The Rapa Nui Little Ice Age drought: evidence, potential causes and socioecological impact

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The occurrence of a century-scale drought in the small subtropical island of Rapa Nui/Easter Island (SE Pacific; Fig. 1) between approximately 1570 CE and 1720 CE was first proposed by Cañellas-Boltà et al. (2013). The evidence was a sedimentary gap indicating the desiccation of Lake Raraku, one of the three permanent freshwater sources of the island, together with Lake Kao and the Aroi mire. Superficial currents are lacking due to the high porosity of the constituent volcanic rocks. Further palynological and geochemical (C, N) analyses by the same team on the Aroi peats suggested the occurrence of a dry climatic phase and a conspicuous landscape opening, between ca. 1500 CE and 1700 CE (Rull et al., 2015). This body of evidence was interpreted in terms of a middle Little Ice Age (LIA) island-wide arid phase that coincided with major ecological and cultural transformations, notably total island deforestation and the shift from the ancient Raraku-centered *moai* cult to the Kao-centered Birdman cult (Fig. 1).

According to Rull (2016) complex feedbacks and synergies between environmental and cultural drivers would have been involved in these transformations. For example, anthropogenic deforestation using fire could have been exacerbated by increased forest flammability and reduced regeneration capacity due to aridity. The migration of the cultural core from the Raraku to the Kao catchment would have been fostered by the desiccation and deforestation of the former, while the latter would have remained the only freshwater source on the island during the LIA drought. This would have contributed to the end of the *moai* cult, as the hard basalt of the Kao crater is unsuitable for carving these statues, which were formerly sculpted on the soft Raraku tuff. The shift from the rigid dynasty-based society represented by the *moai* cult to the more dynamic Birdman cult, where the island authority was renewed yearly, was also interpreted, in part, as an adaptation to changing environmental conditions. Despite these deep transformations, the ancient Rapanui society exhibited high resilience and remained healthy, although minor population declines are not disregarded, by developing novel cultivation practices – known as new gardening – based on small protected gardens and terracing (Mulrooney, 2013; Stevenson et al., 2015). This picture contrasted with the classical and popular view of the Rapanui society as responsible for their own collapse by overexploitation of the island's natural resources (Bahn & Flenley, 1992).

