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How Landscapes Change

Human Disturbance and Ecosystem Fragmentation in the Americas

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Gay A. Bradshaw, Pablo A. Marquet

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1 Biodiversity and Human Impact During the Last 11,000 Years in North-Central Chile

L. Núñez and M. Grosjean

1.1 Introduction

During the pre-Columbian period (11,000 ^{14}C years B.P.–1540 A.D.), the interaction between humans and their environment can be characterized as relatively harmonious with regard to the effects of resource exploitation patterns and subsistence practices in arid and semi-arid ecosystems of north-central Chile. The strong dependency on local resources stimulated a close coupling between environmental change and human population. However, since the 16th century, ecosystems in this area have been exposed to three trends that have dramatically disrupted a long-term relationship between human populations and natural resources. First, the appearance of European settlements focused on mining activities and created urban markets for agricultural products. Second, the establishment of European land-use patterns that, by focusing on economically important and highly productive plant and animal species, out-competed and displaced local native and less productive species to marginal areas and led to the widespread degradation of soils. Third, local indigenous populations retreated into "refuge areas" where they were able to maintain their traditional pattern of resource use which is based on self-subsistence and exchange of the surplus production.

From the 16th to the 20th centuries, European human occupation substantially modified the natural composition, structure, and function of ecosystems in the area. This disruptive role of humans reached a climax with the large-scale expansion of mining after 1950. In addition to fostering the emergence of rural poverty, mining and associated activities intensified environmental degradation by exploiting the scarce and very slowly recharging water resources of the Atacama Desert. Today, available freshwater is almost exclusively used in the new cities and mines in the Atacama. We will characterize the environmental history of the Atacama through a description of the various stages of human-environment interactions through the centuries.

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1.2 Principal Phases of Human-Environment Interaction in North-Central Chile

1.2.1 Biodiversity Changes at the Pleistocene-Holocene Transition

Chronostratigraphical excavations in the Tagua-Tagua basin (34°30′S, 71°10′W, see Fig. 1.1) identified two sites with a total of 12 mastodon remains (*Stegomastodon humboldti*) associated with Fell-type projectile points dated between 10,120 and 9900 ^{14}C years B.P. The identification of cultural and natural events at the Pleistocene–Holocene transition shows that the Paleo-Indian occupation was strongly related to specialized hunting of Pleistocene mega-mammals. The habitats of these animals, and therefore hunting sites, were concentrated around lacustrine paleoenvironments as a result of increasing drought stress (Nuñez et al. 1994a).

Palynological evidence confirms the existence of a resource crisis that significantly affected the mega-fauna around 10,000 ^{14}C years B.P. In fact, in less than 1000 years, there was a marked decrease in open park vegetation formations of conifers and southern beech (*Nothofagus*) trees as a consequence of a decrease in humidity and an increase in temperature compared to present values (Heusser 1983). These vegetation patterns gave way to a herbaceous steppe dominated by Amaranthaceae under dry environmental conditions (Heusser 1983). Around lacustrine basins and wetlands, this change took place around 9300 ^{14}C years B.P. when taxa associated with marshes and aquatic habitats (e.g., *Anagallis*, Cyperaceae, *Typha*) decreased and Compositae and Ubellifera dominated in an arid landscape. This process of increasing desertification was associated with an abrupt decrease in available water, plant and animal resources. In response to this climatic shift, most faunal elements including Pleistocene mega-mammals and their main predators (i.e., humans), concentrated their activities around the few remaining water bodies (Villagrán and Varela 1990; Núñez et al. 1994a).

The extinction of mastodons and the presence of Paleo-Indian butchery sites around Lake Tagua-Tagua appear to be correlated with environmental changes, that is, increasing aridity forced mega-mammals and the humans who hunted them to occupy less stressful near-lake environments during the Pleistocene–Holocene transition. This crisis was apparently widespread and significantly affected the "ecorefuges" of North and South American proboscideans (Bryan et al. 1978; Correal 1981; Haynes 1991). Rather than targeting specialized hunting as the only cause of extinction (Martin and Klein 1984), our findings at Tagua-Tagua suggest that environmental changes were also important in enforcing the concentration of mastodon herds around lake "ecorefuges" where they were opportunistically hunted by humans. These environmental events in central Chile coincide with the disappearance of proboscideans all over the world at the end of the Pleistocene (12,000–10,000 ^{14}C

