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Triumph of the Commons: Sustainable Community Practices on Rapa Nui (Easter Island)

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Abstract: The history of Rapa Nui (Easter Island) has long been framed as a parable for how societies can fail catastrophically due to the selfish actions of individuals and a failure to wisely manage common-pool resources. While originating in the interpretations made by 18th-century visitors to the island, 20th-century scholars recast this narrative as a "tragedy of the commons," assuming that past populations were unsustainable and selfishly overexploited the limited resources on the island. This narrative, however, is now at odds with a range of archaeological, ethnohistoric, and environmental evidence. Here, we argue that while Rapa Nui did experience large-scale deforestation and ecological changes, these must be contextualized given past land-use practices on the island. We provide a synthesis of this evidence, showing that Rapa Nui populations were sustainable and avoided a tragedy of the commons through a variety of community practices. We discuss this evidence in the context of Elinor Ostrom's "core design principles" for sustainable communities and argue that Rapa Nui provides a model for long-term sustainability.

Keywords: archaeology; collapse; Polynesia; resilience; tragedy of the commons

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1. Introduction

Past human communities offer powerful examples of how natural and social resources can be successfully managed in ways that attend to environmental challenges. The study of ancient communities, therefore, is a vital area of investigation for exploring possible strategies for addressing contemporary concerns over a sustainable future and is an emerging focus of the historical sciences (e.g., [1–15]). Indeed, in recent forums, questions of sustainability, resilience, and collapse within the context of human–environment interactions were highlighted as "grand challenges" for contemporary archaeology [16,17]. The lessons we might gain from historical examples, however, are dependent on their empirical foundations and require a critical evaluation of the evidence for environmental change, anthropogenic impacts, and human responses. Effective use of archaeological case studies involves the careful evaluation of whether these histories demonstrate sustainability, "collapse," or something in between [18].

Rapa Nui (Easter Island, Chile) is often held up as a model for how the study of human–environment interactions has direct implications for the future. Rapa Nui is a tiny (164 km^2) and remote island in the southeastern Pacific, located more than 3500 km from South America and ca. 2000 km from Pitcairn, the nearest inhabited island (Figure 1). The island was initially settled by Polynesian voyagers as part of the large-scale human expansion into East Polynesia in the 12th–13th century AD, after which point current evidence indicates the island was completely isolated [19–24]. The island is famous for its impressive megalithic constructions, for the human impacts on its environment, and, controversially, as the location of a demographic and cultural collapse stemming from the unsustainable use of resources [25,26]. Many have characterized Rapa Nui's history as a "tragedy of the commons" [27], i.e., a case of societal failure following the selfish actions of individuals and their failure to properly manage common-pool resources in the face of a changing environment. Diamond's (e.g., [28,29]) popular accounts, for example, famously present Rapa Nui as a paragon of a population that demonstrated astonishing cultural achievements but, through its own decisions, ended up catastrophically failing.

