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Commentary: Rain, Sun, Soil, and Sweat: A Consideration of Population Limits on Rapa Nui (Easter Island) before European Contact

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A commentary on

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Rapa Nui (Easter Island) has long-presented a challenge to researchers seeking to explain the nearly 1,000 multi-ton statues carved and more than 600 transported across this tiny, remote island where Europeans observed a population just a few thousand in number. The stark contrast between the island's impressive monuments and its marginal resources led to early European speculations of a once larger population under more prosperous conditions, most famously espoused in Diamond's (2005) narrative of "collapse." Recently, Puleston et al. (2017) bring needed attention to the issue of pre-contact population size for Rapa Nui to examine the "collapse" debate. Their work combines demographic and agricultural productivity modeling with parameter estimates from Rapa Nui and other Pacific Islands. While such modeling has many strengths, their conclusion—that the island once supported a population of 17,500—is based on questionable assumptions and contradicts a range of available evidence.

Given early European observations, the conclusion that Rapa Nui once supported a population of 17,500 *requires* a pre-European demographic collapse, in contradiction to archeological and historical evidence, including some of the authors' own work (e.g., Mulrooney et al., 2009, 2010; Stevenson et al., 2015). Predilections for large population estimates follow assumptions, sometimes tacit, that hundreds or even thousands of workers were needed to make and move the multi-ton statues and even more required to produce surplus food in support of these activities. Recent quantitative analyses and experiments demonstrate that relatively small numbers of people could transport the statues (Lipo et al., 2013). Popular notions of "collapse" can be traced to historical misconceptions as some have described (e.g., Lipo and Hunt, 2009; Mulrooney et al., 2009; Hunt and Lipo, 2011). There are currently few *archeological* indications that the population was ever much larger than the ca. 3,000 witnessed at European contact (Hunt and Lipo, 2009) or clear evidence for the precipitous decrease in land-use expected in a massive pre-contact population decline (Mulrooney et al., 2010; Mulrooney, 2013; Stevenson et al., 2015) required if Puleston et al.'s conclusions were valid. In addition, there is little evidence for the level of conflict expected with a dense population of 17,500 on such a small island, including limited lethal skeletal trauma, no systematic production of lethal weapons, nor fortifications

(Lipo and Hunt, 2009; Hunt and Lipo, 2011; Gill and Stefan, 2016; Lipo et al., 2016; Owsley et al., 2016; DiNapoli et al., in press). Moreover, Rapa Nui lacks the kind of dense, nucleated settlement pattern often cited for elsewhere in Polynesia and expected for 17,500 inhabitants on a 164 km^2 island (Kirch, 1984, 2017; Morrison and O'Connor, 2015). Early European population estimates around 3,000 are consistent with an archeologically-documented low-density and dispersed settlement structure (McCoy, 1976; Morrison, 2012).

The population estimate of 17,500 chosen by the authors reflects a fallacy of averaging where the number argued as the "most likely" is arbitrary and apparently little more than subjective preference. In their modeling, maximum population size ranged from 0 to 30,000, but they do not explain how or why the mean is an accurate estimate of the "true" number. Moreover, and as emphasized by the authors, the outcomes are highly dependent on how they chose to parameterize the model, with N values, length of fallow period, amount of labor participation, fertility controls, and degree of surplus used to support "elites" being critical. Yet, the critical soil N values are not well understood, and there are essentially no archeological or ethnographic data available that would allow the authors to estimate these model parameters in a valid way. From a modeling perspective, lacking reasonable parameter values, one must choose outcomes that best fit any empirical evidence. In the authors' "low-N" scenarios, average population sizes are around 3,500, in contrast to their preferred 17,500 in the "high-N" situations. Based on limited evidence for Rapa Nui, the low-N values are just as likely, or more likely, than the high-N values. The results of the low-N scenarios, however, do correspond to the limited empirical demographic evidence we have—the observations of early European visitors. Finally, paleopathological evidence of dietary stress (e.g., enamel hypoplasia, Polet, 2006), suggests that the lower values are consistent with the conditions of food-limited demography for the island.

Importantly, their model neglects annual variance in agricultural productivity. When there is variance in productivity, population growth is limited by minimal productivity and better modeled using the geometric mean rather than the arithmetic mean (Renshaw, 1993; Nations and Boyce, 1997; Freckleton and Watkinson, 1998, p. 113), and populations in variable environments can stabilize at substantially lower levels than under more constant conditions. Rapa Nui has unpredictable annual rainfall and on longer-term timescales, resulting in potentially substantial variability in food productivity (Genz and Hunt, 2003; Morrison, 2012). Consequently, models ignoring temporal variability could, and likely, dramatically overestimate population sizes (Boyce et al., 2006; Lee et al., 2009). As Maynard Smith (1974, p. 13; cited in Boyce et al., 2006, p. 141) points out, "the use of deterministic rather than stochastic models can only be justified by mathematical convenience." The significance of variance in productivity also raises the question whether Hawai'i or other comparisons to Rapa Nui's mean growing productivity are warranted. In the Pacific, Rapa Nui is distinctive in its poor soil fertility, seasonality, pre-contact land-use, settlement patterns, and investments in monument construction, making analogs with other islands potentially misleading.

In addition to the issues raised, this study suffers from problems of irreproducibility. The authors do not provide comprehensive data, adequate description of methods, computer code, or results needed to replicate or verify the outcomes of their model; at odds with current best-practices in science, and in archeology in particular (e.g., Marwick et al., 2017). Studies that include relatively complex computational models, but no code or necessary data needed for model replication, remain essentially unverifiable "black boxes" (Morin et al., 2012).

Ultimately, building an empirically supported and theoretically sound framework for estimating past populations of Rapa Nui is vital to explaining the remarkable archeological record of the island. We need good demographic models with empirically estimated parameters, including longer-term variability in productivity and, critically, whose outcomes can be replicated and evaluated against the archeological record. In the case of Puleston et al. the problems are not necessarily embedded in the model, but in unsound assumptions and a conflation of what might be *possible* with what is *probable*. Successful models depend on dynamic and empirical sufficiency (*sensu* Lewontin, 1974) and are evaluated on the degree to which they are useful. Thus, if the results of a model contradict multiple lines of empirical evidence, then the model is not wrong, but instead not useful for this particular case. Such is the case in this study of pre-contact Rapa Nui.

AUTHOR CONTRIBUTIONS

CL, RD, and TH: wrote the paper. All authors gave final approval for publication.

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