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Continuities and discontinuities in the socio-environmental systems of the Atacama Desert during the last 13,000 years

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ABSTRACT

Understanding how human societies interacted with environmental changes is a major goal of archaeology and other socio-natural sciences. In this paper, we assess the human-environment interactions in the Pampa del Tamarugal (PDT) basin of the Atacama Desert over the last 13,000 years. By relying on a socio-environmental model that integrates ecosystem services with adaptive strategies, we review past climate changes, shifting environmental conditions, and the continuities and discontinuities in the nature and intensity of the human occupation of the PDT. As a result we highlight the importance of certain key resources such as water, an essential factor in the long-term trajectory of eco-historical change. Without water the outcome of human societies becomes hazardous.

1. Introduction

To a large extent, the history of humans is the history of a species in constant interaction with and mutual modification of its environment. Understanding how human societies interacted with environmental changes is a major goal of archaeology, human ecology, and other socio-natural sciences. To this end, scholars have been concerned with the causes that led to the collapse or changes in social systems. The debate has confronted environmental causes and social factors. Recently, Roscoe (2014) has emphasized that "anthropological and archaeological research, with its integrative and universalist approach to social analysis" has the potential to improve our understanding of the long-term impacts of climate change (Costanza et al., 2007; Kintigh et al., 2014a,b; Roscoe, 2014). We add that combining both anthropological-archaeological data with ecological and paleoecological records can help characterize and explain past human practices within an eco-historical perspective as well as call attention to possible

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future ecological scenarios (Dearing et al., 2015, 2006; Van der Leeuw and Redman, 2002; Verstraeten, 2014).

Widespread desertification can affect large human populations and particularly socio-economically vulnerable communities and indigenous peoples, as it has been occurring in the African Sahel (Anderson et al., 2006; Geleta, 2014; Palmer and Smith, 2014). Alternatively, human practices can alter and transform the landscape considerably by means of several social, subsistence and ritual activities that produce, distribute and consume goods and services in order to maintain social and biological life. Today, there is growing consensus that major structural transformations in human societies, often documented as dramatic changes in the archaeological record such as regional abandonment, can be triggered by multifactorial internal and external factors (Aimers, 2007; Kohler et al., 2012; Rowland, 2008).

The goal of this paper is to present and discuss major trends in the long-term history of human-environment interactions in the Pampa del Tamarugal (PDT), located in the hyperarid core of the Atacama Desert in northern Chile. Using an eco-historical perspective, we focus on determining the social, economic, and technological, continuities and discontinuities that developed during key cycles of water availability, as inferred from archaeological and paleoenvironmental records during the entire span of human presence in the region.

2. The Atacama Desert

The Atacama Desert is a key region for examining how humans coped with climate change in environments considered extreme. Arid regions such as the Atacama cover more than a third of the planet and are very sensitive to climate change (Holmgren et al., 2006; Jimenez et al., 2011; Le Houerou, 1992; Ortega et al., 2012). Large variations in rainfall and temperature can drive large swings in productivity on inter-annual and even longer timescales (Noy-Meir, 1973). Like other subtropical arid regions (IPCC-AR4, 2007; Sheffield and Wood, 2008; Wang, 2005), the Atacama is predicted by regional models to become even more extreme (Minvielle and Garreaud, 2011; Urrutia and Vuille, 2009; Vuille, 2013), expecting substantial decreases in precipitation (20–30%) and increases in temperature (rising up to 3 °C) and frequency of extreme hot events. In sum, the future is uncertain but past ecological and archaeological records are key sources of information to attempt to model how human societies respond to significant changes in resource availability.

Our specific study area is known as the Pampa del Tamarugal (PDT) basin and is situated in the hyper-arid core of the Atacama Desert (Fig. 1). The PDT basin is surrounded by five ecosystems: (a) the Pacific coast and Coastal Cordillera to the west, (b) the quebradas that drain the Andes to the east, (c) the Altiplano in the high Andes to the east, (d) the exorheic valleys to the north, and (e) the Loa river and the Salar de Atacama basin to the south. These ecosystems were part of the broader landscape of the groups that inhabited the PDT throughout time.