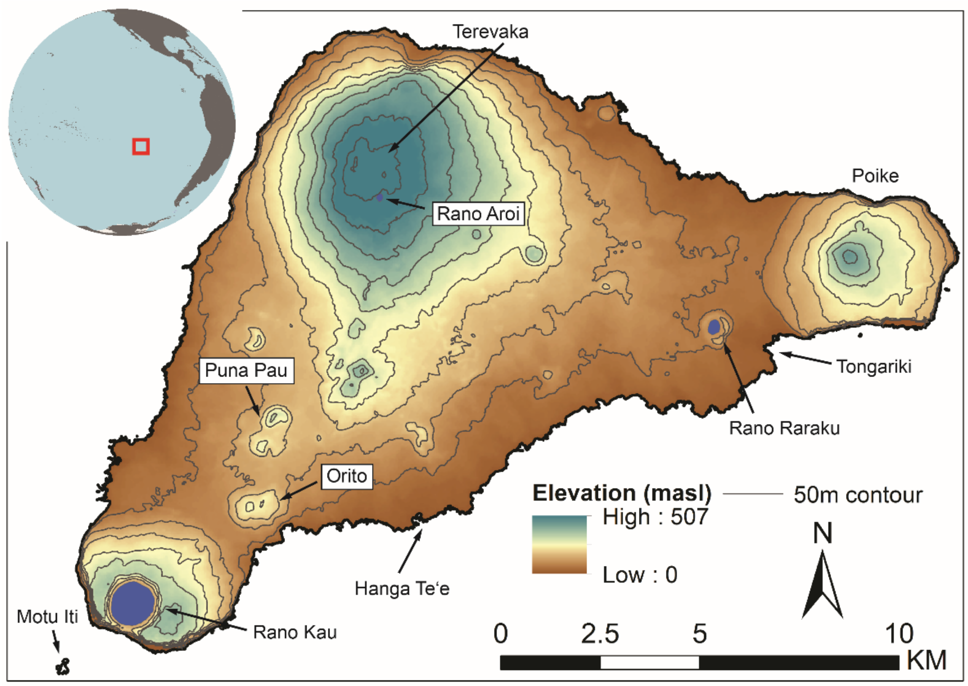

Figure 1. Rapa Nui (Easter Island) with locations mentioned in the text.

While in recent years, most aspects of this "extreme" collapse narrative have been debunked, many continue to argue for some form of environmentally-induced large-scale crisis in demography, land use, and/or cultural practices in pre-contact Rapa Nui (e.g., [30–33]). Emerging evidence, however, demonstrates that Rapa Nui communities were sustainable in several respects and continued their lifeways and traditions despite the changing ecological conditions and inherent environmental constraints imposed by their marginal island (e.g., [18,19,26,34–41]). Here, we review current evidence for Rapa Nui community practices within the context of ecological economics research on sustainable management of common-pool resources. We argue that while Rapa Nui populations did cause large-scale changes to the island's environment, the available data show that communities were resilient to these changes, devised a series of adaptive techniques for dealing with environmental challenges, and lived sustainably for more than five centuries before the arrival of Europeans. We present a model for how a tragedy of the commons was likely avoided through cooperative strategies of common-pool resource management, drawing on Elinor Ostrom's [42,43] work in ecological economics.

2. Rapa Nui and the Tragedy of the Commons Narrative

Scholarly discussion and interest in Rapa Nui began with the arrival of Dutch, Spanish, and English explorers in the mid- to late-18th century. When these European explorers arrived, they encountered an island largely devoid of trees and surface freshwater sources and with a population in the low thousands who had somehow manufactured a spectacular series of megalithic platforms (*ahu*) and statues (*moai*) (Figure 2). The assumed incongruity between the state of the environment and human communities compared to the impressive monuments sparked an enduring notion of the "mystery of Easter Island."

Figure 2. Ahu Tongariki, a ceremonial platform on Rapa Nui with several *moai* statues. Photo by R.J. DiNapoli.

For years, this "mystery" was explained by way of a once much more prosperous population who lived under more idyllic environmental conditions. While claims of societal collapse stemming from anthropogenic environmental catastrophe had been discussed for several decades (e.g., [44,45]), they became widely popularized beginning in the 1990s by Diamond, Flenley, Bahn, and others (e.g., [29,46,47]). A central assumption of the tragedy of the commons narrative is that the islanders engaged in an island-wide cult of massive statue construction and transport, a kind of "*moai* mania," that led to the over-consumption of the island's common-pool resources to feed its overly large population. The natural resources that were over-harvested in this narrative were soil nutrients, birds, marine resources, fresh water, and especially palm trees, assumed important for food and as necessary materials to transport *moai* statues. Over the centuries, demand for the island's resources increased dramatically, leading to a dwindling forest, the extinction of land bird species, soil erosion, the loss of soil nutrients, and the depletion of fresh water and local fisheries. Ultimately, resource availability was exceeded by the demand required to sustain the island's outsized population and their reckless behavior, leading to an ecological catastrophe. Thus, the islanders suffered from the consequences of their own decisions to unsustainably harvest resources: warfare, starvation, cannibalism, depopulation, and cultural collapse. Diamond ([29] (p. 62)) characterizes the story in this way: "in just a few centuries, the people of Easter Island wiped out their forest, drove their plants and animals to extinction, and saw their complex society spiral into chaos and cannibalism. Are we about to follow their lead?"

