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Three Millennia of Climatic, Ecological, and Cultural Change on Easter Island: An Integrative Overview

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Eastern Island (Rapa Nui) is famous for the legacy of an extinct civilization symbolized by the megalithic statues called *moai*. Several enigmas regarding the colonization of the island its deforestation and a presumed cultural collapse of the ancient civilization still remain elusive. According to the prevailing view, the first settlers arrived between AD 800 and AD 1200 from east Polynesia and overexploited the island's natural resources causing an ecological catastrophe leading to a cultural collapse (Flenley and Bahn, 2003). The main evidence for this theory was the abrupt replacement of palm pollen by grass pollen in the sediments of the island's lakes and mires (Raraku, Kao, and Aroi), which was interpreted in terms of a thorough deforestation between approximately AD 1200 and AD 1400/1600 (Flenley and King, 1984; Flenley et al., 1991; Mann et al., 2008). This ecocidal view is widely accepted not only by the scientific community but also by society, thanks to its popularization by the mass media. Under this perspective, Easter Island has been considered a microcosmic model showing how human selfishness can eventually cause our own destruction (Diamond, 2005). Another view is that Polynesian colonizers arrived slightly later, between AD 1200 and AD 1300 (Wilmshurst et al., 2011), and the deforestation—which was not completed until AD 1650—was the result of massive palm fruit consumption by rats carried to the island by the first settlers (Hunt, 2006, 2007). According to this view, the cultural collapse did not occur until the European arrival (AD 1722) and was a genocide caused by the introduction of previously unknown illnesses and slave trading (Lipo et al., 2016).

During the last decade, the study of Easter Island has benefited by the proliferation of lake and peat coring and the introduction of new analytical methods. Former paleoecological analyses were based on sediments that contained frequent age inversions and extensive sedimentary gaps hiding the paleoecological trends of a significant part of the last millennia (Rull et al., 2010, 2013). A recent improvement has been the finding of new paleoecological sequences with continuous sedimentation during the last 3000 years, which has provided new insights on paleoecological trends with potential climatic and cultural implications (e.g., Cañellas-Boltà et al., 2013; Rull et al., 2015). Other progress has included the development of multiproxy studies including independent evidence for either ecological or climatic changes. Former paleoecological studies were based mostly on pollen analysis alone and attempted to derive climate changes from biological evidence, which is inadequate to evaluate the ecological responses to climatic changes. Recent studies include detailed lithostratigraphic, sedimentological, geochemical, and biological proxies, which allow separation of ontogenetic factors from external environmental drivers of ecological change,

notably climatic changes and human activities (Sáez et al., 2009; Cañellas-Boltà et al., 2012, 2016; Margalef et al., 2013, 2014). The introduction of new analytical techniques to identify remains of cultigens, as for example phytoliths and starch, has been useful to locate human fingerprints in sedimentary sequences (Horrocks et al., 2012a,b, 2013, 2015; Bowdery, 2014). New developments based on DNA analysis of modern humans and food remains from ancient skeletons have shed new light on the origin of settlers (Thorsby, 2012; Thromp and Dudgeon, 2015). In addition, some new analyses and meta-analyses on radiocarbon dates associated with archeological remains have provided relevant information on human activities, land use and demography (Mulrooney, 2013; Stevenson et al., 2015). We believe that the incorporation of these new findings into a coherent history needs the development of a novel synthesis of the historical and recent evidence into a holistic framework, where the different interpretations are viewed as complementary, rather than incompatible, contributions. This paper is a first proposal for such an integrated approach.

Concerning human settlement, archeological and anthropological evidence is consistent with the Polynesian origin of the ancient civilization represented by the *moai* (Flenley and Bahn, 2003). Using this evidence, the former hypothesis of Heyerdahl (1968) that Amerindian settlers would have arrived several centuries before the Polynesian colonizers was dismissed. However, new findings have revitalized Heyerdahl's proposal (albeit not his cultural interpretation). Indeed, recent palynological analyses revealed that the first deforestation event recorded so far occurred at 450 BC and was associated with the initiation of fires and the first appearance of *Verbena litoralis*, a human-dispersed weed of American origin (Cañellas-Boltà et al., 2013; **Figure 1**). In addition, Thromp and Dudgeon (2015) found starch remains of *Ipomoea batatas* (sweet potato), also of American origin, in the dental calculus of human skeletons as old as AD 1330 and concluded that this plant was important in the diet of the ancient islanders four centuries before the European contact. Thorsby (2012) analyzed the gene pool of modern Polynesian descendants and found evidence of Amerindian contact before, at least, two centuries prior to the European arrival (**Figure 1**). Therefore, the presence of Amerindian settlers before and/or during the development of the ancient *moai* culture is strongly supported from varied and independent sources of evidence.