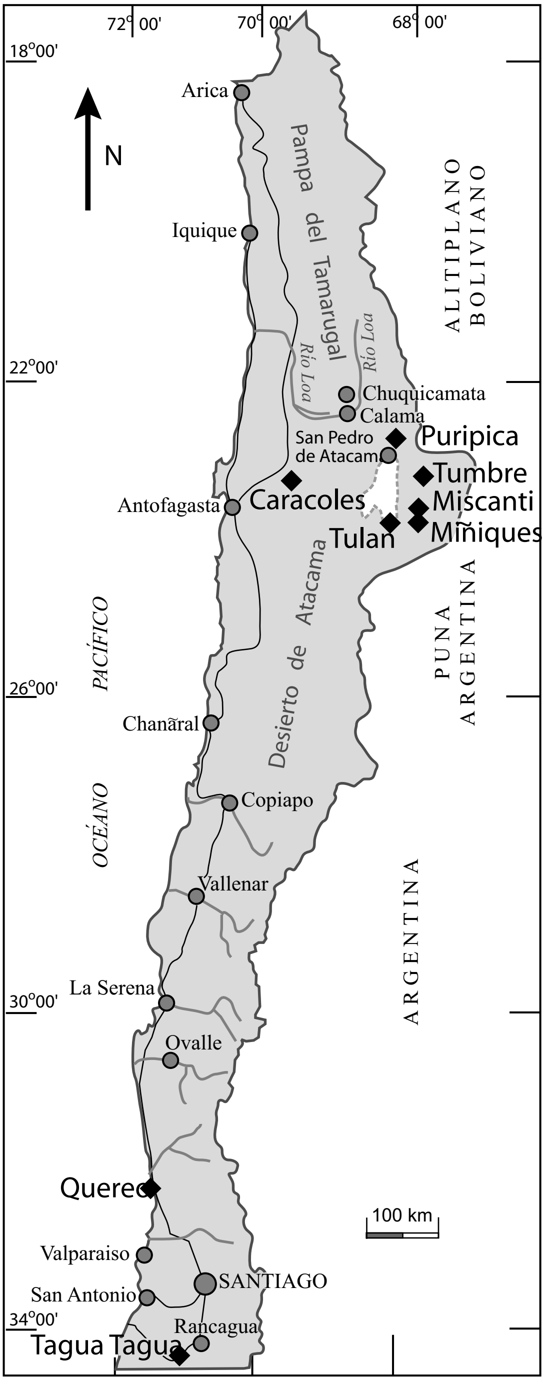

Fig. 1.1. Study area and sites discussed in the text

years B.P.), and with similar responses by Clovis groups found in North America (Haynes 1991). During this short transition period, Pleistocene hunter populations and mobility increased across North America and down to the southernmost areas of South America, opportunistically exploiting habitats with mega-mammals in a critical period of abrupt environmental change.

Evidence of similar environmental change was also found at Quereo (700 km north of Tagua-Tagua; Villagrán and Varela 1990; Veit 1994; see Fig. 1.1), suggesting that abrupt changes took place at a larger spatial scale than previously thought (Nuñez et al. 1994b). The El Niño Southern Oscillation (ENSO) may have played a major role in controlling the late Pleistocene/early Holocene precipitation pattern in this part of the world. However, little is known about the presence, function and causes of such large-scale and long-term moisture changes, and the variability of the Humboldt Current in this area (Grosjean et al. 1995; Kull and Grosjean 1998).

In contrast to increasing aridity in central Chile at the Pleistocene/Holocene transition, favorable and more humid conditions emerged and prevailed further north in the Atacama Desert during that time. The Atacama High Puna in northern Chile is presently located in an extremely arid area where the tropical summer rainfall belt and the extratropical winter precipitation belt converge and sometimes overlap. The high altitude plateau or Altiplano, between 19° and 27°S, is so arid that even today no glaciers can survive. Its sensitivity to changes in effective moisture makes this a particularly important area for studying shifts in the intensities of tropical and westerly circulation belts, and examining the phenomenon of moisture changes in the tropical Andes during the Holocene. Current research supports the hypothesis that the humid environmental conditions of the Atacama Desert during the Late Glacial and early Holocene were related to the intensification of the summer monsoon (Invierno Boliviano) which expanded its reach and caused increased precipitation as far as 24°S and resulted in favorable water, faunistic, floristic, and edaphic resources for human occupation of the area between ca. 12,000 and 8000 ^{14}C years B.P. (Messerli et al. 1993, 2000; Grosjean and Nuñez 1994; Betancourt et al. 2000; Kull et al. 2002).

