology changed, and many of these changes were advantageous to the human harvesters in ways the harvesters had not foreseen. Jack Harlan, an evolutionary biologist, and his co-workers first outlined many of these unintended changes.

Where plants grow in the wild, only the seeds that escape human harvesting and are dispersed on the ground have a chance of sprouting and growing to form next year's stand. Just the opposite is true, however, once humans begin to store seed stock to

The compaction of seeds is a good indicator of domestication. In the wild *Chenopodium* plant known as lamb's-quarters, on the right, seeds are distributed in numerous small clusters. On the left, in contrast, the seeds of a domesticated *Chenopodium* plant are tightly compacted at the top of the main stem.

plant the following year. Now the seeds that are collected have a better chance of contributing genetic material to the next generation's prepared seedbed than those that are lost. And harvesters are less likely to miss seeds that are conveniently packaged in terminal clusters at the ends of stalks. Over time, plants that retain their seeds long enough to be harvested and that package them in convenient clusters both contribute more seeds to next year's seed stock and generate a larger harvest. Harvesting, then, coupled with storage and deliberate planting, inadvertently encourages plants to increase their harvest yields as they respond to the newly imposed selection guidelines for reproductive success.

These two automatic responses by plants to the harvesting of stored seed stock—retention of seeds and their packaging in terminal clusters—also result in recognizable morphological changes in the plants, changes that serve as markers of domestication. These are the markers that archaeobotanists look for in the fragmented seeds and other plant parts they recover from archaeological sites. When they compare plant assemblages from different time periods, for example, they look for a stronger attachment of seeds to stalks that indicates an increased retention of seeds.

Several other important morphological markers of domestication are the result of the intense competition among plants that sprout in prepared seedbeds. Seedlings that sprout quickly, grow rapidly toward the sun, and then shade nearby seedlings with their spreading leaves have a distinct advantage. Young plants that can literally put their neighboring competitors in the shade markedly improve their own chances of surviving to harvest and contributing seeds to the next year's planting cycle. Over time, such pressures strongly favor plants whose seeds have both greater start-up food reserves within and substantially reduced inhibitions to rapid sprouting.

The seeds of wild plants commonly remain dormant in the ground for months until winter is over, the rains come, or conditions are otherwise suitable for germination. Thick impermeable seed coats are often essential in the seeds of wild plants that have to survive, exposed to the elements, from one growing season to the next. Once humans take over the responsibility for safely storing seeds away from moisture and predators, however, thick seed coats are not necessary. Since any delay in germination after the seed is planted will often, in the face of competition for nutrients and sunlight, reduce a young plant's chances of contributing to the harvest (and the next year's planting), its seeds lose much or all of the ability to lie dormant and sometimes acquire a thinner seed coat. Similarly, by favoring seeds with greater start-up food reserves, seedbed competition selects for larger seed size.

Like plants' automatic responses to harvesting, the two automatic responses to seedbed competition (larger seeds, thinner seed coat) thus inadvertently make the harvest both larger and more easily processed. A thinner seed coat and a larger seed size are key morphological markers of domestication that investigators often look for in seeds recovered from archaeological sites. They provide clear evidence of deliberate planting. With the aid of scanning electron microscopes and light microscopes, archaeobotanists patiently examine and measure ancient seeds, looking for the morphological characteristics that indicate whether or not domesticated plants were yet present at particular settlements of known age.

In sum, a few seemingly simple steps brought remarkable changes to the relationship between human societies and particular plant species. When human beings took control of the reproductive cycles of some populations of certain species by harvesting, storing, and planting their seeds in prepared areas, they effectively created a separate and parallel world for these plants. Populations of the same species that grew beyond the human realm continued to be shaped by the rules of reproductive competition and survival in the natural world, but those plants now controlled by humans became subject to new rules for success. These new rules favored plants with larger seeds that could sprout quickly and that were retained on the plant at harvest and packaged in terminal clusters for easier collection. These changes, rather than being deliberately caused by humans, were probably in large measure unintentional and automatic responses to

In a timeless tableau, women harvest grain. A several-thousand-year-old cave painting from Tassili n'Ajjer, Algeria.

human planting, part of the adaptive syndrome of domestication.

