Dynamic Human Landscapes of the Rio del Oso: Restoration and the Simulation of Past Ecological Conditions in The Upper Rio Grande Basin

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Abstract—The successful restoration of riparian ecosystems to sustainable conditions requires that we understand the dynamic historical relationships between humans and the environment. Research is needed that measures the continuing effects of past human activities on contemporary ecosystem structure and function. An interdisciplinary approach is needed that incorporates expertise from archaeology, paleoecology, plant ecology, and geology. In this paper, I discuss how prehistoric peoples have altered ecological processes and changed the vegetation and overall physiography of northern New Mexico's Rio del Oso Valley. In the Rio del Oso study, we are using paleobotanical, sedimentary, archaeological, and historical data sets to reconstruct past vegetational structure and function, and to identify the cumulative influences of past human activities on today's ecosystems. This information is used to generate three dimensional simulations of environmental conditions through time. These computer reconstructions and analyses of past landscapes will give land managers a greater range of information for use in planning, decision making, and restoration.

Historical Information and Restoration

The landscapes of the Rio Grande and its tributaries have been modified, shaped, and domesticated by humans for at least twelve millennia. Yet the myth of the pristine wilderness prevails among those intent on restoring or preserving this land in its so-called "pre-settlement conditions" (cf. Grumbine 1992). Often, "pre-settlement" refers to pre-A.D. 1850, seemingly negating thousands of years of Native American land use and environmental influence (Quigly and others 1996). Not only does this lack of ecological understanding limit our knowledge of past ecosystem dynamics, it also restricts the future range of restoration efforts possible in the Basin.

The National Resource Council defines restoration as the return of an ecosystem to a close approximation of its conditions before disturbance (1992). Before the objectives of a restoration effort can be established, the ecosystem needs first to be evaluated. Appropriate reference conditions need to be established as goals for restoration of various ecosystem components. The interactions between biotic and abiotic components of the ecosystem must be identified. Additionally, the significant linkages between biotic communities for reestablishing historic ecosystem structure must be understood. Christensen and others emphasize that ecosystem management needs clear long-term operational goals and sound ecological models. Understanding ecological complexity and interconnectedness, recognizing the dynamic character of ecosystems, and acknowledging humans as ecosystem components is crucial for successful restoration, as well as sustainability (Christensen and others 1996:669-670).

Evaluation of an ecosystem's historic structure and function for the purposes of restoration, as indicated above, needs to include study of long-term anthropogenic processes. However, our understanding of how landscapes have developed under cumulative human influences remains limited, and assumptions, rather than the systematic study of past conditions, perpetuate myths about ecosystem development. For example, degradation by over-grazing and other extractive processes may appear obvious. However, we often know little about how a specific ecosystem may have been manipulated, altered, and maintained by humans before such degradation took place. What were the dynamic historical conditions of landscapes we now consider degraded? What long-term processes, including human processes, contributed to this pre-grazing environment? Although historical documentation from personal journals and photographs seem to answer these questions, such sources provide only a glimpse of past landscapes from a synchronic visual, spatial, and temporal perspective. For restoration to be successful, a more comprehensive and diachronic knowledge of past ecosystem dynamics that includes anthropogenic processes needs to be developed.

Addressing this lack of information, Rocky Mountain Research Station's Cultural Heritage Research Work Unit is developing an interdisciplinary approach for quantifying anthropogenic influences on ecosystem structure and function. Our first study area is located in northern New Mexico's Rio del Oso Valley where a variety of cultures have shaped and changed the landscape for at least 7,000 years. In this paper, I first provide a short discussion of how human-induced environmental change has been identified in various areas world-wide. Then I describe the Rio del Oso study and our use of paleoenvironmental information to construct visual models of past vegetational landscapes. Finally I offer a refinement to our conception of restoration.

