



LANDSCAPE EVOLUTION AND HUMAN AGENCY: ARCHAEOLOGICAL CASE STUDIES FROM DRYLANDS IN WESTERN SOUTH AMERICA AND AUSTRALIA¹

LA EVOLUCIÓN DEL PAISAJE Y LA AGENCIA HUMANA: ESTUDIOS ARQUEOLÓGICOS DE TIERRAS ÁRIDAS EN SUDAMÉRICA OCCIDENTAL Y AUSTRALIA

Gregory Zaro², Heather Builth^{3}, Claudia Rivera^{4*}, Jimena Roldán^{5*}, and Graciela Suvires^{6*}*

Landscape represents a dynamic point of articulation between humans and the environment. While often dichotomized, humans are active participants in the environment and often play a pivotal role in its transformation over time. In this paper, we use case studies from western South America and Australia to illustrate the importance of studying long-term dynamics between humans and the environment. Such investigations can bring significant historical depth to environmental change and the role humans have played in altering courses of landscape evolution and species biodiversity. Humans comprise a critical element in environmental change, and collectively, our results hold strong implications for issues related to sustainability and effective management of our planet's desert resources.

Key words: Dryland environments, agriculture, sustainability, South America, Australia.

Los paisajes representan un punto dinámico de articulación entre los seres humanos y el ambiente físico. Mientras que a veces se presentan como opuestos, los grupos humanos son participantes activos en el ambiente y frecuentemente cumplen un papel muy importante en su transformación a través del tiempo. En este artículo se usan estudios arqueológicos del oeste de Sudamérica y de Australia para ilustrar la importancia de investigar interacciones, a largo plazo, entre los grupos humanos y el medio ambiente. Estas investigaciones pueden ofrecer una mayor profundidad en el conocimiento histórico al cambio ambiental y asimismo precisar el rol que han jugado los grupos humanos en modificar trayectorias particulares en la evolución del paisaje y de biodiversidad de las especies. Los grupos humanos constituyen un elemento crítico en el cambio ambiental y, en conjunto, nuestros resultados tienen fuertes implicancias para temas relacionados con sostenibilidad y la gestión efectiva de los recursos desérticos de nuestro planeta.

Palabras claves: paisajes áridos, agricultura, sostenibilidad, Sudamérica, Australia.

With the development of an increasingly global economy, the manner in which people interact with their environment holds cross-cultural implications for the successful reproduction and prosperity of other communities. Decisions that humans make today with respect to land use and resource management will have differential consequences for other human groups, both contemporary and future, just as land use in the past has affected the myriad of

ways humans interact with the environment today. As people modify their physical surroundings, irreversible changes may occur that diminish opportunities for particular production strategies, while at the same time creating possibilities for other strategies not initially feasible. These human imprints on the environment constitute a cumulative component of landscape evolution, which serve to shape and re-shape resource distribution and biodiversity on

¹ Artículo seleccionado de las presentaciones al Second Southern Hemisphere Desert Conference (Arica, octubre 2005).

² Department of Anthropology and Climate Change Institute, 5773 South Stevens Hall, University of Maine, Orono, ME 04469-5773, USA. Gregory.Zaro@umit.maine.edu

³ School of Geography and Environmental Science, Monash University, Vic. 3800, Australia. Heather.Builth@arts.monash.edu.au

⁴ Universidad Mayor de San Andrés, La Paz, Bolivia. clauri68@yahoo.com

⁵ INGEMA, CONICET, Facultad de Ciencias Naturales e IML, Universidad Nacional de Tucumán, San Miguel de Tucumán, Argentina. jimena_rolدان@yahoo.com

⁶ Consejo Nacional de Investigaciones Científicas y Técnicas, Universidad de San Juan, FCEFN, San Juan, Argentina. graciela_suvires@yahoo.com.ar

* Co-authors contributed equally to this paper and are listed alphabetically.

our planet. Consequently, environmental change is rooted in historical contingency, and it is conditioned by the interplay of both biological and geophysical processes.

In this paper, we take an historical ecological perspective to demonstrate the value of investigating long-term dynamics between humans and the environment, including various courses of land use and the role humans play in landscape evolution. As a point of articulation between humans and their physical surroundings, landscapes provide an excellent avenue through which to investigate this interactive relationship. Following similar approaches (e.g., Balée 1998; Balée and Erickson 2006; Crumley 1994; Denevan 1992; Hayashida 2005; Lentz 2000; Redman 1999; Redman et al. 2004; van der Leeuw and Redman 2002), we illustrate the importance of archaeology in providing significant historical depth to environmental change and the role of human agency. At the same time, archaeological studies can generate greater long-term contexts for contemporary landscapes. We use archaeological studies from dryland environments in western South America and Australia to illustrate these points (Figure 1).

Dryland Environments and Ecosystemic Change

Nearly one third of land on our planet is classified as arid or semiarid, where rainfall either limits productivity or is highly unpredictable (Whitford 2002:1). Yet, humans have inhabited dryland environments for millennia, and they constitute a chief component of these ecosystems. However, only in the past several decades have we come to realize the fragility of such landscapes, and that when degradation occurs, recovery is often slow or sometimes absent (Browman 1987; Dregne 1986). While all environments are subject to human-induced change, arid and semi-arid lands are particularly vulnerable because of their fragile nature.