These changes made crop plants dramatically more important as sources of food than wild stands. Such plants would produce larger and more dependable yields than wild ones, and they would lose substantially fewer seeds at harvesting. Their seeds were larger, and thinner seed coats made processing easier. This serendipitous response to planting, so advantageous to the planters, is one of the most interesting and perhaps most important elements in the process of plant domestication. Among all the various human efforts to reduce risk by manipulating resources, the planting of stored seed stock would have yielded very rapid and dramatic benefits, and the results would have encouraged further experimentation. It is likely that human societies also began to deliberately select plants for other characteristics soon after they first undertook intentional planting, adding to the list of morphological markers of domestication.

What attributes in a wild plant would have made it a likely candidate for deliberate planting? Obviously a wild plant that hunter-gatherer societies already relied on as an important food source would have been a prime candidate for experimentation. In general, one could expect successful domesticates to have those attributes that would make them able to thrive in the environment that humans had created and now controlled. "Generalist" plants that could do as well in disturbed soil as in the wild would be better able to make the transition to the human environment than plants with more stringent habitat requirements. Species adapted to growing in dense stands would be better candidates for domestication than those that grew in more dispersed patterns. Similarly, species able to tolerate the moisture, temperature, and other conditions of storage would be good candidates for domestication, as would those whose rates of mutation and genetic variation enabled them to adapt rapidly to the new selective pressures.

The Domestication of Animals

Just as some wild plant species are more predisposed than others to respond rapidly and successfully to human planting, so too are some species of wild animals clearly preadapted to domestication. As early as 1865 Francis Galton proposed that almost all animal species had at one time or another been "auditioned" by human societies for possible domestication. While many may have been called, few species of animals have in fact been chosen to fill the new role of domesticate. Galton suggested that the reason was that the role was difficult to fill. To negotiate the transition from the wild to a domesticated life, he argued, animal species had to meet a particular set of behavioral and physiological requirements:

> 1, They should be hardy; 2, they should have an inborn liking for man; 3, they should be comfort loving; 4, they should be found useful to the savages; 5, they should breed freely; 6, they should be easy to tend.

Many of the inherent aspects of physiology and behavior Galton pointed to are today recognized as important elements of preadaptation to domestication. His criterion that candidates for domestication "should be found useful" reiterates a basic point already made in regard to plants—that wild species that were already important sources of food would be particularly likely candidates for efforts to domesticate them. Galton's other five aspects of preadaptation all have to do with the relative ease with which wild animal species would be able to respond to and survive in the human environment. As in the case of plants, there were two key elements of the initial domestication of animal species: some individuals were separated from populations in the wild, and then humans made a concerted intervention in the life cycles of the now captive populations. Once these individuals were brought under control, human societies assumed responsibility for managing the size and location of the area the animals occupied, their food supply, and their successful reproduction. These three dimensions of human management—space, feeding, and breeding—define in large measure the elements of preadaptation Galton recognized.

Specialized feeding habits, for example, represent a major barrier to domestication. Flexible feeders such as pigs and goats would be far better able to adjust to the feeding opportunities offered under human control. In addition, species better able to adjust to new conditions of disease, temperature, and confinement would be good candidates for domestication ("they should be hardy").

Similarly, animal species vary considerably in the number and narrowness of the behavioral, physiological, and situational cues that are necessary preconditions for successful reproduction. Obviously, those species with the fewest and least constraining sets of cues are good candidates for domestication ("they should breed freely"). The ability to reproduce in crowded conditions, for instance, could be an essential attribute for successful domestication.

Crowding under human management represents a formidable barrier to domesticating species that are largely solitary in the wild. Species vary considerably in the size and composition of the groups they form at different seasons of the year, and in the size of the "home range" that those groups typically occupy. Relatively solitary and strongly territorial species that defend their territories against intruders would be incapable of easy group interaction. Even in the wild species whose females and young live in groups through part or all of the year, the males' territorial behavior and patterns of reproductive competition can make breeding and control in confinement impossible. Species that in the wild form gregarious and highly social groups comprising both sexes, on the other hand, are good targets for domestication. Similar behavioral barriers to domestication exist in species such as antelopes and gazelles, which are adapted to escape from fleet-footed predators. They can run extremely fast and are skittish or high-strung in temperament. Sophisticated fencing is needed to contain them, and they often panic when they are so constrained. As a result, they are difficult to feed and to breed under close control ("they should be easy to tend").