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Identifying Past Anthropogenic Ecological Change

Human-induced environmental change has been identified in environments around the globe. In a review of pollen and charcoal studies from around the world, Walker and Singh discuss a broad range of data from Western Europe, Africa, Asia, Australia, and North and South America. They suggest that the event most detectable in the pollen and microcharcoal record is deforestation, and that this was caused and aided by human-set fires (1993:108). Additionally, increases in microscopic charcoal, changes in fossil pollen assemblages, and faunal extinctions also indicate human occupation (Burney 1993 and 1997; Chambers 1993a). Paleobotanical research in the Peruvian Andes shows that human-caused deforestation for agricultural purposes took place at least 4,000 years ago (Chepstow-Lusty and others 1998). Throughout the British Isles as early as 10,000 B.P. (before present) reduced arboreal pollen, with a corresponding increase in microscopic charcoal and archaeological evidence, indicates that human activity was responsible for the transformation of forest into peatlands (Caseldine and Hatton 1993; Edwards 1988; Simmons 1988). On the island of New Guinea forest clearing is suggested by changes in pollen assemblages and significant increases in microscopic charcoal dating before 30,000 B.P. The human role in this environmental change is corroborated by the presence of stone axes and adzes (possibly used for forest clearing), from archaeological sites that date to the same period. Indeed, such clearing of vegetation may have begun much earlier in New Guinea, as suggested by the discovery of ground-stone axes, complete with grooves for hafting to a handle, dating to at least 40,000 B.P. (Hope and Golson 1995:821-823).

In the Americas, ethnographical accounts, historical records, and archaeological information show that people directly affected ecosystems by manipulating vegetation. Landscape patterns in native California were altered by human activities such as sowing and broadcasting seeds, transplanting shrubs and small trees, and pruning a variety of plants to induce greater productivity (Blackburn and Anderson 1993:19). Fire was used to clear vegetation and increase the productivity of plants and animals important for human survival. By 1492 agricultural fields were common, as were settlements with networks of roads and trails, all of which had local impacts on soil, microclimate, hydrology, and wildlife 1992:370). Subsequently, the introduction of Old World livestock, intensive agriculture, and industrial development into existing Native American land-use systems resulted in a combination of anthropogenic influences producing hybrid landscapes (Whitmore and Turner 1990:416).

Human actions of one century have a cumulative environmental effect when combined with human actions from another century. Succeeding occupation and abandonment causes a landscape's developmental trajectory to evolve in a new direction (see Tainter and Tainter 1995:28). Over the course of generations, repeated and changing levels of human disturbance become part of the ecological processes in an ecosystem (Allen and Hoekstra 1992:272). Each new anthropogenic landscape is built upon an antecedent landscape. Such is the case in the Rio Grande Basin of New Mexico where Puebloan agricultural landscapes were constructed upon those created by earlier foragers, and Spanish colonial landscapes were built upon Puebloan farming landscapes.

Rio Del Oso Study

The Rio del Oso is an eastern-flowing tributary of the Rio Chama that drains the northern portion of the Jemez Mountains of north central New Mexico (fig. 1). Most of the Rio del Oso watershed is administered by the Santa Fe

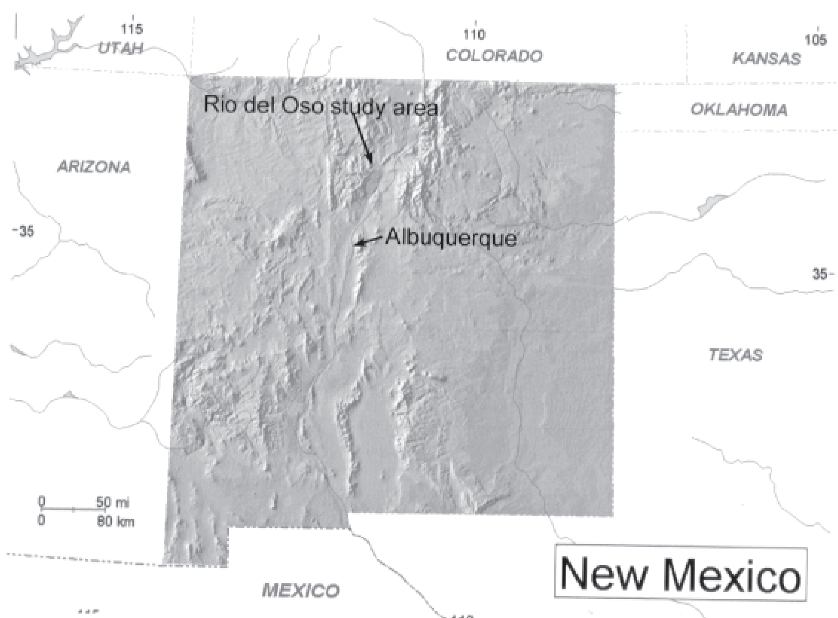

Figure 1—Rio del Oso study location.