Such claims are pervasive in the literature (e.g., [28,30,47–56]). Recently, for example, Lima and colleagues ([30] (p. 8)), argued that:

> "demographic and social collapses seem to be the rule across different farming cultures in the Pacific Islands. Intense pressures on the island ecosystem services were required by the high-energy labor invested in the building and maintenance of the old socio-cultural system, materialized in the monumental architectural tradition of the ancient ahu moai cult …. Rapa Nui experienced a long-term climatic trend towards drier conditions since the initial colonization of the island. This, concomitant with a gradual decrease in rainfall and island productivity, explains the process of expansion and demographic collapse experienced by the Rapa Nui society."

Thus, the actions of past communities and their failure to adaptively respond to changing environmental conditions are reasoned to have caused a demographic and cultural collapse, leaving the people of the island in an environment forever degraded in contrast to previous times of ecological abundance. It is in this state that Europeans purportedly found the island when they first visited it in 1722 AD (Figure 3).

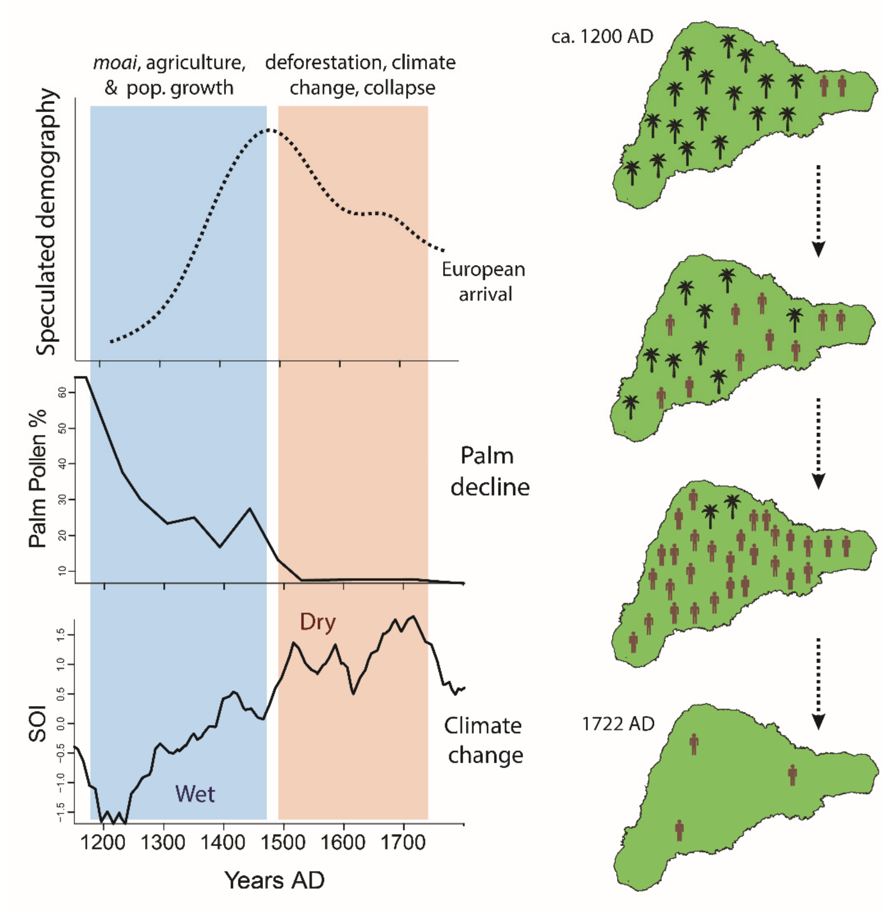

Figure 3. The tragedy of the commons on Rapa Nui. In this narrative, as exemplified by Lima et al. [27], early communities began to remove the forest, establish intensive agriculture, and construct and transport *moai* statues. These efforts required trees as mechanisms for *moai* transport, and forests were cleared to support a growing population needed as labor. The success of these groups led to further population growth and increased labor available for statue construction. Populations grew larger, and those in power intensified competition with one another over dwindling resources. Communities built even greater numbers of statues, leading to further loss of the forest. Around 1500 AD, deforestation and climate change led to ecological, demographic, and cultural collapse. Europeans arrived in 1722 AD and witnessed the aftermath of these events. SOI refers to the Southern Oscillation Index.

In this way, the general narrative of "collapse" and ecological degradation that characterizes many accounts of Rapa Nui fits longstanding and prevailing conceptions about human behavior: Western religious traditions about humanity's "fall from grace" for disturbing the natural world (e.g., Milton's 1667 classic biblical tale Paradise Lost); contemporary concerns about the implications of human activity on the natural world that emerged from post-World War II exuberance (e.g., [57]); mid-20th century narratives of collapse induced by the exhaustion of non-renewable resources [18]; and deep concerns about the impacts of unbounded global population growth, including predictions of mass starvation due to the depletion of natural resources (e.g., Ehrlich's [58] The Population Bomb that directly influenced the first coherent explication of the "ecocide" narrative [44]), ultimately stemming from the assumption that humans tend to act in selfish ways (e.g., [59]). Such selfish actions are particularly acute in the context of the limited resources that are available to everyone in a community. This scenario is the basis of ecologist Garrett Hardin's [27] classic account of the Tragedy of the Commons. Using a common grassy area that is grazed by multiple sheepherders as an example, Hardin describes a scenario in which shared resources are inevitably over-exploited since individuals tend to act based on self-interest. Herders who allow their sheep to consume the shared fields first receive the greatest reward. Such a benefit structure leads individuals to compete to harvest resources before others can. While individuals can initially prosper, in the long run, the environment is badly degraded and the commons is destroyed. Hardin suggests preventing the tragedy of the commons through the presence of government structures that impose strict rules and regulations on how much of a resource people can use. The commons must be governed from the top-down with penalties for cheaters.

The "tragedy of the commons" story is analogous to the popularized pre-contact "collapse" narrative for Rapa Nui. In the case of the island, ecological destruction was perpetrated by the islanders, who brought the event upon themselves due to a combination of individual greed and the failure of island-wide governance to manage common resources and respond to changing environmental conditions. This account is based on several key assertions. First, it assumes that before the arrival of Europeans there were many thousands of people living on the island, organized into some kind of hierarchical arrangement—a factor presumed necessary for the manufacture and transport of such massive statues. Second, the narrative asserts that the island once had abundant resources that supported such large numbers of people. Third, it assumes that the relatively small number of people and the lack of resources on the island at the time of the arrival of Europeans in the 18th century was the outcome of the selfish actions of ancestral islanders.

It is worth briefly noting the range of past population sizes that have been proposed. Early European visitors consistently noted relatively small contact era population sizes in the low thousands (e.g., [60]). Recently, however, and especially since the increase in popularity of scholarly narratives of collapse beginning in the mid- to late-20th century, estimates of past population sizes have increased exponentially (Figure 4). Despite the lack of direct historic observations or archaeological demographic modeling, claims of past populations in the tens of thousands have become common numbers cited in the past 30 years (see Table S1).