Finally, and perhaps most important, highly social and gregarious animals whose behavioral patterns are based on a dominance hierarchy are strongly preadapted to domestication. Groups that have a dominant leader are predisposed to submit to a human herdsman who steps into the position of the lead male. Thus, to become domesticated, a wild animal species should have a preexisting capacity for submissive behavior. Such a predisposition also dramatically increases the ability of human herders to communicate commands to their captives ("they should have an inborn liking for man").

In sum, the ideal candidate for domestication would be a wild animal that is already an important food source, does not depend on rapid flight to escape predators, is a placid dietary generalist, is highly social and gregarious, has an established pattern of social interaction based on a dominance hierarchy, and tolerates breeding and feeding in close confinement. It is no accident, then, that when we examine the origins of agriculture in the Near East, we find that the goat and sheep, two of the first an-

Kurdish sheep herders drive their flock, in Turkey. Sheep were excellent candidates for human control and domestication because of their social and submissive herd structure.

imal species in the world to be brought under domestication, fit this profile quite closely. Both species are relatively placid and slow-moving foragers. Neither species is territorial, and both sheep and goats form highly social groups having a single dominant leader. In addition, such groups maintain small home ranges, and thus are predisposed to human constraint.

The Transition to Domestication

Given this general profile of preadaptation, what progression of increasing intervention in the life cycles of preadapted wild species leads human societies to the critical point of domesticating them? Scholars have proposed various stages of human manipulation that might develop into full captivity and control, from random hunting through intentional specialized hunting to following herds of animals, enclosing them in pens, and keeping them as pets. As with efforts to "improve" the environment by intervening in the life cycles of selected plant species, some forms of manipulation point to domestication, others don't.

Human beings could try to enhance the habitats of hunted species by eliminating either their predators or their competitors or by burning the landscape or clearing woodlands to encourage the growth of the food plants. Efforts of both kinds could well produce an increase in the animal populations and make for good hunting, but they will not lead to domestication. Similarly, specialized hunting strategies targeted at free-living animal populations would not significantly shift an essentially predator-prey relationship toward domestication. Such efforts do not lead toward the three elements essential to animal domestication: constraint of the movement of target populations, regulation of their breeding, and control of their feeding both to ensure and to shape successive generations.

These three elements are the core of the conceptual shift that marks the transition to domestication. Richard Meadow, director of the zooarchaeological laboratory at Harvard University, has insightfully described this conceptual shift as a change in focus from ensuring the deaths of living animals to ensuring their survival—more particularly, to ensuring the creation of progeny. To manage captive populations a society must master an entirely new set of tasks and develop complex new areas of knowledge. No longer do the skills of stalking and killing wild animals determine a dependable meat supply, but rather the knowledge of how to sustain, manage, and regenerate animal populations largely or entirely under human control.

Any efforts to manipulate wild animal populations that would contribute to this newly required body of knowledge could contribute to their initial domestication. For example, the practice of capturing young wild animals and rearing them to adulthood, which is widespread among hunter-gatherer societies today, could certainly have provided auditioning opportunities. During such episodes of captivity, the captors could have assessed the predisposition of species to captivity and learned many aspects of their management, from food requirements to breeding patterns. The rearing of wild youngsters as pets would not easily lead to their successful breeding as adults, but it would still provide considerable insight into the skills necessary to manage captive populations.

Hunter-gatherers might have attempted the partial management of wild animals that were already important food sources and were preadapted to domestication—social herds with a dominance hierarchy and small home ranges. A herd of such

A child and his pet. Hunter-gatherer societies would have consistently brought home young wild animals to raise as pets, becoming familiar with their habits and needs, and learning about their potential for control and domestication.

animals might have been kept in a compact group to be preyed upon whenever meat was required. Humans might have constrained the movement of wild species within a small area with a favorable habitat and a supply of water. The habituation of these animals to human herders/hunters could have been an important early step along the pathway to domestication.