National Forest. I selected the Rio del Oso as my study area because of its complex richness of recorded archaeological sites. More than 280 archaeological sites including four large pueblos have been recorded in the lower portion of the drainage (Anschuetz 1995). Although the anthropogenic qualities of the Rio del Oso landscape may not be readily discernable, this place has been shaped into the landscape we see today by thousands of years of human activity. The archaeological data of the Rio del Oso valley covers the Archaic period (5500 B.C. to A.D. 600), the Coalition period (1200-1325), the Classic period (1325-1600), and the historic Hispanic period (beginning c.1600).

During the Archaic period hunter-gatherers occupied the valley and likely affected the Rio del Oso landscape by burning its vegetation, dispersing seeds, and selectively harvesting plant and animal species. So far, archaeologists have found little evidence for human occupation of the valley between the late Archaic and the Coalition periods. However, from A.D. 1200 through 1600, the Puebloan groups greatly altered the valley by creating villages, agricultural features and other systems of land and water use (Anschuetz 1995).

When historic Hispanic groups moved into the Rio del Oso they constructed small settlements and farms, built roads and water ditches, and produced their own unique landscape patterns in the valley (Wozniak and others 1992). During the first part of this century the Forest Service assumed administration of the area, creating yet another pattern of human-use and environmental change by restricting grazing, building roads and fences, and attempting to restore vegetation.

Data Sources and Methods

The primary goal of our research is to develop an integrated, interdisciplinary approach to identify and measure cumulative anthropogenic effects on landscapes. Data in the Rio del Oso project ranges from historical and ethnographic records to archaeological and paleobotanical data. The Santa Fe National Forest has provided digital vegetation data, land type, watershed coverages, and Digital Elevation Models (DEMs), and has made all archaeological site records and field maps available. Additionally, I am using Forest Service administrative records, 1935 aerial photos, and 1991 color infrared aerial photos to reconstruct the valley's environmental history and document vegetational change for this century.

With these data map layers have been developed including vegetation, landform, watershed, and archaeological site coverages. All four data sets will be used, either individually or in combination, to develop visual models of the existing vegetational environment. In this interdisciplinary study, we are using archaeological, paleobotanical, sedimentary, geomorphological, and historical data to identify past human-induced ecological change through time. Our research questions include:

1. What interdisciplinary data sources, research methods, and analytical approaches can be used to develop GIS data layers of past and cumulative human-created landscapes?
2. Using the above methods, can we identify and quantify the extent of human-induced vegetational change for specific periods relative to the different technologies and economies of the cultures that occupied the land during those times?
3. Using data from the above sources, is it possible to produce three-dimensional landscape models that accurately illustrate the environmental history of an area? Which sources of information are the most useful? Do the resulting landscape simulations provide a useful model for understanding human and environmental interactions?
4. Is it possible to develop a set of methods and techniques that can be applied to ecosystems different from those in northern New Mexico?

Fieldwork and Paleobotanical Analysis

Fieldwork began during the summer of 1996 with the collection of soil samples from an exposed, 5 m stratified section of alluvial sediments. Pollen, phytoliths, microscopic charcoal, and radiocarbon samples were extracted from each stratum. Four prehistoric human hearths, or ash-stain features, were uncovered while preparing the vertical surface of the cutbank for sample collection. During sampling, geologist Dr. Stephen A. Hall (geologist and research partner, Department of Geography, University of Texas at Austin) identified seven distinct paleosols in the profile (Hall personal communication 1996).

In 1997 pollen, phytoliths, and microscopic charcoal were extracted from the samples by paleobotanist Dr. Linda Scott Cummings (paleobotanist and project collaborator, Paleo Research Inc., Denver, CO). Radiocarbon dates were produced, ranging from 3515 B.C. to A.D. 1350, for the 24 strata. The pollen analysis, when matched with the radiocarbon dates, suggests fluctuations in vegetation and microcharcoal levels over the past 5,512 years. During her analysis Dr. Scott Cummings identified corn pollen in three of the levels dating between 1360 and 1225 B.C., associated with hearths. Although presently inconclusive, this may be some of the oldest evidence of corn in the Rio Grande Basin (see Minnis 1992).