Although humans may have inhabited Peru as early as 12,560 ^{14}C years B.P., the oldest dated evidence of Early Archaic hunters in the Puna de Atacama, in northern Chile, is relatively recent (10,820 ^{14}C years B.P.). Small and highly mobile groups occupied circum-lacustrine sites in the high Puna, the intermediate valleys, the depression of the Salar de Atacama, and the high-elevation sites of the Precordillera. Radiocarbon dates from seven early Archaic sites (of which Tuina, San Lorenzo, and Tambillo are the most important) suggest initial human occupation at 10,800 ^{14}C years B.P., and a rapid termination of this occupational phase at about 8000 ^{14}C years B.P. Hunters exploited modern fauna, such as camelids, deer, birds, and rodents. At the time of human arrival, the paleolakes in northern Chile were close to or already at their maximum extent (between 10,800 and <9200 ^{14}C years B.P.; Geyh et al. 1999), and the humid climate provided abundant water resources for vegetation, animals, and ultimately, humans. Recent excavations show an evident link between initial human occupation and favorable environmental conditions as recorded in paleolake sediments, fossil groundwater bodies, and paleosols (Núñez et al. 2001).

The environmental conditions at the beginning of human occupation in the Atacama Desert remain somewhat debatable. Although mega-fauna dated to late glacial times existed in the south-central Andes, a site unequivocally linking hunters and Pleistocene animals in the Atacama Desert has been missing until recently. At Barro Negro (northwestern Argentina; Fernández et al. 1991), for instance, evidence of Archaic camelid hunters is found precisely at the time when *Equus* sp. became extinct. However, recent excavations in Tuina document for the first time hunting of extinct fauna at 10,060 ^{14}C years B.P. (L. Núñez et al. 2002), suggesting that at least one Pleistocene species survived longer and overlapped for some time with Archaic human occupation. The taxonomy of this bone fragment is currently under investigation. For the Chilean part of the Altiplano, we argue that the onset of favorable environmental conditions and initial human occupation was, notwithstanding the statistically poor dating control of the first human arrival, broadly synchronous. With a few exceptions, the Pleistocene mega-fauna was possibly already largely extinct, although the modern camelids survived and served as the resource basis for the Early Archaic hunters.

Lake sediment records from the Altiplano suggest that the paleolakes disappeared very rapidly at about 8000 ^{14}C years B.P. (Grosjean et al. 1995; Geyh et al. 1999), and extremely arid conditions were established from then onwards. The severe decrease in resources in the Atacama Desert at that time is reflected in a synchronous drastic depopulation of the area ("Silencio Arqueológico"), suggesting that the favorable humid early Holocene environment was the precondition for early hunting and gathering societies in this area.

1.2.2 Camelid Domestication During the Mid-Holocene: the Rise of a New Human-Environment Interaction

Multi-proxy data for the extremely arid mid-Holocene period (8000 to around 3000 ^{14}C years B.P.) are scarce. The lake levels were extremely low, most basins were completely dry, and the lake sediments were eroded by wind and destroyed. While the paleoenvironmental conditions (i.e., active lacustrine basins) were good for the Early Archaic occupations before 8000 ^{14}C years B.P., resources were very poor in the Atacama Desert during the mid-Holocene and only available in special places along small rivers and wetlands such as the Quebradas de Puripica and Tulán (Fig. 1.1) which served as ecological refuges for hunters and gatherers in the Atacama Desert.

Twenty Archaic campsites intercalated between more than 30 alluvial deposits caused by heavy rainfall events between 6200 and 3100 ^{14}C years B.P. were discovered in Quebrada Puripica. For the first time, we found evidence of discrete human occupation in this area, filling the regional hiatus in the Atacama basin ("Silencio Arqueológico") between 8000 and 4800 ^{14}C years B.P. The unique detailed stratigraphy of this site allows a stepwise transformation of the early- and mid-Archaic tradition into the late Archaic complex culture with domesticated animals to be documented. The early hunting tradition (prior to 6200 ^{14}C years B.P.) changed by 5900 ^{14}C years B.P. into a system with large campsites, intensive exploitation of wild camelids, and an innovative lithic industry. The culmination of this process of cultural transformation occurred in the late Archaic (5100–4800 ^{14}C years B.P.) which was characterized by hunting and animal domestication (*Lama glama*), major use of local lithic materials, the development of a consolidated architecture, and rock art showing camelids in a naturalistic style (Santoro and Núñez 1987; Núñez 1992).