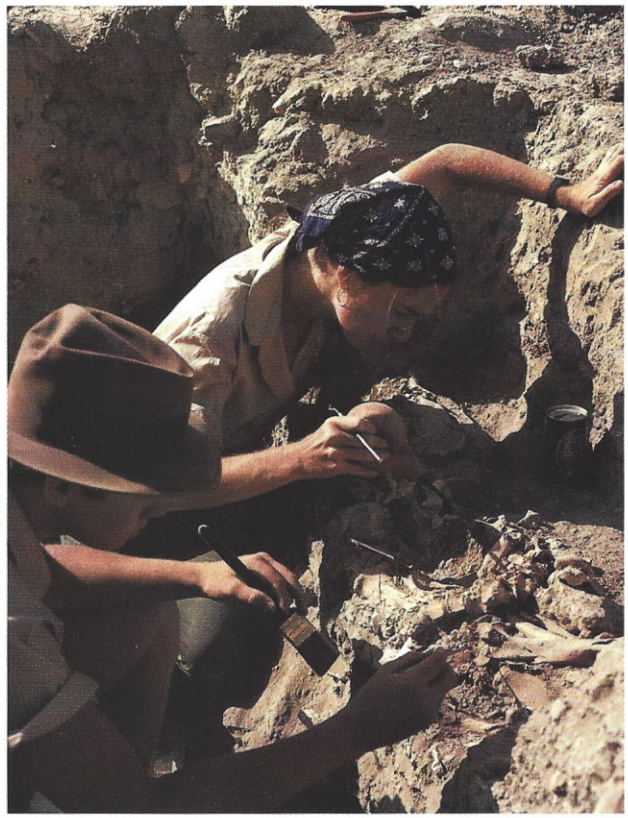
Markers of Animal Domestication

The critical point on the road to the domestication of seed plants is the deliberate planting of seed stock in prepared seedbeds, and the associated separation of these plants from wild populations. The analogous point that marks the transition to the domestication of animals was reached when humans isolated a herd or flock of animals and undertook to control their reproduction. Like seed plants, animals responded to the new set of selective pressures they encountered, to the confinement and crowding of the human environment, and underwent a variety of morphological changes. In many cases, however, these morphological markers of domestication are not so uniformly present in individual organisms as those that appear in plants. As a result, the evidence of early domestication is easier to read in ancient seeds than it is in bone fragments excavated from ancient settlements. Unlike seeds, individual bones only rarely carry clear structural changes indicative of initial captivity and domestication.

For a time in the 1970s it was thought that such a basic structural signature of animal domestication had been found. After analyzing the microstructure of bones from the sites of Suberde and Erbabain in Turkey, Dexter Perkins of Columbia University and Patricia Daly of the University of Pennsylvania believed they had found clear and consistent differences between the bones of wild and domesticated sheep and goats. Bone consists of crystals of calcium phosphate (hydroxyapatite) deposited along long fibers of the protein collagen. According to Perkins and Daly, hydroxyapatite crystals were oriented perpendicularly to the long axis of collagen fibers in the wild animals, whereas they were more randomly oriented in the bones of animals thought to be domesticated. If Perkins and Daly were correct, a simple microscopic examination of a thin section of bone could establish whether an animal was wild or domesticated.

To test the validity of the proposed marker of animal domestication, Melinda Zeder of the National Museum of Natural History, Smithsonian Institution (then an undergraduate at the University of Michigan), looked for differences in the bone structure of modern wild and domesticated sheep from the Near East. Four wild sheep killed in the Tarus Mountains near the Caspian Sea were found to have the expected perpendicular orientation of crystals. A dozen domesticated sheep acquired from traditional pastoral societies in remote rural areas of Iran, however, also had hydroxyapatite crystals oriented perpendicular to the long axis of collagen fibers, contrary to what Perkins and Daly predicted. It was later found that the random orientation of crystals Perkins and Daly observed in some archaeological bone samples had been caused not by domestication but rather by chemical processes that took place long after the bones had become buried in the ground. Since Zeder showed the crystalline structure marker to be invalid, no other clear micromorphological marker of domestication in animals has been proposed.

This is not to say, however, that no morphological changes associated with domestication can be observed in animal bones recovered from archaeological sites. On the contrary, a variety of changes in skeletal elements have been employed to distinguish domesticated animals from wild individuals of the same species. Such morphological markers provide a valuable way of recognizing the presence



Melinda A. Zeder, Smithsonian Institution archaeologist, excavating a small domesticated donkey at the site of Tel Halif in the southern Levant.