Dryland environments are neither stagnant nor homogeneous entities within which communities operate; rather, they are fluid and constantly changing. In ecological terms, “communities” have historically been identified as aggregations of organisms within a defined spatial scale. However, as Whitford (2002:3) notes, communities of organisms should be conceived as “constantly accommodating

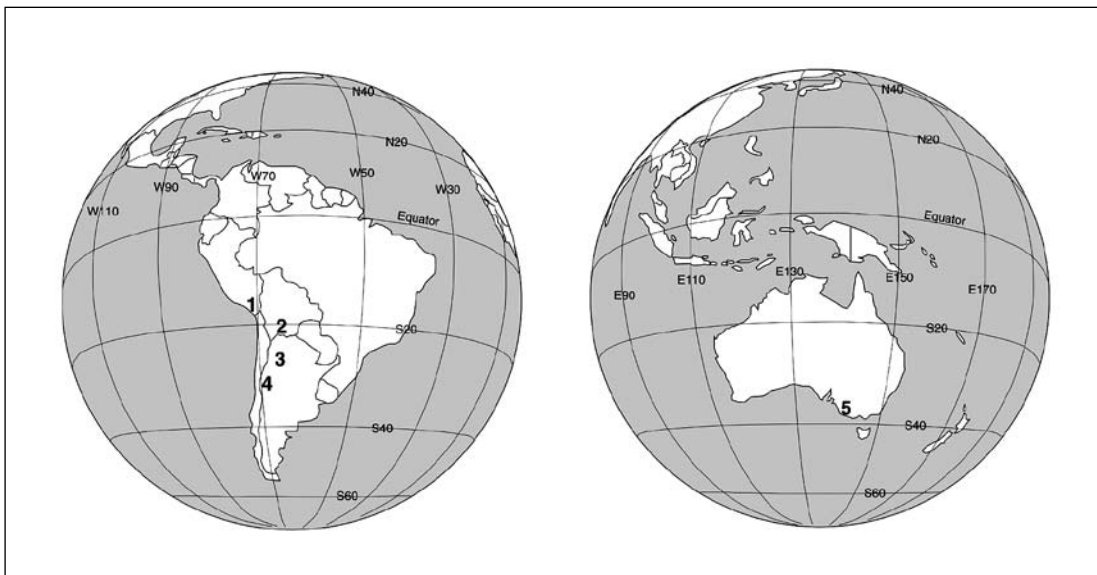


Figure 1. Map showing the locations of principal case studies mentioned in the text: (1) the coastal Osmore desert of Southern Peru, (2) the Cinti Valley of South Central Bolivia, (3) the Tañ Valley of Northwest Argentina, (4) the San Juan province of West Central Argentina, and (5) the Mount Eccles lava flow of Southwest Victoria, Australia.

Ubicación de los principales casos de estudio mencionados en el texto: (1) desierto Osmore de la costa sur del Perú, (2) valle Cinti del centro sur de Bolivia, (3) valle Tañ del noroeste de Argentina, (4) provincia de San Juan del centro oeste de Argentina y (5) flujo de lava de Mount Eccles del suroeste de Victoria, Australia.

and changing in character as the result of natural selection of species to the presence or absence of associates." Indeed, change is the natural state of the environment, a point underscored by the New Ecology and its focus on nonequilibrium dynamics (Zimmerer 1994). Consequently, human agency merely accelerates, retards, or alters particular courses of change and biodiversity. As a co-evolutionary process, the line between anthropogenic and natural environments becomes blurred, compelling van der Leeuw and Redman (2002) to champion the term "socio-natural environment" as a way to speak of this wholly interconnected and co-evolving relationship.

Human decisions to modify land use and manage resources occur in a number of interwoven environmental, cultural, and temporal contexts, but over-emphasis on strictly events of cause or effect may ignore the processes that lead to those events (Morrison 1994). As part of a process, human actions are shaped and reshaped by earlier human-environment dynamics. Foster and colleagues (2003) have referred to past human impacts on the environment as "land use legacies," a term that accentuates the pervasive and long-lasting effects of human activities on courses of environmental change. A better understanding of deep historical trajectories of landscape evolution more effectively helps to frame contemporary environments, while also serving to enhance our understanding of land use legacies far into the future.

The Human-Environment Continuum

While often dichotomized, in reality humans and their environment are richly interconnected and should be treated as a dynamic relationship that continuously transforms the socio-natural environment. Ingerson (1994:65) offers a conceptual understanding of this interaction, urging investigators to conceive of nature and culture as points on a quantitative spectrum rather than as qualitative opposites. With respect to landscapes, direct causality between nature and culture becomes a non-issue, and in effect, environmental change becomes an outcome not strictly of human or non-human processes, but rather as a result of the relationship between them. Gunn (1994:67) underscores this point, noting that "biological systems, soils, and hydrology are so completely interactive with humans and culture, and appear to have been

so for at least a million years, that they should be treated as a richly networked analytical unit." In fact, creating a dichotomy between natural and anthropogenic causation only fosters the notion of a non-existent pristine nature (Crumley 1994; Denevan 1992; Head 2000).

To understand the role of human agency in environmental change, the human-environment relationship may be more effectively conceptualized as a continuum of human and non-human processes where both play relative roles in ecosystemic change. On the one hand, human activities like terrace construction, control of hydrology, introduction of non-native species to particular regions, soil manipulation, and waste deposits may all lead to long-lasting imprints on the environment. In the coastal Osmore desert of southern Peru (Figure 1), for instance, late prehispanic (AD 1,200-1,400) farmers at the site of Wawakiki constructed stone-faced terraces and high-gradient canals along steep and sparsely vegetated hill slopes to reduce risks associated with excessive soil erosion and evaporation of a very limited water supply (Zaro 2007; Zaro and Umire Alvarez 2005). Upon abandonment of the site sometime during the early fifteenth century, the hyper arid conditions and local topography left much of the agricultural infrastructure well intact for several hundred years. By the beginning of the seventeenth century, Spanish colonists arrived in the area and took advantage of this largely anthropogenic landscape by reactivating many of the existing canals and terraces. Their decisions to do so were largely historically contingent, conditioned by an expedient mentality toward land use and the existence of a landscape that was already "naturally" equipped with an agricultural technology. Terrace walls that were not reactivated or maintained were eventually breached, which ultimately augmented soil erosion and degradation (Zaro 2005). Accelerated erosion among neglected terrace systems has been documented elsewhere, and it is not an uncommon effect of such circumstances (Redman 1999). In this respect, human agency played a profound role in landscape evolution between the thirteenth and eighteenth centuries, though continuous interactions with topography, available water and drainage, tectonic activity, and other geophysical processes provided a dynamic context in which farming activities were carried out. Furthermore, these land use legacies continue to shape the desiccated environment centuries later.