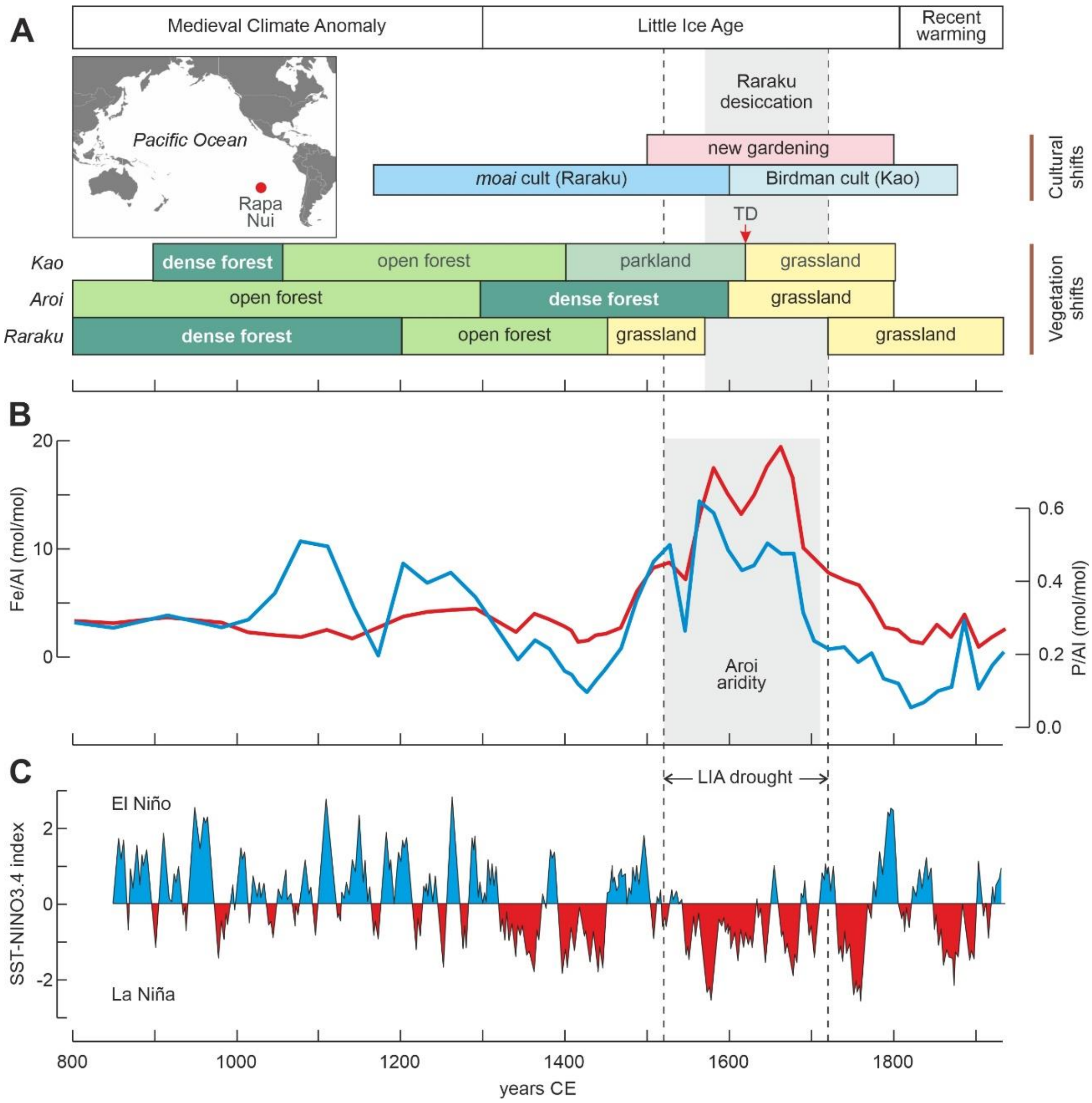

Figure 1. Last-millennium climatic, ecological and cultural shifts on Easter Island with emphasis on the LIA drought bracketed by dashed lines. A) Summary of vegetation and cultural developments mentioned in the text (Rull, 2021). TD, total island deforestation. B) Elemental ratios demonstrating the desiccation of the Aroi mire (Roman et al., 2021). C) ENSO variability reconstruction using the normalized SST-NINO3.4 index (Delcroix et al., 2022).

Until recently, these interpretations were based on a few paleoecological, mostly palynological, records by a single research team. Regarding the potential causes for the Rapa Nui LIA drought, it was observed that this event occurred during a prolonged dominance of La Niña conditions but no further considerations were made (Rull, 2021). In the last few years, additional independent evidence for the LIA drought from other proxies and research teams has emerged that supports the occurrence of this climatic reversal across the island and sheds light on its potential causes, in terms of the climatic mechanisms involved.

The occurrence of the island-wide LIA drought has recently been supported by the finding of a prolonged aridity between 1520 and 1710 CE in Aroi, coinciding with the drying out of Lake Raraku (Roman et al., 2021). The evidence is a conspicuous increase in Fe/Al and P/Al values attributed to strongly oxic conditions created by aerial exposure, suggesting a highly desiccated mire (Fig. 1). Roman et al. (2021) also support the idea that the drought could have affected the entire island, as the Aroi mire is located within the area of maximum precipitation, and this would have triggered dramatic cultural shifts mediated linked to the above quoted freshwater crisis (Rull, 2016). Among the potential causes, these authors mention shifts in the subtropical storm track or the Intertropical Convergence Zone (ITCZ), as proposed in earlier literature, but do not discuss them in depth. Although not mentioned by Roman et al. (2021), their work supported the idea that Lake Kao was the only freshwater source during the LIA drought, as demonstrated by the continuity of its lacustrine sedimentary record during this climatic phase (Seco et al., 2019). This, combined with a significant intensification of human activities around Lake Kao by 1600 CE – attested by the total forest removal and the coeval abrupt increase in proxies for fire, cultivation and grazing (Seco et al., 2019) – is consistent with a population migration of the Rapanui from Raraku to Kao and the associated social, political and religious shifts (Rull, 2016).

More recently, Delcroix et al. (2022) have suggested that the El Niño Southern Oscillation (ENSO) variability could be an important driver of the Rapa Nui climate, especially in relation to the occurrence of century-scale aridity phases. This statement is based on the observation that, during the last 4-7 decades, the colder ENSO phases known as the La Niña events, have caused significant precipitation deficits, as measured instrumentally. These authors modeled the ENSO variability over the last millennium (850-1851 CE) using a new ENSO index called SST-NINO3.4, and observed remarkably high recurrences of La Niña events during the 15th to 17th centuries, as the potential causes for relevant precipitation deficits on Rapa Nui. According to Delcroix et al. (2022), the timing of these arid events is remarkably coherent with anthropogenic deforestation and geochemical aridity proxies, as quoted above (Rull et al., 2015; Seco et al., 2019; Roman et al., 2021). These authors emphasize that, although deforestation was primarily anthropogenic, aridity could have affected forest flammability, as formerly proposed by Rull (2021).

The influence of ENSO variability on Rapa Nui climate has long been discussed (Rull, 2021), and a number of authors consider that this climatic system is highly influential, while others believe that it has little or no effect on the island’s climate. The most recent study in this sense, based on instrumental climatic data from 1955 to 2017, reports no significant correlations between interannual precipitation variability and large-scale climatic phenomena such as the ITCZ, the South Pacific Convergence Zone (SPCZ), the Southern Annular Mode, the ENSO and the Madden-Julian Oscillation (Steiger et al., 2022). Rather, the interannual variability is proposed to be fundamentally stochastic. These authors observe that the seasonal precipitation cycle is caused by seasonal changes in the number of large rain events, and that interannual variability is largely driven by the number of the largest rain events. The cause for these events may be a combination of atmospheric rivers, cold fronts, cut-off lows and other kinds of low-pressure systems, with some influence of the South Pacific subtropical anticyclone dynamics.