Additionally, surface samples for pollen, phytoliths, and microscopic charcoal were collected from areas near our stratified section. The data from those samples are being used to develop control ratios of pollen frequencies to trees- and shrubs-per-acre. These ratios will be used with the three-dimensional GIS to reconstruct the hypothetical tree and shrub densities of past landscapes.

During reconnaissance of the valley in 1997, other stratified deposits containing buried soils were identified, and sediment samples were taken from newly discovered cutbanks as well as from a peat bog located at the head of the drainage. New surface samples were also collected from the Rio del Oso's riparian habitat. We conducted additional analysis and developed new methods for analyzing opal phytoliths during 1998. Dr. Scott Cummings identified an abundance of phytoliths that appear to be from woody plants, possibly from tree species. Appropriate phytolith comparative collections being unavailable in the United States, she took the phytolith samples to Israel where they

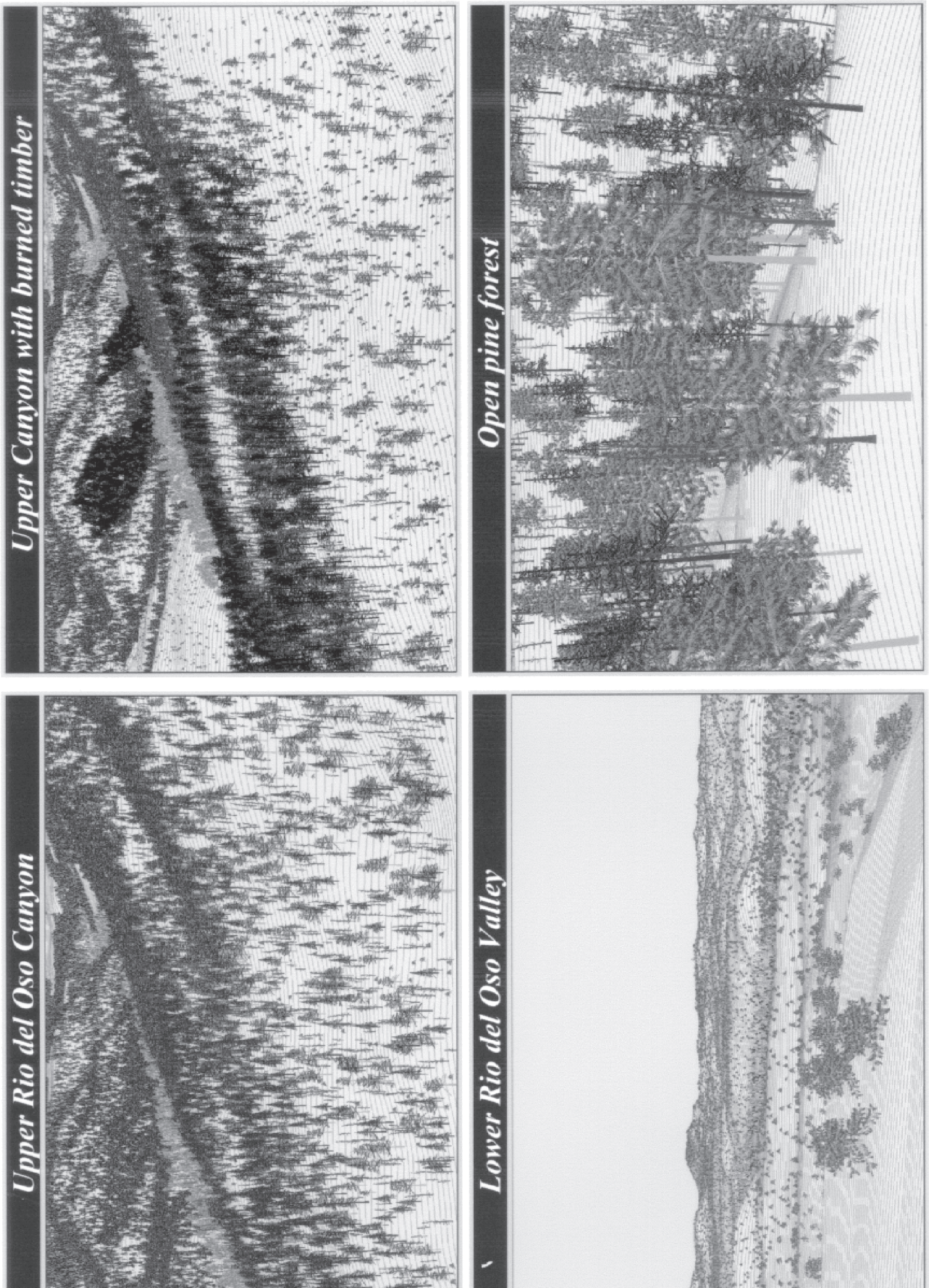

Figure 2—Hypothetical simulations of Rio del Oso landscapes.

were compared to tree phytoliths identified by Israeli scientists (Scott Cummings personal communication 1998).