The interaction between the geographical setting, mid-Holocene climates of general aridity, and the existence of storm-related sediment deposition contributed to a concentration of resources at Quebrada Puripica which functioned as an "ecorefuge" in a generally hostile environment. Here, humans established more stable and permanent settlements, domesticated wild camelids, and developed pastoralism to compensate for the harsh and uncertain environment. It appears that human occupation was restricted to areas which produced a source of stable resources. All other early Archaic sites in the Atacama basin at large had apparently been abandoned by the onset of mid-Holocene aridity at 8000 ^{14}C years B.P. The cultural transitions observed within the Puripica stratigraphy do not necessarily suggest environmental forcing. However, it is interesting to note that the end of the "ecorefuge" in Puripica (i.e., the beginning of down-cutting and the cessation of alluvial deposits) coincides with a period of increasing precipitation and the onset of modern climatic conditions at about 3000 ^{14}C years B.P. (Valero-Garcés et al. 1996; Grosjean et al. 2002).

1.2.3 The Transition from Mid-Holocene to Modern Climate: Pastoralism and Agricultural Changes

The generally harsh environmental conditions peaked during the mid-Holocene. Subsequently, (i.e., after ca. 3600 ^{14}C years B.P.) precipitation rates increased, lake levels recovered, and the modern climate regime was established, reaching about 200 mm precipitation per year in the highlands (Grosjean 1994). The transition from the extremely dry mid-Holocene conditions to the slightly more humid modern climate is clearly seen in the sediments of Laguna Miscanti (Valero-Garcés et al. 1996; Grosjean et al. 2002). Lake sediments show the variable nature of this transition, suggesting that changes were probably forced by a series of alternating changes in moisture regime, and not due to a slow, progressive change.

The restoration of resources to modern conditions was synchronous with the expansion of camelid breeding in the circum-Puna area as found, for instance, in the Quebrada de Tulán (Tulán-54) some 30 km west of Lagunas de Meniques and Miscanti (Fig. 1.1). This was also the time when the altitudinal range between 3000 and 4500 m became inhabited by flocks of domestic camelids, and irrigated agriculture began to dominate the subsistence economy between 3000 and 2400 m (Núñez 1992).

During the Formative Period (4000–2000 ^{14}C years B.P.), exploitation of domesticated mammals (*Lama glama* and *Cavia* spp.), specialized hunting (*Vicugna vicugna, Lama guanicoe*, rodents and birds) and irrigated agriculture with corn (*Zea mays*), quinoa (*Chenopodium quinua*), potatoes (*Tuber*), squash (*Cucurbitas spp.*), chili pepper (*Capsicum* spp.), and gathering of tree fruits (*Prosopis* sp.) gave rise to a diverse use of Andean and Subandean animal and plant resources in the Atacama Desert. Such a situation allowed a subtle and equilibrated management of natural resources in, around and from isolated permanent settlements, which initially emerged in oases with spring water and river flow.

1.2.4 Changes During the Historic Period (16th–20th Centuries)

Pre-Hispanic hunting, gathering, agriculture, and pastoralism created a varied signature upon the landscape, while Hispanic colonization imposed a radical change on the landscape by intensifying the water and land resource use and the exploitation of local flora and fauna within only 300 years. In fact, the pre-Hispanic tropical-Andean complex of crops (major components: maize, squash, beans, quinoa, chili peppers, potatoes, etc.) was replaced by the exotic European mix of crops (grapes, olives, wheat, alfalfa, barley, vegetables, and citrus fruits such as oranges, lemons, and limes). In addition, the local domesticated fauna (camelids) had to compete with non-Andean animals such as horses, cows, sheep, pigs, donkeys, goats, rabbits, poultry and other European domesticates. At the same time, new (European) forage patterns were established which resulted in the over-exploitation and degradation of natural grasslands. A significant increase in alfalfa cultivation was also needed for the increasing exotic animal population. These animals were brought by the Europeans mainly for working in mineral ore exploitation, transportation of construction materials and agricultural products, and for meat. During this readjustment, alfalfa became the dominant crop, marginalizing the "chacras de pan llevar" (local food crops), and played a major role in the new economy, which was based on large-scale mining, traffic and transportation of goods in a trans-Andean space.