Recent palynological results on peat and lake cores with nearly continuous sedimentation during the last three millennia suggest that forest clearing did not occur at the same time over the whole island and proceeded at different rates according to the site analyzed. For example, in Lake Raraku, situated in the coastal lowlands, the deforestation was a long and gradual process that took place in three pulses at 450 BC, AD 1200 and AD 1500 (Cañellas-Boltà et al., 2013; **Figure 1**). The first signs of cultivation in this catchment were recorded slightly before AD 1400 (Horrocks et al., 2012a). Contrastingly, in the Aroi mire, located inland at higher elevations, a densification of the former open palm forests occurred at AD 1250 and the resulting dense forests were removed abruptly, between AD 1520 and AD 1620, using fire (Rull et al., 2015). Cultivation inside the Aroi catchment did not start until AD 1640 (Horrocks et al., 2015). These results are compatible with a heterogeneous pattern of land use and occupation prior to the European contact (Stevenson et al., 2015), with a conspicuous pattern of coastal abandonment toward inland/upland settlements, which was characteristic of many eastern Pacific archipelagos during the same times (Nunn, 2003, 2007).

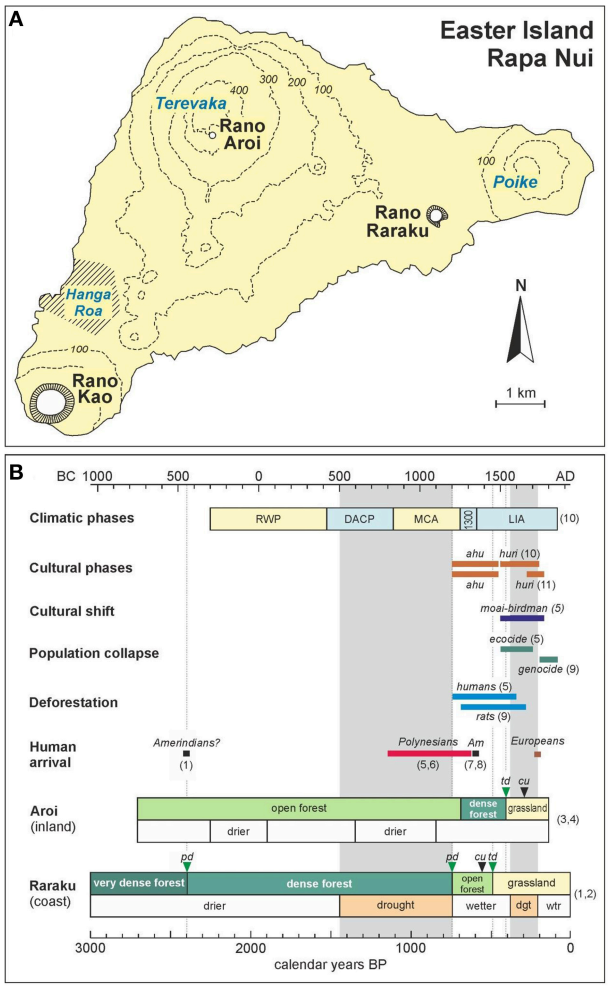

FIGURE 1 | (A) Sketch map of Easter Island indicating the localities mentioned in the text. **(B)** Summary of the climatic, ecological, and cultural trends of Easter Island over the last three millennia. The uppermost climatic phases summarize the current northern hemisphere and Pacific climatic phases according to Nunn (2007). Drought phases recorded at Raraku are shaded and deforestation pulses are highlighted by dotted lines. RWP, Roman Warm Period; DACP, Dark Ages Cold Period; MCA, Medieval Climate Anomaly; 1300, "1300 event;" LIA, Little Ice Age; Am, Americans; cu, first evidence of local cultivation; dgt, drought; pd, partial deforestation; td, total deforestation; wtr, wetter. References: 1, (Cañellas-Boltà et al., 2013); 2, (Horrocks et al., 2012a); 3, (Rull et al., 2015); 4, (Horrocks et al., 2015); 5, (Flenley and Bahn, 2003); 6, (Wilmshurst et al., 2011); 7, (Thorsby, 2012); 8, (Thromp and Dudgeon, 2015); 9, (Hunt, 2007); 10, (Nunn, 2007); 11, (McLaughlin, 2007).