In 1999 we will excavate backhoe trenches at the first sample location and at three of the localities identified in 1997. Additional samples will be taken from those locations and the trenches will enable further study of the geomorphology of the Rio del Oso Valley. Future research will include the calculation of areas affected by prehistoric activities, the identification of zones around archaeological sites and features representing levels of land use, and the refinement of interdisciplinary methods for application to other types of landscapes. We also will continue to establish indices of surface pollen, phytolith, and microscopic charcoal, which represent different habitat types in the Rio del Oso drainage.

Simulation of Past Landscapes

The Rio del Oso landscape simulations are based on vegetational assemblages reconstructed from paleobotanical, ecological, archaeological, and historical data. Analyses, of the paleobotanical samples by Dr. Scott Cummings will identify variations in absolute and relative pollen and phytolith frequencies, assemblages representing specific habitats, past fire frequencies, and human-induced vegetational change through time. The quantities of vegetation (for example, trees-per-acre) will be derived from the surface and subsurface data as described above. This information will be used to produce three-dimensional simulations of past vegetational landscapes (fig. 2) from a variety of viewsheds within the Rio del Oso drainage for each stratigraphic level. The simulations are grouped according to their radiocarbon dates into corresponding archaeological periods.

The simulations are created using a visual simulation system designed by Resource Analysis Systems for natural resource management. This software, called Visual F/X, produces three-dimensional landscape perspective scenes as if seen through a 35mm camera with a 50mm lens. It allows the user to define up to 14 basic tree forms and control the crown width, height, and trunk diameter. A DEM (digital elevation model) is used as the base map and vegetation density is derived from estimated trees- and shrubs-per-acre figures. Additionally, we utilize digital vegetation, soil, timber, and watershed map data. The paleobotanical data (for example, pollen) are grouped by ecological or phytogeographic categories to help illustrate how plant distribution and ecological conditions have changed through time (Pearsall 1989:286). These data will be used to help identify temporal and spatial fluctuation of vegetation type areas, for example, riparian cottonwood-willow habitat.

Linking Past Vegetational Patterns to Ecological Processes

Along with compiling paleobotanical data that show ecological change, and represent that change graphically, we also need to identify reliable indicators of past human-caused environmental change (see Birks and others 1988). How does analysis of pollen and other organic particles indicate human manipulation and change of the environment? The answer to this question may depend on the "sensitivity of an ecosystem to human exploitation and the degree to which this is reflected in the pollen analytical signal" (Walker and Singh 1993:104). In order to discern "natural" paleobotanical change from that caused by human manipulation, Walker and Singh suggest four criteria:

1. It [the paleobotanical record] should reflect ecological processes operating at levels and rates that are unprecedented under 'natural' conditions but are readily explicable as resulting from human actions of defined kinds.
2. The necessary human activities should be within the technological capacity of prehistoric peoples of the relevant age and region.
3. There should be some acceptable reason why the humans might have taken the hypothesized action (ideally exemplified by the pollen itself, for example, crop pollen).
4. There should be strong evidence (ideally artifacts stratified into the pollen-analyzed deposits) for human occupation at the appropriate time within the pollen catchment (Walker and Singh 1993:104-105).

When these criteria are applied to the pollen and charcoal records of Europe, there is striking evidence for an anthropogenic influence resulting in the transformation of western European forests between 7000 and 6000 B.P. This ecological change is attributed to clearing land for agriculture (Walker and Singh 1993:106-107). Although the Rio del Oso project includes the study of landscapes created before and after the introduction and use of agriculture, these criteria will be used to help determine human-induced environmental change from that caused by climate change and other natural occurrences. However, I have added another criterion to help with the identification of anthropogenic change: Two or more paleobotanical indicators, for example, pollen, phytoliths, macrobotanical remains, packrat middens, ethnographic information, or historical photographs should correlate when data sets are analyzed and compared.