In other cases, non-human processes may dominate trajectories of landscape change, which may include geophysical forces related to geology, hydrology, and seismology. In the San Juan province of west central Argentina (Figure 1), geophysical processes have overshadowed any role human agency has played in local landscape change. The San Juan region is characterized by a desert landscape, with indigenous occupation primarily restricted to oases. Field investigations and interpretations of aerial photographs have identified different geomorphologic units, which have helped to define long-term landscape change related to relief evolution in the piedmont area. Alternating periods of greater and lesser discharge rates have led to considerable differences in age, grain size, and slope of alluvial fan deposits in the region (Suvires 2000). Consequently, drainage patterns have varied through time as these geomorphic processes continue to unfold. Similarly, tectonic activity associated with a major fault system has altered the steepness and slope direction of the terrain, which in turn has affected drainage patterns and led to the abandonment of some earlier depositional systems. The Zonda fault is perhaps the most important in the area because of its influence on drainage patterns. It has a 3 m high scarp and a difference in the surfaces of both blocks of 7.4 m. It is argued to be 141 thousand years in age, though it was reactivated during a 1952 earthquake in San Juan (Paredes and Bastías 1987; Perucca and Paredes 1999). Thus, in the relatively depopulated study area in the San Juan region, geophysical processes have and continue to play a powerful role in landscape evolution, where direct human activities have constituted a comparatively small force toward local environmental change.

In some cases, the human component plays a particularly strong role in environmental change, while in other cases non-human biological and geophysical processes may dominate, and especially where human activity has remained minimal or even absent. Although human agency is often isolated for analytical purposes, in reality landscapes should be treated as part of a historically contingent process that wholly integrates all biotic and abiotic elements. Indeed, humans are part of nature, borne out of natural evolutionary processes through time. It becomes imperative, then, to include humans in nature and minimize the kinds of dichotomous thinking that falsely separates us from the physical world (Head 2000). In this context, contemporary landscapes are

not simply cultural *or* natural components of the present, but rather they are culminations of long-term processes of human-environment interactions.

Landscape Evolution in Southern Hemisphere Drylands: Archaeological Case Studies from Western South America and Australia

Agricultural landscape evolution in the Cinti Basin of South Central Bolivia

The Cinti Valley is located in an area of rugged mountains and deeply incised valleys of south central Bolivia (Figure 1). The valley is roughly 80 km long, and it has traditionally been an important corridor linking *puna* or *altiplano* populations of the west to lowland populations toward the east. In general, the valley can be divided into an upper zone (2,800-3,600 masl) with numerous, small sub-basins separated by rocky formations, and the Cinti canyon (2,200-2,500 masl), characterized by a narrow valley flanked with red sandstone formations to the west and synclinal formations to the east. The two zones are separated by a narrow, steep canyon with relatively poor agricultural soils and sparsely vegetated slopes.

Based on hydrology, topography, temperature, and vegetation, the Cinti region is classified as sub-humid-dry, generally with one or two months of water surplus and six to seven months of water deficit (Cortés 1994). The lower valley is semi-arid, where a water deficit sometimes occurs up to twelve months per year and xerophytic species dominate the landscape. The Cinti region receives an annual mean of 476 mm of precipitation, but it occurs in marked wet and dry seasons. Greatest precipitation extends from October through March, while the months of April through September remain relatively dry. While Cinti Basin rivers exhibit marked seasonal variation in runoff, their presence has permitted intensive irrigation and expansion of agriculture in a typically semiarid environment (ZONISIG 2000). However, frost, hail, drought, and excessive rainfall may adversely affect farming throughout the region, though these risks differentially impact production strategies according to local soil structure, vegetation, and agricultural technology.

The first sedentary agricultural villages emerged in the valley during the Formative Period (2,000 BC-AD 400), primarily situated near streams, naturally protected areas, and other good cultivable

terrain (Rivera Casanovas 2004:58). During the following Early Regional Developments period (AD 400-800), population levels continued to grow and social complexity increased, evidenced by larger, more nucleated settlements and by the establishment of new settlements in previously unoccupied regions (Rivera Casanovas 2004:63-68). Agricultural expansion and intensification accompanied population growth with the construction and maintenance of extensive systems of terraces and irrigation canals. These trends continued into the Late Regional Developments period (AD 800-1,430) and Late Horizon (AD 1,430-1,540), where both expansion and intensification of agricultural management is evident, especially during Inka expansion into southern Bolivia (Rivera Casanovas 2005).

Archaeological and paleoenvironmental evidence suggests that locally forested areas, primarily consisting of xerophytic species, had been cut down to modify and expand agricultural lands, while woody resources were exploited for fuel and other domestic purposes (Rivera Casanovas 2005). These activities provoked rapid changes in ecosystemic properties, primarily with respect to a loss of ground cover and subsequent erosion, but also with respect to an overall decline in biodiversity through time (Vetté and Rojas 1998; ZONISIG 2000:140-142).

Terrace construction significantly decreased the effects of soil erosion along the steep and more moderately sloping flanks of the valley, beginning possibly as early as the Formative Period (2,000 BC-AD 400), but occurring in most dramatic fashion during the Late Regional Developments (AD 800-1,430) and Late Horizon (AD 1,430-1,540) periods (Rivera Casanovas 2004). Such investments may have also enhanced soil moisture retention, perhaps mitigating risks related to severe dry spells or shortened rainy seasons. By the Spanish colonial period, farmers intentionally transported large amounts of soil to the Cinti canyon, where deep alluvial soils were minimal (Rivera Casanovas 2004:28). To this end, local communities used loamy soils to build up the landscape and enhance its agricultural potential, which today continues to support the local wine industry.