At around the middle of the 19th century, the industrial revolution first reached the Atacama Desert. New British mining technologies made large-scale smelting possible. This contrasted very much with the pre-Columbian manufactories and technologies for small-scale processing of gold, silver, and copper (Bermudez 1963; Núñez 1992). Smelters for silver and copper in the Pampa del Tamarugal, the Río Loa, in Caracoles, Chuquicamata and in the oasis of San Pedro de Atacama (Fig. 1.1) rapidly overexploited the locally available fuel wood resources (*Prosopis* forests, Algarrobo and Tamarugo; Bermudez 1963) in the area of Calama even to total deforestation (Phillipi 1860). In turn, the scarcity of local fuel wood stimulated overexploitation of many plants in remote areas of the high Andes, such as the cushion plant Yareta (*Azorella compacta*), which was gathered for fuel in the copper mine of Chuquicamata.

Increased urbanization in the Atacama Desert fostered the drastic overexploitation of local wood from the 18th to the beginning of the 20th century. Suitable wood for construction was taken from cactus and *Prosopis* trees. The limited supply was supplemented with imported pine "pino de oregón" from North America, even though many large trees were also used for fuel wood ("rodelas" de Tamarugo) and made into charcoal. Even small shrubs such as "Pingo Pingo" and others were carried with animal caravans from the oasis of San Pedro de Atacama to the town of Caracoles, the most important silver mine in former Bolivia (Phillippi 1860). A system of roads built in the early 20th century increased access to and exploitation of high altitude fuel wood sources of the Andean steppe as well as facilitating the spread of invasive species. Finally, fuel wood demands diminished with the use of electricity and petroleum. However, new pressures on these resources are likely to emerge in the future. First, because local economies (crop production, labor, and capital) in valleys and oases have historically been forced to become part of the urban markets, the termination of mining in an area will again produce serious readjustments in the relationship between the local population, their economy and their natural resources (e.g., a sudden return to self-subsistence). Second, demands for water will become even more pressing. Twentieth century mining technology is based mainly on lixiviation, which requires enormous amounts of water. Given the economic importance of mining, government policy is likely to continue to favor mining companies and urban populations over local people in rural areas in water rights conflicts. The extreme arid conditions of the area already make water a scarce and precious resource for rural people and ecosystems. The most striking case is the Loa River basin, where the river discharge has been reduced to a fraction of its natural flow during the pre-Hispanic and Hispanic agricultural periods. Surface water diversions and groundwater extractions have significantly affected wetlands, which are crucial for the survival of a highly diverse and largely endemic flora and fauna. Some wetlands have been greatly reduced in extent or have disappeared completely, severely affecting both the ecosystem and traditional patterns of resource use (Messerli et al. 1997). In short, the entire landscape of the Loa River changed dramatically due to the overexploitation of water resources.

All of these changes have significantly affected the structure and form of present-day ecosystems, habitats and landscapes of the Atacama, which are highly fragile and host a large number of endemic species adapted to this extreme environment (Villagrán et al. 1983; Marquet 1994; Marquet et al. 1998). Humans continue to play a paramount role in the modification of these landscapes. The introduction of exotic species, in particular, endangers indigenous flora and fauna and many of the bio-physico-chemical processes. The Atacama Desert has never experienced such rapid expansion of mining and urbanization as it is undergoing today, and demands on water resources will only increase as this process continues (Romero 2002).

Current patterns of land and resource use are not sustainable. Without consideration of an "ethic of survival" and requirements of local biodiversity in water resource planning and assessment, sustainability cannot be achieved (Messerli et al. 1997). Unless the amount, origin, and recharge rates are scientifically established, and water distribution is evaluated relative to local cultural and environmental conditions, we can expect the environmental crisis to intensify. This process may be accelerated by continued migration of people from the Andes into urban centers, increased mining activities, escalating tourism, and progressive desertification of arable lands due to their low productivity and high prices for water. In this sense, achieving equitable distribution of water resources among various users (mining, urban consumption, agriculture, and natural ecosystems) and a transparent water policy are the two most urgent ethical issues for the future of the Atacama Desert.

Today, it is not clear how this problem will be solved. However, the people in rural areas, their culture, their traditional methods of cultivating the land, the flora, fauna and their natural habitats deserve consideration when planning for the future. Cultural heritage and biodiversity do not have a direct economic value. Thus, cultural values and natural habitats must not compete with economic values in a global market system.

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