These two specimens from the Ali Kosh site in Iran illustrate how the horns of wild goats differ in cross section from those of domesticated animals, providing a morphological marker of domestication for this species. The wild goat horn (left) has a more four-sided cross section, with a peak facing toward the front (top), while the horn of the domesticated goat (right) is more triangular in cross section, flat along the medial side with a peak facing backward (bottom).

of domesticated animals in archaeological bone assemblages. A very distinctive change in the cross sections of the horns of domesticated goats and sheep, for example, distinguishes them from wild individuals. Similarly, a distinctive size reduction in the teeth of pigs has been used to identify the initial domestication of this Old World species. Whether they result from relaxation of selective pressures in the wild or from deliberate human selection over generations, however, such morphological markers of domestication may not appear for some time after the animals have been domesticated. As a result, zooarchaeologists today build their arguments not simply on the presence or absence of a limited number of isolated morphological markers, but on the patterns of change that can be seen only by examining larger assemblages of bones that represent whole herds or flocks.

In the ideal situation for this kind of "whole herd" analysis, one would begin with a deep archaeological site that revealed a vertical sequence of deposits that spanned the full transition from hunting and gathering to agriculture. If each layer in the sequence of deposits yielded large and well-preserved assemblages of animal bones, zooarchaeologists could then start with all the bones of a particular animal species found in the lowest, earliest layer. Let's locate this long-occupied settlement in the Near East, and let's say the bones belonged to goats. By carefully identifying, measuring, and analyzing all of the goat bones found in the lowest layer of the site, zooarchaeologists could determine the group profile of the wild goats hunted by the earliest human inhabitants of the settlement. Various bones could be measured to establish the range in size of the animals culled from the wild herd by human hunters. Their range in age could be determined by analyzing tooth eruption and wear patterns, annual growth rings in the teeth, and whether or not bones had finished growing. By measuring skulls, horns, pelvises, and other distinctive bones, zooarchaeologists could establish how many animals were female and how many were male. They could document the growth patterns and pathology of bones to show the general health of the animals. Tooth eruption patterns, seasonal growth rings in teeth, and the presence of very young animals could indicate the seasons of the year in which the animals were killed. By comparing the numbers of these animals with the representation of other animal species found at the settlement, researchers could determine how important they were as a source of food.

Moving up through time through the layers of the site, the investigators could similarly scrutinize each succeeding deposit of goat bones and produce a profile of each goat herd. Once all the layers of the site had been analyzed in this way, the search would begin for any patterns of change in the herd profiles that might mark increasing human control. A change in one aspect of the herd profile that could be linked to captivity and reproductive control, such as age composition or male-female ratio, would certainly provide some evidence that domestication had begun. A much stronger and more convincing case could be made should related changes be observed in several characteristics of the goat herd, all of which could be linked to captivity and human control of breeding.

To extend this ideal situation to a more regional scale, let's suppose that a good number of such deep-layered settlements scattered across the Near East were all carefully excavated and their goat herd profiles tracked through time. If a characteristic set of changes in goat herd profiles linked to captivity and human control were documented at all of the excavated settlements, then an even stronger case could be made that the observed changes constitute good evidence of the initial appearance of domesticated goat herds at particular times in particular places.

Unfortunately, such an ideal research situation does not exist today. Few settlements have been excavated that provide opportunities to track changes in the profiles of any species through the full transition from wild to domesticated. Lacking a comprehensive set of sites to work with, zooarchaeologists working in different regions of the world have to settle for an incomplete, fragmented mosaic of evidence. Excavated settlements were often occupied for only short spans of time, so each settlement provides information about only one part of the transition. While some sites produce large, well-preserved assemblages of bones, others yield less useful collections. Perhaps the excavation is smaller and less effort is made to recover bones, or perhaps the bones are not as well preserved in the ground. Given the scattered and partial evidence, the small fragments of the domestication puzzle that must be drawn together from many settlements of different times, what are the various changes in herd profiles that zooarchaeologists look for as possible indications that the animals were living in captivity, their reproduction controlled by human herders?

When animals are held in captivity and their movements are constrained, the impact on the captive herd could in some respects be almost immediate. For example, bone pathologies might be brought on by the physical trauma, poor diet, and higher stress and infection rates of confinement. At the agricultural village of Tepe Sarab in western Iran, numerous cases of chronic arthritis and evidence of gum disease in goats have been cited as early evidence of confinement and domestication. A high frequency of bone pathology in goats from a farming settlement at the 'Ain Ghazal site in Jordan has also been proposed as marking the early domestication of this species.