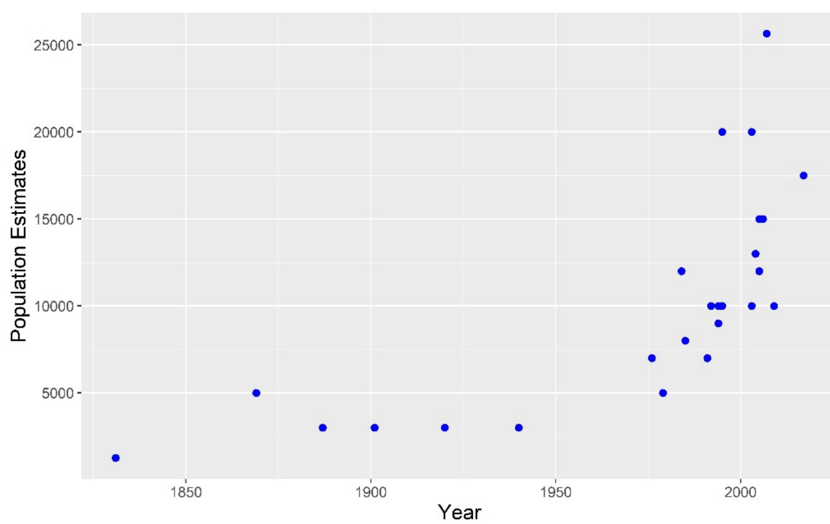

Figure 4. History of claims for maximum pre-contact population size (data from Table S1).

As we will discuss, there has been significant work conducted in the past decade that challenges these assumptions (e.g., [38,41,61–63]). Yet, the "tragedy of the commons" narrative persists, given general misunderstandings about the emerging knowledge of Rapa Nui's past, coupled with persistent concerns about humanity's inevitable impacts on the planet. With the looming impacts of climate change, the recognition that humans are forever altering the environment has only grown more urgent. The Rapa Nui collapse story offers what seems to be a compelling example of the consequences of the failure to heed warnings about the future of our ecosystems—a past example showing that our selfish actions will likely have dire ramifications.

The "tragedy of the commons" scenario, however, is not an inevitable outcome for communities that rely on limited resources and lack a top-down governance structure. Ostrom [42] has proposed a compelling set of alternative conditions, known as "design principles," that can lead to sustainable group-level cooperation over the use of common resources, whereby cooperative behaviors are an outcome of individual actions that reward individuals while also offering group-level benefits. The recognition that sustainable cooperative behavior can emerge among groups even when resources are limited offers new avenues for explaining the remarkable archaeological record of Rapa Nui. Such investigations are timely, given the emerging empirical evidence showing that Rapa Nui's history is inconsistent with the tragedy of the commons narrative. In this paper, we first review the state of our knowledge about the archaeological record of Rapa Nui in the context of community sustainability and resilience. We then explore how such extensive cooperation among community members might emerge in the absence of top-down governance in ways that would also avoid a tragedy of the commons. As we will show, existing archaeological evidence supports a model of the island's communities, organized in a way that fits the expectations of Ostrom's core design principles.

3. Human–Environment Interactions on Rapa Nui

To discuss what we now know about sustainable practices on Rapa Nui, we must first define what sustainability is, and how we might measure it archaeologically. Most approaches in sustainability science draw on the statement issued in the 1987 Brundtland Report [64], which defined sustainability as development or action that "meets the needs of the present without compromising the ability of future generations to meet their own needs." The "needs" often focus on a series of "pillars of sustainability," such as environmental protection, economic vitality, social equity, and the maintenance of cultural traditions and heritage, among others, whereby a sustainable society balances the tradeoffs between these different aspects to increase human and environmental wellbeing (e.g., [65–68]). Strumpf et al. [69], for example, outline a set of key components of sustainability, including continuation; normative orientation; asymmetric relationships between contemporary individuals, future generations, and the environment; systems of mediation; limits of the biophysical environment; and risk and uncertainty.