An essential part of this analysis involves bridging the gap between the paleobotanical record and interpretation of vegetational landscapes. This interpretation is very important for producing the simulations discussed above. Pollen and phytolith analysis identifies pollen producing plants inside and outside an ecosystem. The paleobotanical record accounts for a generalized sample of vegetation from a large area (Pearsall 1989).

Designating a group of species that *represents* a specific vegetation community will help describe the vegetational variation of specific habitats within the Rio del Oso landscape. For example, an assemblage of species may represent riparian areas while another group may represent species growing mainly in upland habitats. It should be possible to estimate vegetation density by comparing representative species groups to the index surface of samples and then compare the variation in pollen frequencies for each species and each habitat assemblage. Such densities would be calculated as trees and shrubs per acre for spatially discrete habitats. From this record a specific group of plant species may be identified within a given range of pollen frequencies which would identify human alteration of vegetational patterns. Comparing the fossil habitat assemblages and their associated species frequencies to an index of current habitat pollen frequencies gives us an estimate of the expansion and contraction of individual habitats through time (Berglund and others 1996; Pearsall 1989).

However, vegetational reconstructions are only the first step in understanding how the Rio del Oso landscape developed under human influence. As stated earlier, we also need to understand ecological processes. The following definitions for *ecosystems*, *ecological landscapes*, *anthropogenic* landscapes can be used to link landscapes, ecosystems, and human influences. Using Lindeman's definition, an ecosystem is "the system composed of physical-chemical-biological processes active within a space-time unit of any magnitude, i.e., the biotic community plus its abiotic environment" (1942:400). An ecological landscape is the spatial matrix in which organisms, populations, and ecosystems are set (Allen and Hoekstra 1992:56). Anthropogenic landscapes are formed within and become integral to ecological spatial matrices; they include process as well as form. Such landscapes are "land shapes," areas which are made up of a distinct association of forms both physical and cultural (Sauer 1925:25-26). Landscape is the way we produce or reconstruct our physical, material world; a kind of human sculpting of the natural universe (Wilson 1992).

In figure 3, ecosystem processes occurring through time (a) are represented as cyclical, components, while the three surfaces represent the landscape spatial matrix (b). Change in landscape vegetation and geomorphology occurs within the spatial matrix and is represented on the landscape surfaces as differing vegetation (c). Human activities like burning vegetation or practicing agriculture affect ecosystem processes. Over time these human-induced processes, or changes in processes, affect plant community composition, habitat size, as well as carbon, nutrient, water, and decomposition cycles. Changes in function (ecosystem processes) and structure (vegetation patterns and geomorphology) result in variations in the placement of landscape components (see Hobbs 1997). Changes in technologies result in changes in ecological processes. As new, human land-use practices change vegetational patterns (for example, the introduction of agriculture), new anthropogenic landscapes are created within and are part of the ecosystem and spatial matrix. Over thousands of years, this complex relationship between humans and the environment has had a cumulative effect on landscape development.

