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to paleoscientists, lines of thought that run through these discussions: Climates have changed significantly over the past centuries, with large effects on ecosystems; climate trends can reverse or change abruptly — plant and animal communities track these; mechanisms for medium- to high-frequency climate changes are posited, but effects on local regions are poorly understood; useful historical analogs for the present do not exist; climate and ecosystem conditions for the next 50–100 years cannot be accurately predicted, yet likelihood of change is high; the best guess about near-future climates is toward greater extremes and more frequent shifts; human effects are now integral to ecosystems and must be incorporated in planning; social infrastructures for natural resources are built on assumptions of steady states and unchanging climates, and are unprepared for high variability and uncertainty.

Managing ecosystems for resilience becomes a major conclusion of such observations. Resilience will take different forms depending on scale, biomes, and regional histories. Resilient ecosystems may not look like historical or "natural" systems, and templates are not obvious. Much can be learned about resilience by studying responses of historic ecosystems to past climate and environmental change. Thus, understanding how systems vary (fig. 2) and what makes a particular system resilient under different climate change conditions are priority topics in the nexus between paleoscience research and resource management.

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The Human Factor in Paleoclimate

The suggestion that human activities are having a major influence on contemporary climatic patterns is being accepted by an ever-increasing number of scientists and citizens. Today, two-thirds of the terrestrial surface of the planet is covered by agricultural land, livestock grazing areas, and managed forests (Farina 2000). In addition humans use over half of the accessible fresh water on Earth and more atmospheric nitrogen is fixed by human activities than by all natural terrestrial sources combined (Vitousek *et al.* 1997:494). The more we study, the clearer it becomes that virtually all ecosystems throughout the world are strongly influenced by human activities. Anthropogenic forces are something that must be factored into any analysis of the condition of the atmosphere, land surface, or climate. Moreover, we expect these human drivers to become even more dominant in the future, leading to the much-feared impacts on our global systems.

The more difficult question is how far back into the past have humans been a significant force in environmental transformations and climatic change. Where past impacts have been siginificant a better understanding of them would significantly improve modeling of future climate change. After reviewing the growing archeological literature on this subject, I have argued elsewhere (1999) that substantial human impacts, especially through dramatic changes in land cover, are as old as the introduction of agriculture (2,000 to 10,000 years ago depending on region) and some forms may be much older. The introduction of agriculture is regarded by many to be the single most important transformation in human history. The shift from nomadic hunting and gathering to a settled agricultural village existence heralded changes in almost every facet of life and laid the necessary foundations for the growth of urban society and political hierarchies. Looking back from the perspective of today, the decisions and innovations that were associated with the introduction of agrarian village life must have been rational at the time, but we now know they had social consequences of debatable merit and long-term environmental impacts that were unquestionably negative and ultimately undermined the very subsistence base they had worked so hard to establish. People settled into sedentary communities, population aggregated into denser settlements, and increasingly, communities relocated themselves to favor certain geographic locations over others. Initially this meant a preference for arable land that could be easily farmed with available rainfall, but even in prehistory the best land was soon filled. Further growth was only possible through the intensification of production, which meant a further aggregation to areas where irrigation was practical. This led to higher productivity per acre, as witnessed by the fact that 40% of modern crop production comes from only the 16% of agricultural land that is irrigated (Matson *et al.* 1997:506). The key point is that over the millennia, as world population has increased dramatically, it has not spread itself evenly over the landscape, but has increasingly favored select locations over vast stretches that remain lightly settled, if at all. Accompanying this concentration of human settlement and intensified agrarian strategies has come massive redirection of natural processes, such as the impoundment and redistribution of surface water through irrigation, the construction of flood control devices, or the spread of urban settlement itself.

Figure 1: Salinization has undermined the productive potential of this region in southern Iraq, as it did to many regions in the past.

Also relevant to our consideration of land cover change is that agriculture involves the substitution of a managed community of domesticated plants and animals for the species native to the region. Suppression of competition for light, water, and minerals usually has meant the removal of native trees and shrubs in favor of planted cereal grains, an overall reversal of the naturally occurring successional sequence. With more intensified efforts to increase productivity and to respond to the opportunities in a market

economy many farmers chose to specialize in fewer crops, leading to large areas with monocrop fields.