In summary, the most recent paleoecological and paleoclimatic investigations on Rapa Nui strongly reinforce the idea of a prolonged LIA drought between approximately 1520 and 1720 CE, the associated freshwater crisis and the shift from a Raraku-centered to a Kao-centered Rapanui society. In contrast, the debate around the potential influence of the ENSO variability on the LIA arid event remains. The link between the LIA drought and the ecological and cultural developments is also strengthened by the geographical extent of this climatic reversal, which encompasses the whole island, therefore affecting the whole Rapanui society. The complex interactions among climate, vegetation and humans have recently been analyzed using a socioecological framework called EHLFS (Environment-Human-Landscape Feedbacks and Synergies), which can provide non-deterministic integrated explanations (Fig. 2).

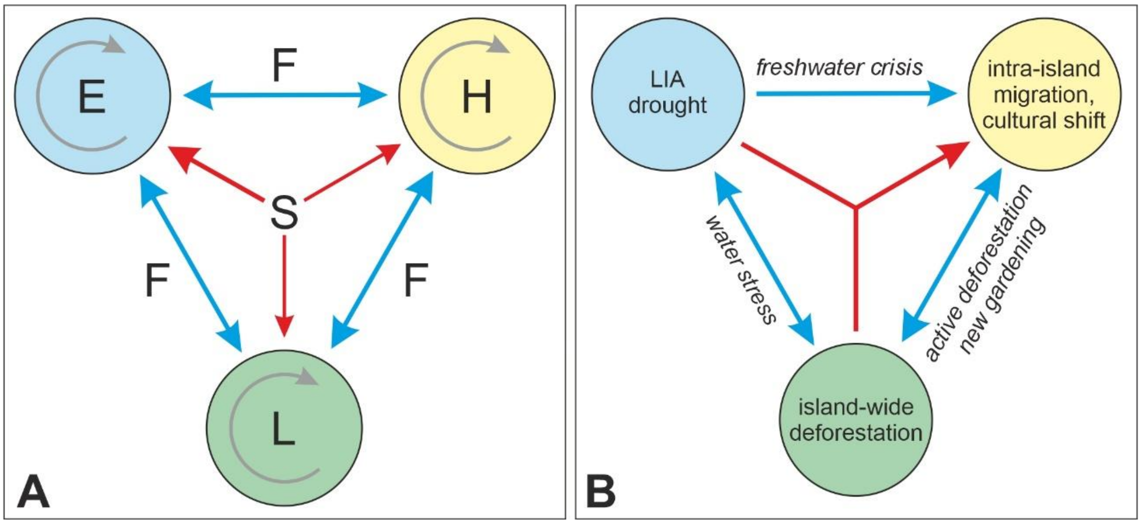

Figure 2. The EHLFS framework for socioecological analysis (A) and its application to the LIA drought occurred on Rapa Nui (B). E, environment; H, humans; L, landscape; F, feedbacks; S, synergies. Modified from Rull & Stevenson (2022).

The EHLFS framework applied to the Rapa Nui LIA drought phase conceptualized the former interpretations by Rull (2016), which were supported and enriched by the independent evidence found in recent years. In this context, major feedbacks occurred between landscape transformation (deforestation) and climate, which magnified each other thus exacerbating ecological change (Fig. 2). The same is true for deforestation and gardening, two anthropogenic activities that magnified one another and, coupled synergistically with climatically-driven freshwater shortage, precipitated intra-island migrations and cultural change. The non-deterministic nature of climate change is supported by the fact that both deforestation and cultural changes were irreversible, despite the return of wet climates at the end of the LIA. Indeed, forests did not regenerate and the newly emerged sociopolitical status associated to the Birdman cult remained until European contact (1722 CE), which marked the beginning of the true Rapanui collapse, caused by slave trading and the introduction of alien epidemic diseases (Rull & Stevenson, 2022). The EHLFS framework is able to accommodate the main drivers and processes that occurred on the island under a holistic perspective, and emerges as a useful conceptual tool for sociecological analysis of situations characterized by complex environment-landscape-human interactions.

More research is needed to elucidate the potential causes for the LIA drought. Studying this event as part of high-resolution millennial scale-climatic and ecological records seems to be crucial for understanding the main mechanisms involved and the corresponding ecological responses, thus allowing to model potential future trends under current global warming (Steiger et al., 2022). Until recently, such records seemed difficult to obtain due to the occurrence of large sedimentary gaps and frequent age inversions. However, the recent recovery of continuous sedimentary records in the three wetlands of the island encompassing the last millennium (Rull, 2021), encourages the pursuit of longer and high-resolution records. Regarding archaeological evidence, the EHLFS framework can be viewed as a useful hypothesis provider to focus future research on the potential cultural developments linked to the LIA drought.

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