Currently, land use encompasses both irrigation agriculture and pastoral activities in the Cinti region. Agriculture is generally restricted to the valley bottoms and terraced areas in the piedmont, while pastoral activities of goats and sheep tend to be restricted to the grass and shrub lands of the

upper slopes. However, introduced herbivores (like sheep and goats) have few physiological adaptations to arid and semiarid environments and are often more conducive to overgrazing of endemic plants within these ecosystems than native herbivores (Whitford 2002:322). Consequently, human decisions to introduce non-native species can often have profound effects on other living organisms within fragile desert landscapes. Among the upper slopes of the Cinti Valley, overgrazing by goats is one of the principal causes of continued degradation. Because of uncontrolled grazing, they have been characterized as depredators, leading to accelerated deterioration of ground cover and advanced soil erosion in the area (ZONISIG 2000:140-142, 170-172).

Over the past several thousand years, human activities related to land use and resource exploitation have resulted in significant landscape modification and manipulation of hydrology, soil morphology, and vegetation patterns throughout the Cinti Basin. However, neither complete abandonment of agricultural nor pastoral activities would necessarily return the environment to a previous ecosystemic state prior to significant human action. Rather, the integration of both bio- and geophysical processes would interact with contemporary landscape elements to create a new, historically contingent environment. In this sense, the landscape is the product of a long-term and wholly interactive sphere of biotic (including humans) and abiotic elements within the Cinti Basin ecosystem.

Prehispanic agriculture and soil chemistry in the Tafi Valley, Tucumán, Argentina

The Tafi Valley is located in northwest Argentina in an intermontane setting of the pre-Andean region about 1,800 to 2,300 masl (Figure 1). Most of the valley is presently covered by grasses, and the climate is classified as semiarid, with annual precipitation generally ranging from 400 to 550 mm (Sampietro and Vattuone 2005). Extensive paleoenvironmental research in the region has documented a considerably detailed environmental history for the area from the Late Pleistocene through the Holocene (Sayago and Collantes 1991): from the Early Holocene until about 7,500 BP, the climate was sub-humid and warm, turning to cold and dry by the Middle Holocene; by 3,000 BP, temperate and sub-humid conditions were established.

Ongoing research in the Tafí Valley indicates that environmental change catalyzed by human agency is not restricted to simply macro-level indications like terrace construction, directed changes in biodiversity, or manipulation of drainage patterns. Rather, as in most cases, human activities impact micro-level processes as well, such as changes in soil chemistry and morphology (Holliday 1992). The study presented here was carried out among agricultural terraces associated with the site of El Tolar during the Formative Period (700 BC-AD 1,000). El Tolar is specifically associated with the Tafí culture, dated between $2,296 \pm 70$ years BP (González 1962) and $1,140 \pm 50$ yr BP (Berberían et al. 1988). The archaeological culture is primarily defined by settlement patterns, agricultural activity, and stone sculpture (Bennett et al. 1948; Berberían et al. 1988; González 1962, 1977; González and Núñez Regueiro 1960). Settlement patterns and associated landscape features suggest that both cultivated plants and domesticated animals comprised a significant component of the local subsistence economy (Sampietro 2002; Sampietro and Vattuone 2005).

Soil properties (e.g., pH, texture, organic matter, phosphates, calcium) may be used to understand significant changes imposed on soil chemistry and morphology by agriculture. Similar approaches have been successfully employed elsewhere in dryland environments, and particularly in the Southwest region of the United States (New Mexico) and in the Colca Valley of the arid Western watershed of Southern Peru (Dick et al. 1994; Eash and Sandor 1995; Sandor 1992; Sandor and Eash 1991, 1995; Sandor and Furbee 1996). In the Tafí Valley, profiles associated with agricultural terraces show evidence of compaction, darkening of soil, concentration of phosphates, alterations in the value of copper, structural differences, and changes in organic material content. Combined, the characteristics identified in profiles indicate the presence of a well-defined paleosol with traces of anthropogenic activities (Roldán 2004). The paleosol exhibits optimal morphological and chemical characteristics for plant development within the terraced area, owing to a slightly acidic pH, good structure, texture, and quality of organic material, and concentrations of micronutrients (Fe, Mn, and Cu) that are non-toxic towards cultivable plants (Roldán 2004). While paired samples have not yet been analyzed from nearby uncultivated areas, the paleosol associated with

Formative Period terraces in the Tafí Valley exhibits concentrations of organic phosphorus with values elevated beyond those normally expected for soils in the region. Because soil tends to lose minerals as a result of agricultural activities, farmers often utilized organic fertilizers like *guano* (commonly exploited by prehispanic farmers) to replenish soil nutrients and ensure successful cultivation. This may have been the case in the Tafí Valley, though this proposition is only speculative and is currently being tested further. It is also pertinent to consider that the warm and humid climatic conditions during the Tafí occupation of the valley may have facilitated agricultural production (Roldán 2004). This is evident in the relationship between the paleosol and the period of occupation of the site, which correlates with a notable change in the climate becoming warmer and wetter (Sampietro and Sayago 1998; Sampietro and Vattuone 2005).

Analysis of soil chemistry underscores the point that human agency effects change on multiple levels, both micro- and macro-, which can result from intentional and unintentional processes. The very presence of human populations within an ecosystem would logically assume that their activities will impact particular courses of change, whether that impact is large or small, long-lived or short term. In the case of prehispanic agriculture in the Tafí Valley, soil chemistry continues to exhibit characteristics related to plant cultivation, and levels of organic phosphorus have remained relatively high as a result of terrace construction and possibly the addition of organic fertilizers, even centuries after the area had been abandoned. As a result, contemporary elements of the Tafí Valley landscape are historically rooted in several thousand years of human-environment dynamics. This kind of analysis may strengthen studies of landscapes elsewhere, where the legacies of land use practices may be more ephemeral, or the longevity and sustainability of such practices poorly understood.