Although agriculture has in most cases led to short-term increases in productivity, the imbalances created through deforestation, soil erosion, and soil mineral depletion undermined the sustainability of the newly established food production system in many localities, leading to food shortages, and eventual abandonment. Case studies of early farming successes followed by local disasters have been documented in 7th millennium BC. Jordan (Rollefson and Kohler-Rollefson 1992), the prehistoric American Southwest (Kohler 1992), ancient Greece (Van Anadel *et al.* 1990), and many other areas (see Redman 1999). Over time, the cumulative effect of these types of episodes in a region would be widespread land cover transformed in support of agriculture as well as many landscapes that have reverted to a degraded forest condition after the demise of the agrarian system. This in turn may have been followed once again by new efforts at farming, leading to regions exhibiting mixed use landscapes with both cultivated fields and remnant patches of degraded natural vegetation (see Butzer 1996 for a discussion of the Eastern Mediterranean).
Despite local setbacks, the introduction of agriculture led to regional and even continental scale land cover transformation as long ago as 6000 BC. With the adoption of a food producing economy most communities became sedentary and increased in size. With the control of production, the ability to store annual food surpluses, and the advantages derived from investment in facilities and more sophisticated equipment the foundation was laid for regional and eventually for global population increase. Taken together this led to what I consider the second major transformation in the human career, the emergence of complex, hierarchical society. Cities and state political organization are their most obvious manifestations, but their growth is tied to a fundamental transformation in human perception of the natural world. With the ability to produce and store more goods than one could consume and a food production strategy in which some tracts of land were more valuable than other tracts, there emerged far more developed concepts of value and ownership. When one could use only what one could consume there would be less impetus to produce a surplus, but if that surplus could be transformed into objects that yielded special status or represented power over others, the drive to produce more would be strong. Prestige goods, especially those whose production could be controlled by being made of exotic raw materials or according to a guarded technology played a central role in the emergence of hierarchical urban society. The environmental implications of this transformation are dramatic: a multiplication in demand for food production, extraction of minerals, and construction of public works. With these changes came early mass production industries, regular long distance movement of goods, huge urban aggregations of population, and the initiation of large-scale military campaigns. Evidence of a human imprint on the landscape became even more pervasive than with farming villages alone. These cultural landscapes were characterized by vast fields of cereal grains, orchards, terracing of mountain slopes, canals and levees to redirect surface water flow, and cleared and often paved roadways to facilitate the movement of goods and people. Periods of deforestation (the Maya; Rice 1996), soil erosion (west Mexico; O'Hara, Steet-Perrott, and Burt 1993), or salinization of irrigated lands (Mesopotamia and American Southwest; Redman 1992) were sometimes the result of growing urban populations, while at other times these state level societies were able to stabilize the land surfaces and regenerate soil fertility to produce an agricultural regime that could be sustained for centuries (west Mexico; Fisher and Thurston 1999).

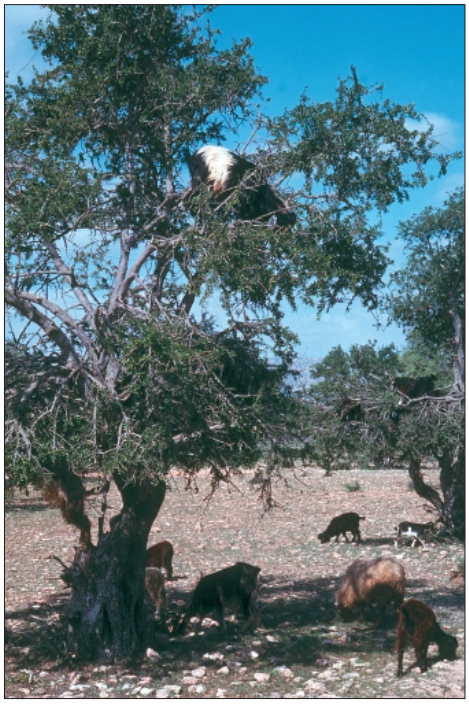

Figure 2: Goats consume both leaves and twigs on these oak trees. Note the goat foraging in the tree in the foreground.

Figure 3: Young villager gathering vegetation for her domestic hearth in the western Mediterranean region.

There is increasing archeological evidence documenting that for long periods of time people have had a widespread impact on land cover distributions and therefore on climate change. The far more difficult questions revolve around what that relationship was and how significant were these impacts. The answer to these questions will only come with continuing cooperation between archeologists and paleoclimatologists. Increasingly precise reconstructions of habitats and land cover changes and accurate correlations with changes in local societies are necessary if we are to move beyond hypotheses to a working science.

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