The little water available in the PDT occurs in seasonally activated streams and springs and depends, almost exclusively, on summer rainfall occurring in the western slope of the Andes (e.g. Houston, 2006; Magaritz et al., 1990; Muñoz et al., 2007). These events feed the desert ecosystem through underground aquifers and superficial runoff (Briner, 1985; Gajardo, 1994; Luebert and Pliscoff, 2006; Villagrán et al., 1999). Precipitation variability has had a strong impact on the availability of water resources for various ecosystems at different timescales, from the last 13 millennia to the last several centuries, as revealed by diverse array of proxy records (Latorre et al., 2003; Mujica et al., 2015; Nester et al., 2007; Quade et al., 2008).

3. Theoretical framework

Our general framework for understanding socio-environmental systems and their resulting dynamics is based on a variation of the conceptual model proposed by Marquet et al. (2012) to explain the emergence of socio-cultural complexity in early coastal societies of the Atacama Desert. Given that environmental and social systems are in constant interaction, our model focuses on the interaction between ecosystem services and adaptive strategies to describe socio-environmental continuities and discontinuities (Fig. 2). Specifically, the model integrates: (i) ecosystem services, defined as the available resources and energy provided by the environment and dependent on their own complex interactions (e.g., coastal upwelling drives marine productivity, and aquifer recharge increases freshwater availability), and (ii) adaptive strategies, which correspond to specific behavioral outcomes that together articulate human responses and strategies for appropriating, utilizing and producing the available ecosystem services (e.g. fishing, hunting, farming, exchange, and their combination). Adaptive strategies exist in the space of possibilities for human life defined by the supply of ecosystem services. Some adaptive strategies will fare better in this space, increasing in importance as a result of the interaction between demographic factors (the number of interacting individuals through social leaning), the impact of this number upon the generation of cumulative cultural evolution reflected for simplicity in technological and ideological changes, and their demographic feedbacks (Boyd et al., 2011; Henrich, 2008; Marquet et al., 2012). More formally, the basic components of an adaptive strategy are: (1) demography, including the population parameters that characterize human communities in terms of group size and growth trends (e.g., birth rates, death rates, fertility, etc.), (2) technology, which corresponds to the tools and procedures for extracting, processing and producing resources and energy (e.g., hunting, gathering and fishing instruments and techniques, agricultural terraces and irrigation canals, storage systems, etc.), and (3) ideology, which provides the cognitive and institutional framework that mediates human-environment interactions (e.g. resource sharing, group structure, division of labor, funerary practices, beliefs systems, etc.) and how humans interact among themselves. The nature and extent of ecosystem services available to human societies constrain specific adaptive strategies by means of the intervening components (Boyd and Richerson, 2005). Changes in one component will inevitably lead to alterations in other components, and thus upon the adaptive strategy itself, as well as on the type, rate, scale and intensity with which ecosystem services are used. Moreover, the availability and abundance of ecosystem services (caused by either internal or external factors) will impact the adaptive strategies by means of specific systemic responses in the intervening components. A given adaptive strategy can lead to the eventual under-exploitation, overexploitation or their sustainable use of ecosystem services, by means of regulating access to more resources or using them more efficiently (Ellis, 2015; Smith and Zeder, 2013), but this will depend upon the dominant ideology of the group, their technological means as well as their number. In other words, the nature of an adaptive strategy conditions both the demand of ecosystem services but also the generation of innovations (e.g. Henrich, 2004) to potentially solve the problems that this exploitation could generate, if the dominant ideology thinks it is important to do so.

By linking together social and environmental aspects within an adaptive framework, our model is compatible with other human ecology models that predict demographic and technological change in human societies (Henrich, 2004; Powell et al., 2009). Moreover, following Clarke's (1968) early archaeological modeling work, our systems approach is not deterministic but aims at pro-

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