Anthropogenic wetlands in Southwest Victoria, Australia

The Mount Eccles lava flow in southwest Victoria, Australia, extends inland from the coast for approximately 40 km (Figure 1), and the most recent dating of the eruption is 27,000 BP (Head et al. 1991). The lava-derived landscape ranges from about 60 masl in the north near Mount Eccles

to only about 8 masl closer to the coast, and the terrain is dominated by lava surfaces that rise up to 20 m above the neighboring wetlands. The region is characterized by temperate climatic conditions, with marked seasonality and high variance in temperature, light, and precipitation. Rainfall is also seasonal, falling predominantly during the autumn, winter, and spring months and varying between 660–860 mm annually. Winters tend to be wet and cool, while summers are often hot and much drier, with temperatures sometimes reaching in excess of 38°C (CONTEXT 1993:12).

Drainage of the area flows from north to south into the southern ocean, where principal creeks and rivers experience significant swelling during the rainy season. Extensive wetlands consisting of both permanent and seasonal swamps characterized the area immediately outside the Mount Eccles lava flow, which became critical environmental variables in Guditjmarra aboriginal land use strategies. Importantly, these seasonal and perennial swamps formed nucleated areas of high biodiversity that supported a range of flora and fauna. Principal among those were a variety of edible plants that included bulbs, roots, tubers, fruits, berries, seeds, leaves and shoots (Clarke 1985; Gott 1982), and wildlife that included various mammals, reptiles, birds, and fish (CONTEXT 1993). However, the Shortfin eel (*Anguilla australis*) may have been the most significant for the development and maintenance of the Guditjmarra socio-economy (Builth 1996, 2000, 2002, 2004, 2006). The environment is composed of a heterogeneous distribution of woodlands and forest juxtaposed with seasonal and perennial wetlands, constituting a favorable habitat for the Shortfin eel. Its importance to local subsistence further catalyzed widespread human-induced landscape modification within the Mount Eccles lava flow and associated wetlands (Builth 2004:170).

Anthropogenic modification of the landscape by indigenous Australians was critical to Guditjmarra socioeconomic complexity (Builth 2004). Geographical and archaeological analysis of the now-drained landscape and associated features indicate that the Guditjmarra had invested considerable capital in the landscape in order to establish and maintain aquaculture as a primary subsistence and socioeconomic activity. Analysis of a digital elevation model of the area also suggests that water flow was maintained through various channels, promoting the introduction of up-stream migrating elvers

direct from the ocean into the modified wetland system, in addition to facilitating the downstream migration of mature eels and their entrapment in a series of weirs. Channel modification, including their excavation through the lava flow, was undertaken to ensure the movement of eels through the system. Additionally, the existing wetland environments had been extended by the construction of dams to bolster the retention of water (Builth 2004:170–171). These modifications expanded the wetlands spatially, encouraging the arrangement of nucleated zones of high-biodiversity relative to the surrounding landscape. These constructions also would have extended the wetlands seasonally, maintaining their integrity to some degree during the hot summer months of low rainfall, when many swamps and wetlands typically diminish significantly in the area. While human activities may have been aimed largely at managing microenvironments that were suitable for successful growth, movement, and ultimately the reproduction of the Shortfin eel, these alterations to the terrain would have also catalyzed the growth and nucleation of other flora and fauna around these wetland areas that were valued within the Guditjmarra subsistence economy.

There is still some debate surrounding the chronology of human-induced changes to the landscape. The fact that some wetland structures during the nineteenth century remained abandoned (though well-preserved) while others were in use suggests that some were possibly constructed during the late prehistoric period (Couatts 1985:63). However, without direct dating, the antiquity of these wetland strategies remains uncertain. Currently, there are ongoing multi-proxy analyses of cores extracted from human-altered wetlands, and one hypothesis being investigated is that the system may be the product of technology associated with both flood and drought control in response to long-term climate change through the Holocene. Due to the nature of soil formation and botanical succession following the eruption, and to the high aridity of the glacial maximum and its paucity of resources (Tibby et al. 2006), it is unlikely to have been extensively exploited by humans until the rise in rainfall towards the end of the late Pleistocene, and more likely into the Holocene. Furthermore, assessment of water levels during the middle and late Holocene indicate that wetland infrastructure situated among lowermost elevations were probably ineffective prior to about 2,000 years ago (Head 1989). This suggests that,

while not limited to the past two millennia, human agency in landscape evolution has probably been most pronounced over that span.

During the early nineteenth century, European colonization of the region and the subsequent loss of indigenous populations had profound effects on environmental change. Indigenous populations and the British colonists shared little in the manner of cultural values of land use within the Mount Eccles lava flow environment. While the Guditjmara invested greatly to manage and expand the wetlands, to the British colonists, pastureland was highly valued. This required extensive drainage and deforestation in order to convert it to a predominantly grassland environment. With considerably different values of land use, British colonization of the area significantly altered ongoing processes of ecosystemic change, and it significantly reduced the biodiversity that was characteristic of the wetlands distribution. However, the environment in which British colonists entered was not necessarily natural or pristine, either. Guditjmara significantly expanded the wetland environment prior to European arrival, and consequently, species composition and ecosystemic properties were the result of interactive human and non-human evolutionary processes over the previous several millennia. Human activities have left lasting legacies on the landscape, which continues to be characterized by the historically contingent interaction of all biotic and abiotic elements of the Mount Eccles ecosystem.