In archaeology, researchers who have attempted to identify or measure past sustainability focus largely on the first component—continuation, i.e., the longevity or persistence of some phenomenon in the archaeological record (e.g., [4,7,11,12,70–85]). While this component does not capture all aspects of "sustainability" central to the contemporary world, the aggregate and diachronic nature of the archaeological record is well suited for tracking differential levels of persistence and building hypotheses as to why these past traditions succeeded and/or failed. For Rapa Nui, then, our task is to track the history of different cultural phenomena and natural processes over time to assess and contextualize their temporal patterns. We also seek to examine the features of ancient Rapa Nui settlement, subsistence, and cultural traditions in the context of the changing local environment that contributed to the persistence of these traditions, or lack thereof.

Much scholarly discussion of Rapa Nui has focused on pre-contact environmental changes and their potential impacts on human communities. A range of paleoecological evidence indicates that upon human arrival, the island was covered in a forest of palms and other small trees and shrubs (e.g., [86,87]). Early paleoecological work focused on coring of the island's crater lakes, concluded that the evidence showed rapid and catastrophic deforestation, with assumed concomitant soil erosion, a reduction in soil productivity, and the loss of food and surface freshwater, as well as the timber needed to transport *moai* statues (e.g., [46,88–90]). In this way, the unsustainable use of the palm forest is commonly seen as the major driver of the tragedy of the commons.

A range of research now shows a more complicated and gradual process of deforestation (e.g., [87,91,92]). While a major human role in the process is undeniable, given the evidence for landscape burning (e.g., [87,92–94]), the regeneration of the forest was also depressed by seed predation by the invasive Pacific rat (*Rattus exulans*) [91,95]. A period of drought, inferred from Rano Raraku and Rano Aroi sediments between ca. 1520 and 1720 AD, has also been a basis to argue for a climatic role in deforestation (e.g., [33,87,96,97]). Rull [87] argues that the previous claims of an abrupt and catastrophic phase of deforestation are an artifact of the sedimentary gaps and inversions in previous coring studies. A series of recent coring studies at Rano Kau, Rano Raraku, and Rano Aroi demonstrate that deforestation took centuries, was spatially heterogeneous, and the forest was not as dense or extensive as often assumed (e.g., [87,93,94,98]).

The loss of palm forest on Rapa Nui is undeniable and does represent a kind of unsustainable impact on these resources. Yet, how should this loss of palm trees be viewed from the lens of the core characteristics of sustainability outlined above? In many ways, the loss of Rapa Nui's palm forest is rooted in the normative view that ecological change must cause a negative outcome for human populations, and Rapa Nui people should have made a greater effort to sustain these resources. Yet, what should be sustained is always context-dependent [18] and place-based [99–101]. Loss of the palm forest indeed resulted in major ecological changes on the island, but what do the empirical data suggest about how this may have affected the sustainability of human communities?

A common claim or tacit assumption is that the loss of the palm forest resulted in the reduced carrying capacity of the island, as the palms were an important food source. There is, however, little archaeological evidence showing that palms were used as a dietary source. While Orliac ([86] (p. 216)) and Bork and Mieth [102,103] suggest that palm sap and nuts may have been used as dietary sources, there is little empirical evidence that supports these claims [87,91]. Analyses of plant microfossils preserved in the teeth of human remains from archaeological contexts also challenge the assumption that people were consuming resources from palms [104]. The available data point to a dietary focus on dryland cultivation of sweet potato, taro, yams, bananas, and other crops, the consumption of chickens and rats, along with fishing and other forms of marine foraging (e.g., [40,104–109]). So, while parts of the palm may have been consumed at some point in the past, the loss of these sources would not have resulted in significant dietary stress [63]. An additional impact of human expansion and land clearing was the local extirpation or extinction of several sea birds and endemic land birds [110,111]. While these species likely formed some component of the human diet in early pre-contact times, the loss of these birds was largely inconsequential given the importance of introduced chickens in the Rapa Nui diet [112]. It is also likely that bird extirpations resulted in reduced nutrient inputs to Rapa Nui soils (e.g., [113–115]), though this was likely counteracted by cultivation practices (discussed below). In addition, despite claims to the contrary (e.g., [28,51,116,117]), palms were never viable sources of wood for canoes [118]. Thus, the loss of the palm forest seems to have had no substantial economic impact on the human population's ability to support itself. It is also worth noting that agroforestry practices were widespread throughout Polynesia (e.g., [119,120])—surely if palm trees were a critical resource, then Rapa Nui people could have managed these arboricultural resources.