Recent multiproxy surveys have suggested a relationship between climate variability and landscape shifts, some of them of potential cultural significance. Mann et al. (2008) favored the

occurrence of Late Holocene droughts and Sáez et al. (2009) suggested their potential role in deforestation. This view was not shared by Junk and Claussen (2011) who believe that, during the last millennium, climate changes alone might have been too small to explain strong vegetation changes that have occurred on the island. Further analyses on nearly continuous cores from Lake Raraku and Aroi mire have provided additional insights. In Raraku, the first deforestation event (450 BC) took place under climates drier than at present, when the present lake did not exist and the basin was occupied by a marsh (Cañellas-Boltà et al., 2013). Arid conditions intensified between AD 500 and AD 1200, leading to a drought phase coeval with the Classic Maya Collapse of Central America (∼AD 900), attributed to the increased frequency of prolonged droughts (Haug et al., 2003). In the Pacific islands, this time interval was characterized by climatic stability, sea levels higher than today and increasing food production thanks to the development of irrigation practices and terracing. These conditions favored long-distance navigation and new settlements, especially in eastern Polynesia (Nunn, 2007). According to the prevailing theory, the Polynesian colonization of Easter Island occurred during this phase (**Figure 1**). However, Goodwin et al. (2014) suggested that, during the Medieval Climate Anomaly (MCA), navigation to and from Easter Island was possible in both eastward and westward directions.

A significant shift to wetter climates and higher lake levels occurred at AD 1200 (**Figure 1**), roughly coinciding with the onset of a regional Pacific phase called the "1300 event," which represented the transition between the MCA and the Little Ice Age (LIA). The 1300 event was characterized by cool and wet climates, increased storminess due to ENSO intensification and a sea level drop below its present position (Nunn, 2007). During this wet period, which, at Easter Island, lasted until AD 1570, the Aroi and Raraku catchments exhibited disparate landscape trends. In Aroi, open palm forests underwent a densification that transformed them into relatively dense palm forests likely as a consequence of increased moisture availability (Rull et al., 2015). In Raraku, on the contrary, the second fire-driven, likely anthropogenic, deforestation pulse occurred and the reverse shift, from dense forest to open forest, took place (Cañellas-Boltà et al., 2013). Under the ecocidal view, this second pulse coincided with the beginning of the total deforestation of the island, whereas for the defenders of the rats as deforestation agents, the clearing began some 50 years later (**Figure 1**). This wetter phase coincided also with the phase known as *ahu moai* (roughly AD 1200–1500), during which these megalithic statues were built and venerated, which was also the time of maximum prosperity and expansion of the ancient Polynesian culture on the island (Nunn, 2007). A direct cause-effect relationship between climate and cultural traits cannot be established with the available evidence; however, it could be argued that increased water availability would have favored cultural flourishment.

Palm forests were almost totally removed from Raraku and Aroi in AD 1570 and AD 1620, respectively, before the end of the wet phase (**Figure 1**). Again, the sharp increase in charcoal, at both sites, strongly suggests anthropogenic burning. This was the "coup de grace" of the deforestation of these basins and, likely, of the whole island (Rull et al., 2015). A second drought between AD 1570 and AD 1720 occurred when the island was mostly (according to the rat theory) or totally (according to the ecocidal theory) deforested and grass meadows dominated the landscape. The population collapse of the ecocidal theory—which is attributed by its defenders to resource exhaustion and internal wars—occurred during this drought, which suggests that this cultural demise would have not been fully ecocidal but the result of a synergistic effect of climate severity and anthropogenic landscape degradation. Some authors (e.g., Nunn, 2007) consider that the phase of *huri moai*—characterized by the abandonment of the *moai* cult and the toppling of these statues, and the initiation of the birdman cult (**Figure 1**)—began at AD 1500, in which case this cultural shift would have paralleled the demographic collapse. Others believe that the *huri moai* phase started at AD 1680 (e.g., McLaughlin, 2007), in which case, there is no indication of climatic forcing in the paleoecological body of evidence available so far. Wetter climates returned by AD 1720, close to the European arrival, which marked the onset of a genocidal cultural collapse that has been well documented historically (Hunt and Lipo, 2011). The landscape did not experience any significant changes and grasslands dominated the scene.

This preliminary synthesis needs further refinement and could be considered a first approach to a synthetic framework toward a holistic Easter Island history combining climatic, ecological and cultural evidence. An important message is that environmental and human drivers of change can either have separate effects, or can act synergistically, coupled in positive feedbacks (Vegas-Vilarrúbia et al., 2011; Zahid et al., 2015). Under a synthetic framework, it is hoped that hypotheses that are usually presented as incompatible—e.g., environmental vs. cultural determinism, ecocide vs. genocide, or human vs. rat deforestation, among others—may be analyzed under a more complementary perspective. For example, Brandt and Merico (2015) developed a demographic model in which elements of both ecocidal and genocidal hypotheses concur to produce a long and slow population decline between ca. AD 1300 and 1800. The desired synthesis should also benefit from the incorporation of new analytical techniques available in paleoecology, as for example DNA and fecal lipid analysis of sediments, to enhance the possibilities of detection of human fingerprint (Rull et al., 2013). Also, new coring campaigns are necessary to deal with problematic sites, mainly in terms of dating, as for example Rano Kao.

AUTHOR CONTRIBUTIONS

VR conceived the idea and wrote the paper. NC, OM, SP, AS, and SG provided new ideas and participated in discussions and writing.

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