Discussion and Conclusion

Our planet's landscapes are the culmination of both geophysical and biological forces at once, and diachronic analyses of land use practices are critical to understand the role of human agency in shaping those landscapes. One critique of many studies of environmental dynamics is that they tend to focus on direct observation of contemporary biophysical conditions, and therefore only consider the tail end of long and complex sequences of ecological relationships, taking at most several decades or perhaps a century or two into account (van der Leeuw and Redman 2002:599). Using this line of reasoning, parts of the Cinti Canyon, for instance, would appear to be naturally productive farmland with deep alluvial soils. However, the archaeology and history of the area reveal that Spanish colonial farmers were largely responsible for transporting

soil to specific areas three or four centuries ago, while prehispanic farmers had cleared forests and constructed terraces to manage agricultural resources. Vitousek and colleagues (1997) make a particularly cogent argument that humans have impacted most of Earth's ecosystems. However, our archaeological examples from drylands in South America and Australia indicate that the role of human agency in environmental change is rooted much more deeply in antiquity, and long before European colonization of those areas.

Human groups construct terraces, clear forests, control hydrology, manipulate patterns of vegetation, and alter soil chemistry and morphology. In doing so, entire landscapes are transformed—intentionally or unintentionally—by human action. In some respects, these activities might improve or enhance the local or regional landscape for particular purposes while at the same time leading to degradation across time and space. Indeed, some communities consider practices such as fallowing, crop rotation, soil management, and infrastructural investments to the landscape to be long-term conservation strategies (Erickson 2000:349). This certainly may have been the idea behind those infrastructural investments in dryland environments discussed here, but many require continuous human interaction to achieve desired results such as soil retention or high biodiversity. Along the Osmore coast of southern Peru, for example, thirteenth century construction of hillside terraces may have constituted long-term conservation by local farmers, but once terraces were abandoned and subsequently breached, soil erosion accelerated in the area (Zaro 2005). On the other hand, terrace features in the Tafi Valley have generally exhibited greater resilience to ongoing bio- and geophysical processes since abandonment, and in effect, soil chemistry and morphology associated with them continue to exhibit characteristics considered to be significantly elevated beyond values expected for the region had it never been farmed. In each of these cases, our research underscores the point that human agency, whether continuous or discontinuous, has played a significant role in altering courses of landscape evolution. Furthermore, it becomes clear that a landscape's history is not simply a component of the past, but rather it is a historically contingent process that shapes contemporary environments.

It is important to recognize that archaeological investigations of landscapes hold implications for visions of sustainable land use. However,

sustainability is too often an ill-conceived concept that suggests humans can somehow achieve a stagnant balance on the planet. While an in-depth discussion of sustainability is not within the scope of this paper, the term (and most often as it relates to agriculture) has lent itself to numerous definitions that refer to (1) continuity in the use of resources, (2) states of equilibrium between human activities and the environment, (3) alternative strategies to modern industrialized activities, and (4) proper land use management to avoid environmental degradation (Farshad and Zinck 1993; Hansen 1996; Schaller 1993). Many, however, include either implicitly or explicitly an element of permanence. This becomes most problematic once the notion of change is accepted to be the natural state of the environment, with or without human agency. In this context, any meaningful concept of sustainability must include an explicit notion of time (Fresco and Kroonenberg 1992). Because both human and non-human processes affect courses of planetary evolution and biodiversity, approaches to sustainability must account not only for ongoing geophysical and non-human biological processes, but also for the pervasive and wide-ranging changes people inflict on their surroundings. Importantly, humans must be recognized as active components within our planet's

biosphere, and not simply as external disturbances to it. In effect, sustainability should refer more to a relationship between people and the environment rather than an unchanging practice or set of practices. Put simply, it involves managing change. This is perhaps best expressed in a recent volume titled *Imperfect Balance* (Lentz 2000). As part of a historical ecology series, this collection of papers accentuates the point that change is pervasive, and for millennia humans have played an integrated role in the process of environmental transformation. As the limits of fragile desert ecosystems expand, it becomes imperative to understand them, like all ecosystems, as historically contingent snapshots of long-term dynamics between all biological and geophysical processes.

Acknowledgements: We wish to thank Calogero M. Santoro and Claudio Latorre for organizing the 2nd Southern Deserts Conference, and for providing such a stimulating venue in which to present our research. We also want to recognize Lautaro Núñez, Martin Grosjean, Mike Smith, and David S. Thomas for their efforts in making the conference a success. Finally, our paper benefited greatly from the comments of two anonymous reviewers and the Chungara editorial staff. Any shortcomings that remain, however, are strictly our own.

References Cited

- Balée, W.
1998 *Advances in Historical Ecology*. Columbia University Press, New York.
- Balée, W., and C.L. Erickson, editors
2006 *Time and Complexity in Historical Ecology: Studies in Neotropical Lowlands*. Columbia University Press, New York.
- Bennett, W.C., E. Bleiler and F.H. Sommer
1948 Northwest Argentine archaeology. *Yale Publications in Anthropology* 38. Yale University Press, New Haven.
- Berberián, E.E., A.E. Nielsen, E. Argüello de Dorsch, B. Bixio, L.A. Spalletti, J.A. Salazar, and E.L. Pillado
1988 *Sistemas de Asentamiento Prehispánicos en el Valle de Tafí*. Comechingonia, Córdoba.
- Browman, D.L., editor
1987 *Arid Land Use Strategies and Risk Management in the Andes: A Regional Anthropological Perspective*. Westview Press, Inc., Boulder.
- Builth, H.
1996 *Lake Condah Revisited: Archaeological Constructions of a Cultural Landscape*. Honors Thesis, Department of Aboriginal Studies, University of South Australia, Adelaide.
- 2000 The connection between the Gunditjmarra Aboriginal people and their environment: the case for complex hunter-gatherers in Australia. In *Environment-Behaviour Research on the Pacific Rim*, edited by G. Moore, J. Hunt, and L. Trevillion, pp. 197-212. Faculty of Architecture, University of Sydney, Sydney.
- 2002 *The Archaeology and Socioeconomy of the Gunditjmarra: A Landscape Analysis from Southwest Victoria, Australia*. Doctoral Dissertation, Department of Archaeology, Flinders University of South Australia, Adelaide.
- 2004 Mt. Eccles lava flow and the Gunditjmarra connection: a landform for all seasons. *Proceedings of the Royal Society of Victoria* 116:165-184.
- 2006 Gunditjmarra environmental management: the development of a fisher-gatherer-hunter society in temperate Australia. In *Beyond Affluent Foragers*, edited by J. Kim, C. Grier, and J. Uchiyama, pp. 4-23. Oxbow Books, Oxford.
- Clarke, P.A.
1985 The importance of roots and tubers as a food source for southern south Australian Aborigines. *Journal of the Anthropological Society of South Australia* 23:2-14.
- CONTEXT
1993 *Lake Condah Heritage Management Plan and Strategy*. Aboriginal Affairs Victoria and Kerrup Jmarra Elders Aboriginal Corporation, Melbourne.