Deforestation during the establishment of agricultural infrastructure is also claimed to have resulted in reduced carrying capacity stemming from large-scale erosion and exhaustion of soil nutrients (e.g., [28,121]), but multiple studies over the last ca. 20 years have significantly increased our knowledge of Rapa Nui cultivation and shown otherwise. While there is evidence of soil erosion associated with forest clearance and agricultural activities, particularly on the steep slopes of Rano Kau, Poike, and northwest Terevaka (e.g., [92,122]), an island-wide study of current erosion demonstrates that while much of the island is potentially susceptible to erosion, only around 5% of the land surface is severely eroded [123], and much of this is attributed to the post-contact effects of historic sheep ranching [63,122,124].

Our current understanding of Rapa Nui agriculture is that these subsistence strategies were resilient and sustainable. Crop production on the island largely focused on the use of small, walled gardens (*manavai*) and various unique lithic mulching techniques [109] (Figure 5). Lithic mulch takes a variety of forms, from veneers of small stones to large boulder gardens [124–129], and these cover large portions of the island [130]. Lithic mulch is hypothesized to increase productivity and reduce risk and uncertainty, by increasing nutrient inputs from weathered volcanic stone, limiting evapotranspiration, reducing soil erosion, and minimizing temperature variance [109,125,127,131,132]. Multiple soil nutrient analyses of garden and non-garden areas consistently show significantly elevated nutrient levels within lithic mulch gardens [40,132–134]. Thus, rather than resulting in a reduction in productivity, the available data indicate that deforestation and the establishment of agricultural infrastructure increased the overall carrying capacity of the island and represent sustainable subsistence strategies. Moreover, recent isotopic analyses of human remains from archaeological deposits show a broad and varied diet from terrestrial and marine resources [40,107,108]. In sum, our current understanding of Rapa Nui subsistence practices indicates adaptation and resilience to environmental risk and uncertainty.

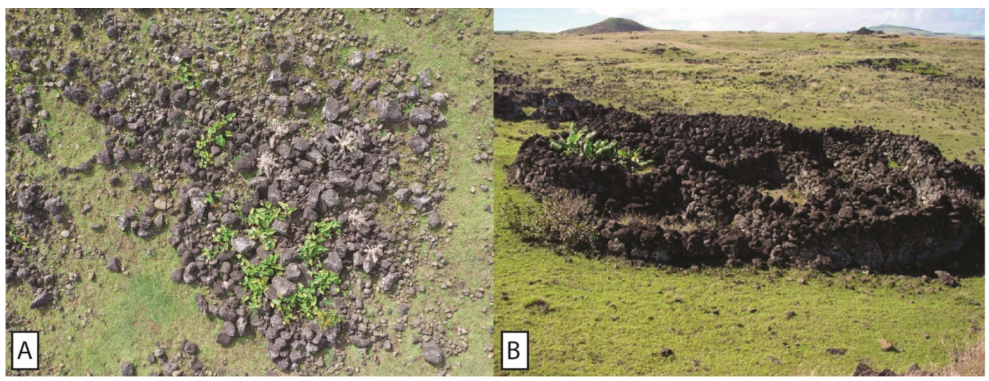

Figure 5. Examples of traditional cultivation practices: (**A**) lithic mulch garden with taro (*Colocasia esculenta*), (**B**) walled garden complex (*manavai*) with banana (*Musa* spp.). Photos by C.P. Lipo.