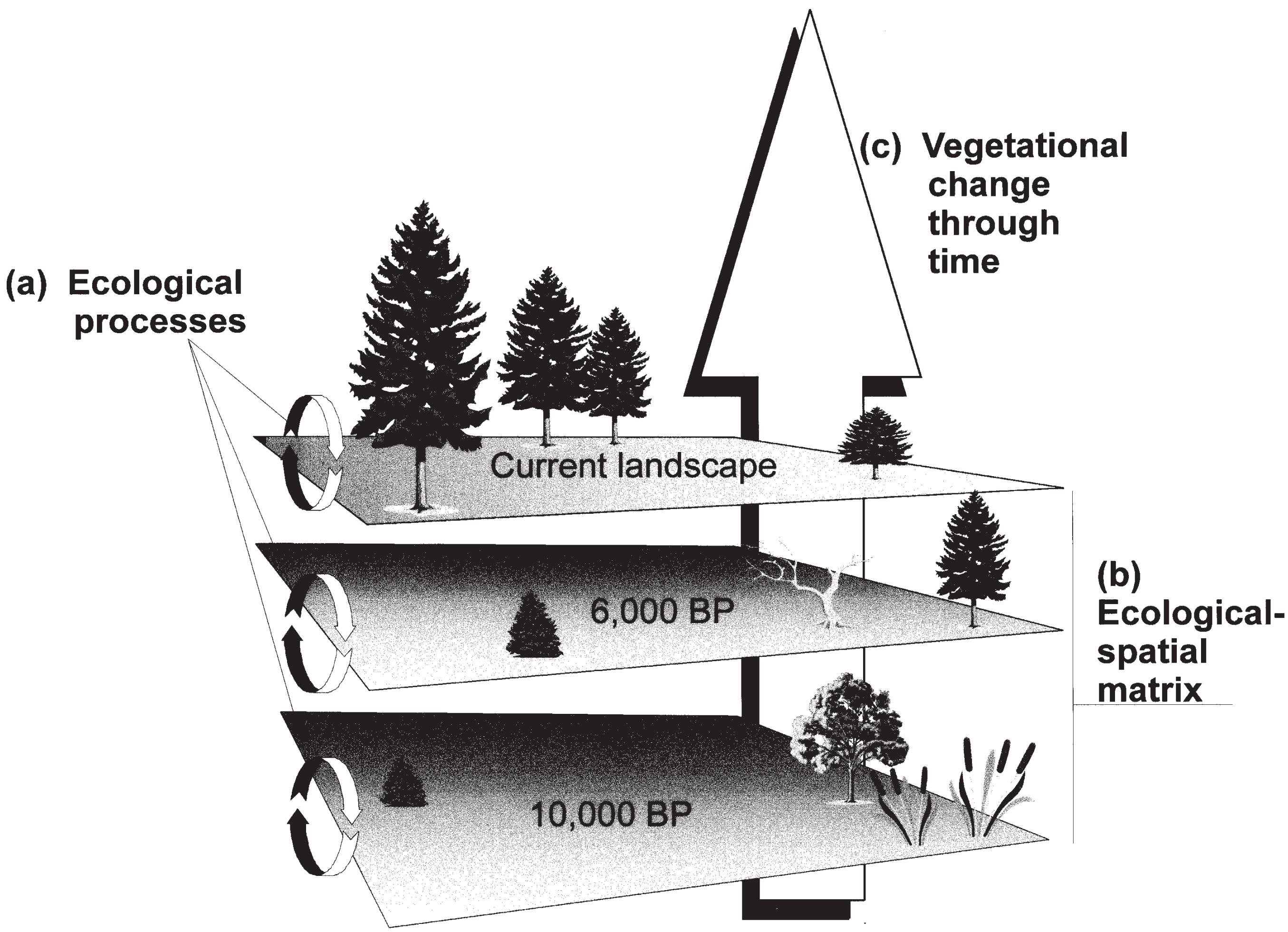

Figure 3—Model of long-term human influences in landscape development. Humans affect landscapes at all levels (a, b, and c).

Restoration

In places like the Rio del Oso Valley human influence is inextricable from the other components and processes that created the landscape we see today. The relationships among ecological and cultural processes can be important for restoration. An alternative to merely restoring vegetative structure (replanting etc.) using reference conditions would be to identify a set of multidimensional *reference dynamics* (natural and anthropogenic). These reference dynamics should include an understanding of the: (1) paleoecological evidence of natural and human-induced change including change in biodiversity and abundance of specific species; (2) technologies and processes responsible for specific environmental change; and (3) temporal and spatial intensity and extent of such change to the ecological-spatial matrix. By understanding these components, a land management agency has more options for restoring and sustaining an ecosystem within a range of ecological, climatic, and sociological constraints.

Conclusions

Public demand for the restoration of ecosystems degraded by grazing, logging, and other extractive uses, daily challenges the ingenuity and resourcefulness of land management agencies. The landscapes we manage today have been modified, shaped, and domesticated by humans for at least twelve millennia. The concept of ecological restoration involves human intervention in ecological processes. Indeed, the word "degradation" reflects human values and varies among cultures (see van der Leeuw 1998). Just as past cultures played an integral role in creating the landscapes we see today, restoration involves the manipulation of ecological processes to achieve landscape conditions desired by society. Current conflicts over public land management is to some degree based on differing definitions of degradation and what ecological conditions are considered desirable (see Raish this volume).

Models of past landscapes like those being produced for the Rio del Oso can help managers to understand better the dynamic processes required for restoring ecosystems to desired conditions. Creating landscape simulations based on paleobotanical, archaeological, and geological data will enable decision-makers to view their restoration options within a *range* of dynamic processes leading to sustainable conditions.

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