- Cortés, L.R.
1994 *Isoyetas, Isotermas, Zonificación Climática, Cuencas, Hidrología e Hidrogeología: Estudio Integrado de los Recursos Naturales del Departamento de Chuquisaca*. CORDECH, Sucre.
- Coutts, P.J.F.
1985 An archaeological perspective of the Western District, Victoria. In *Settlement of the Western District from Prehistoric Times to the Present*, edited by J. Sherwood, J. Critchett, and K. O'Toole, pp. 21-67. Warmambool Institute Press, Warmambool.
- Crumley, C.L., editor
1994 *Historical Ecology: Cultural Knowledge and Changing Landscapes*. School of American Research, Santa Fe.
- Denevan, W.M.
1992 The pristine myth: the landscape of the Americas in 1492. *Annals of the Association of American Geographers* 82:369-385.
- Dick, R.P., J.A. Sandor, and N.S. Eash
1994 Soil enzyme-activities after 1500 years of terrace agriculture in the Colca Valley, Peru. *Agriculture, Ecosystems, & Environment* 50:123-131.
- Dregne, H.
1986 Desertification of arid lands. In *Physics of Desertification*, edited by F. El Baz, and M. Hassan, pp. 4-34. Martinus Nijhoff, Dordrecht.
- Eash, N.S., and J.A. Sandor
1995 Soil chronosequence and geomorphology in a semiarid valley in the Andes of southern Peru. *Geoderma* 65(1-2):59-79.
- Erickson, C.L.
2000 The Lake Titicaca Basin: A precolumbian built landscape. In *Imperfect Balance: Landscape Transformations in the Pre-Columbian Americas*, edited by D. Lentz, pp. 311-356. Columbia University Press, New York.
- Farshad, A. and J.A. Zinck
1993 Seeking agricultural sustainability. *Agriculture, Ecosystems, and Environment* 47:1-12.
- Foster, D., F. Swanson, J. Aber, I. Burke, N. Brokaw, D. Tilman, and A. Knapp
2003 The importance of land-use legacies to ecology and conservation. *Bioscience* 53:77-88.
- Fresco, L.O., and S.B. Kroonenberg
1992 Time and spatial scales in ecological sustainability. *Land Use Policy* 9:155-168.
- González, A.R.
1962 Nuevas fechas de la cronología arqueológica Argentina obtenidas por el método de radiocarbón (IV). Resumen y perspectivas. *Revista del Instituto de Antropología* 5:303-331.
1977 Las culturas del noroeste Argentina. *Arte Precolombino de la Argentina, Introducción a su Historia Cultural*. Filmediciones Valero, Buenos Aires.
- González, A.R., and V.A. Núñez Regueiro
1960 Preliminary report on archaeological research in the Tafí Valley, N.W. Argentina. *Congreso Internacional de Americanistas* 34:485-496. Wien, Alemania.
- Gott, B.
1982 Ecology of root use by the Aborigines of southern Australia. *Archaeology in Oceania* 17:59-67.
- Gunn, J.D.
1994 Global climate and regional biocultural diversity. In *Historical Ecology: Cultural Knowledge and Changing Landscapes*, edited by C.L. Crumley, pp. 67-97. School of American Research, Santa Fe.
- Hansen, J.W.
1996 Is agricultural sustainability a useful concept? *Agricultural Systems* 50:117-143.
- Hayashida, F.M.
2005 Archaeology, Ecological History, and Conservation. *Annual Review of Anthropology* 34:43-65.
- Head, L.
1989 Using palaeoecology to date Aboriginal fishtraps at Lake Condah, Victoria. *Archaeology in Oceania* 24:110-115.
2000 *Cultural Landscapes and Environmental Change*. Oxford University Press, New York.
- Head, L., D. D'Costa, and P. Edney
1991 Pleistocene dates for volcanic activity in western Victoria and implications for Aboriginal occupation. In *The Cenozoic in Australia, Special Publication 18*, edited by M.A.J. Williams, P. De Deckker, and A.P. Kershaw, pp. 302-308. Geological Society of Australia, Melbourne.
- Holliday, V.T., editor
1992 *Soils in Archaeology: Landscape Evolution and Human Occupation*. Smithsonian Institution, Washington D.C.
- Ingerson, A.E.
1994 The nature/culture dichotomy. In *Historical Ecology: Cultural Knowledge and Changing Landscapes*, edited by C.L. Crumley, pp. 43-66. School of American Research, Santa Fe.
- Lentz, D.L., editor
2000 *Imperfect Balance: Landscape Transformations in the Precolumbian Americas*. Columbia University Press, New York.
- Morrison, K.D.
1994 The intensification of production: archaeological approaches. *Journal of Archaeological Method and Theory* 1:111-159.
- Paredes, J.D., and H. Bastías
1987 Formas y rangos de alzamiento del sector norte de la Sierra Chica de Zonda, San Juan, República Argentina. *Décimo Congreso Geológico Argentino* Tomo I, pp. 279-282. Asociación Geológica Argentina, Universidad Nacional de Tucumán, San Miguel de Tucumán.
- Perucca, P., and J.D. Paredes
1999 Descripción de algunas evidencias de fallamiento activo en la Provincia de San Juan. In *Síntesis del Cuaternario de la Provincia de San Juan*, edited by J.D. Paredes, G.M. Suvires, and J.J. Zambrano, pp. 15-26. CDteca de la Biblioteca de la Facultad de CEFN, Universidad Nacional de San Juan, San Juan.
- Redman, C.L.
1999 *Human Impacts on Ancient Environments*. University of Arizona Press, Tucson.
- Redman, C.L., S.R. James, P.R. Fish, and D. Rogers, editors
2004 *The Archaeology of Global Change*. Smithsonian Institution, Washington D.C.
- Rivera Casanovas, C.
2004 *Regional Settlement Patterns and Political Complexity in the Cinti Valley, Bolivia*. Doctoral Dissertation,