Halfway around the world, on the high puna grasslands of Peru, the Telarmachay rock shelter has yielded another possible indicator of animal domestication. Here, in deposits dating to about 5500 to 5000 years ago, a large number of bones of fetal and newborn llamas have been recovered, perhaps evidence of the earliest corralling of this species by human herders. Jane Wheeler argues that newborn mortality rates, which are low among wild llamas (guanacos) today, are as high as 50 percent in domestic herds that are corralled at night. In present-day domesticated herds, high newborn mortality is the result of infections caused by two *Clostridium* bacteria that thrive in dirty, muddy corrals but are not known to infect wild populations of guanacos.

Such disease-related indications of herd management, unfortunately, are often difficult to document in archaeological assemblages of animal bones. Fortunately, however, deliberate human manipulation of the reproduction of newly domesticated animal species is clearly visible in the archaeological record.

When herds are kept in isolation from wild populations and cared for by human herders, they are relieved of the selective pressures that shape wild populations. By imposing their own selection of animals for breeding, herders would be free to modify the size and appearance of the animals, the size of the herd, the relative balance of males and females, and the age profile of the herd in any manner that worked to improve the dependability of the herd as a food source, or walking larder. Managers could, for example, decide to remove large and aggressive males in order to reduce disruption in the herd while facilitating their own control of the important lead male position. But because by doing so they would be clearing the way for the reproductive success of the wimps in the group, they would in the process be reducing the size of the animals in the herd.

In a similar fashion, herders could easily produce and maintain the basic structure of a managed population of domesticated animals through selective harvesting. A breeding herd consisting of numerous females of reproductive age would need only a few males to impregnate them. The vast majority of the young born every year would be slated for slaughter, to be harvested as the need arose, once they approached adult size. Young animals that exhibited desirable traits could be spared for breeding to fill vacancies resulting from old age or death. Just as the seed stock of a domesticated plant is set aside each year to ensure next year's crop while the rest of the harvest is available for consumption, so the breeding herd is the seed stock of the next generation, and the food-stock animals are stored standing up and ready for slaughter. The restructuring of captive herds can take a variety of forms, depending on the species' primary uses (as sources of meat, milk, or skins, or as pack or draft animals).

All of the herd profiles that human societies in different regions of the world could create, manipulating different captive species for different ends, would be similar in one important respect: they would all leave archaeological bone assemblages that

Toe bones are smaller in domesticated cattle, reflecting an overall reduction in the size of these animals. The 7000-year-old first phalanx of an aurochs (right) is from the site of Umm Qseir in northeastern Syria. The much smaller 7000-to-6000-year-old toe bone of a domesticated animal (left) is from the site of Mashnaqa, also in northeastern Syria.

A present-day herder and his assistant in the Alps. Pastoral economies have evolved in many parts of Europe over a period of more than 7000 years.

were different from those left by the hunting of wild populations. In sum, it would seem a rather straightforward task to identify in the archaeological record when animal domestication began, and in general it is. Some clues, such as indications of poor nutrition, disease, and parasites, are only occasionally observed. A decrease in the size of captive animals, in contrast, is easily recognized, and as a result it is today the most widely employed morphological marker of domestication.

There are two quite different causes for such observed size reductions, however, and they can occur at quite different times in the long process of human manipulation of domesticated animals. Deliberate human selection for decreased body size, on the one hand, resulting in an across the board size reduction in a managed population, can come soon after initial domestication, or not for several thousand years, if at all. On the other hand, another kind of reduction in the average size of animals making up a captive managed herd, which has a very different cause, is an excellent early marker of initial domestication. This is the reduction in the average size of animals comprising a herd where the species exhibits clear sexual dimorphism (males are larger than females), and humans have shaped the age-sex profile of the adult herd to optimize meat production—only a few (larger) adult males, and many (smaller) adult females. Thus although often described simply as an observed size reduction associated with domestication, this shift does not in fact reflect any decrease in body size in comparison to wild individuals, but rather indicates the shaping of an adult breeding population dominated by smaller female animals. Together, changes in the individual animals, and the composition of the herd itself, provide a good set of interrelated markers of domestication that can be recognized in archaeological bone assemblages. As we shall see, however, recent innovations have enabled researchers to take into consideration a much wider variety of information in their efforts to identify the initial domestication of plants and animals.