- Department of Anthropology, University of Pittsburgh, Pittsburgh.
- 2005 Sociedades prehispánicas tardías en los valles interandinos del suroeste de Chuquisaca, Bolivia. *Nuevo Aportes* 3. (diciembre). <http://www.arqueobolivia.com/revistas.php> (7 marzo 2007).
- Roldán, J.
2004 *Efectos Antrópicos del uso del Suelo Durante el Formativo en el Valle de Tafi*. Tesis de grado, Facultad de Ciencias Naturales e IML, Universidad Nacional de Tucumán, San Miguel de Tucumán.
- Sampietro, M.M.
2002 Geoambientes y sitios arqueológicos Formativos en el valle de Tafi (noroeste-República Argentina). *Cuadernos del Instituto de Antropología y Pensamiento Latinoamericano* 19:599-611.
- Sampietro, M.M., and J.M. Sayago
1998 Aproximación geoarqueológica al conocimiento del sitio arqueológico "Río Blanco," valle de Tafi, Tucumán (Argentina). *Cuadernos del Instituto de Antropología y Pensamiento Latinoamericano* 17:257-274.
- Sampietro, M.M., and M.A. Vattuone
2005 Reconstruction of activity areas at a Formative household in northwest Argentina. *Geoarchaeology: An International Journal* 20:337-354.
- Sandor, J.A.
1992 Long-term effects of prehistoric agriculture on soils: examples from New Mexico and Peru. In *Soils in Archaeology: Landscape Evolution and Human Occupation*, edited by V.T. Holliday, pp. 217-245. Smithsonian Institution, Washington D.C.
- Sandor, J.A., and N.S. Eash
1991 Significance of ancient agricultural soils for long-term agronomic studies and sustainable agriculture research. *Agronomy Journal* 83:29-37.
- 1995 Ancient agricultural soils in the Andes of southern Peru. *Soil Science Society of America Journal* 59:170-179.
- Sandor, J.A., and L. Furbee
1996 Indigenous knowledge and classification of soils in the Andes of southern Peru. *Soil Science Society of America Journal* 60:1502-1512.
- Sayago, J.M., and M.M. Collantes
1991 Evolución paleogeomorfológica del valle de Tafi (Tucumán, Argentina) durante el Cuaternario Superior. *Bamberger Geographische Schriften* 11:109-124.
- Schaller, N.
1993 The concept of agricultural sustainability. *Agriculture, Ecosystems, and the Environment* 46:89-97.
- Suvires, G.M.
2000 Geomorfología de la provincia de San Juan. In *Argentina: Recursos y Problemas Ambientales de la Zona Árida, Primera Parte: Provincias Mendoza, San Juan y la Rioja*, edited by E.M. Abraham and F. Rodríguez Martínez, pp. 79-86. PAN, Buenos Aires.
- Tibby, J., A.P. Kershaw, H. Builth, A. Philibert, and C. White
2006 Environmental change and variability in southwestern Victoria: changing constraints and opportunities for occupation and land use. In *The Social Archaeology of Indigenous Societies*, edited by B. David, B. Barker, and I. McNiven, pp. 254-269. Aboriginal Studies Press, Canberra.
- van der Leeuw, S., and C.L. Redman
2002 Placing Archaeology at the Center of Socio-Natural Studies. *American Antiquity* 67:597-605.
- Vetté, C., and R. Rojas
1998 *Chuquisaca: Pobreza, Género y Medio Ambiente*. Cep-Embajada Real de los Países Bajos. Editorial Muela del Diablo, La Paz.
- Vitousek, P.M., H.A. Mooney, J. Lubchenco, and J.M. Melillo
1997 Human domination of Earth's ecosystems. *Science* 277(5325):494-499.
- Whitford, W.G.
2002 *Ecology of Desert Systems*. Academic Press, San Diego.
- Zaro, G.
2005 *Human Ecology and Ancient Agrarian Land Use at Wawakiki Spring, South Coast Peru, A.D. 1000-2000*. Doctoral Dissertation, Department of Anthropology, University of New Mexico, Albuquerque.
- 2007 Diversity specialists: Coastal resource management and historical contingency in the Osmore Desert of southern Peru. *Latin American Antiquity* 18:161-179.
- Zaro, G., and A. Umire Álvarez
2005 Late Chiribaya Agriculture and Risk Management along the Arid Andean Coast of Southern Peru, A.D. 1200-1400. *Geoarchaeology: An International Journal* 20:717-737.
- Zimmerer, K.S.
1994 Human Geography and the New Ecology: the prospect and promise of integration. *Annals of the Association of American Geographers* 84(1):108-125.
- ZONISIG
2000 ZONISIG-Zonificación Agroecológica y Socioeconómica, Departamento de Chuquisaca. Prefectura del Departamento de Chuquisaca, Universidad de San Francisco Xavier, Ministerio de desarrollo sostenible y Planificación. Zonisig-DHV Consultores ITC, Sucre.