Several scholars have also suggested that forest loss resulted in reduced surface fresh water with negative consequences for human populations. Today, Rapa Nui is largely devoid of surface freshwater, except for three small crater lakes (Rano Kau, Rano Raraku, and Rano Aroi). Due to the high permeability of the island's geology, aside from ephemeral flows that occur after heavy rains, there are no other permanent surface freshwater sources [135,136]. Some have speculated that this was not always the case, and that surface water was more plentiful prior to forest loss (e.g., [29,46,50,103,112]). In addition, paleoecological and paleoclimatic studies indicate a prolonged drought period in pre-contact times (ca. 1520–1720 AD), wherein the crater lake at Rano Raraku, and likely at Rano Aroi, went completely dry [33,87,96,97,137]. Recent research, however, shows that archaeological and ethnohistoric records demonstrate that Rapa Nui communities relied largely on submarine groundwater discharge (SGD)—locations at the coast where groundwater emerges at the tideline [136,138,139]. These studies also suggest that SGDs are dependable water sources that are resilient to drought events, given the relatively long residence and turn-over times for water in the island's subterranean aquifer [135,140]. Salinity surveys show that these SGD locations are brackish, though a range of evidence indicates that islanders developed water management techniques to intercept this seeping fresh water before it mixed with saltwater [136,138–140]. The use of SGD is most clearly demonstrated in the archaeological record through the construction of *puna*—paved, walled, and well-like features used to trap and impound groundwater just before it emerges at the coast (Figure 6).

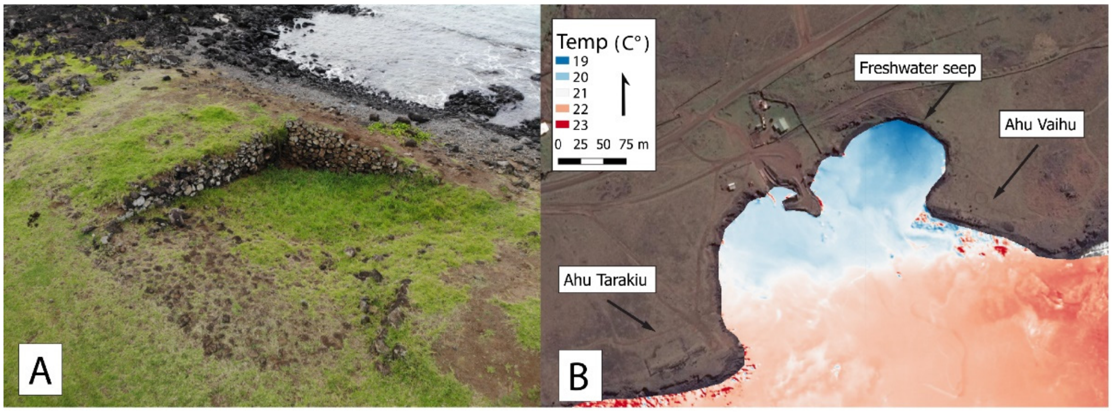

Figure 6. Sustainable freshwater management on Rapa Nui. (**A**) Example of a *puna* (i.e., "well") used to trap and collect seeping groundwater, and (**B**) a thermal infrared orthomosaic at Hanga Te'e showing cooler groundwater (in blue) seeping into relatively warmer ocean water (in red). Figure based on analyses in DiNapoli et al. [140].

Detailed analyses of the archaeological record and experimental results demonstrate that trees were not needed, nor were they used to transport *moai* statues [25,141]. Moreover, given the relatively soft nature of palm wood, they were likely incapable of supporting the weight of even moderately-sized *moai*, weighing thousands of kilograms. This decoupling of the palm forest from megalithic transport and construction is further corroborated by recent chronological studies. Sherwood et al.'s [142] radiocarbon dating program at the *moai* quarry of Rano Raraku indicates the persistence of activity long after the palm forest had largely disappeared. In addition, Bayesian chronological modeling of the tempo of *ahu* construction shows that the manufacture and use of statue platforms continued throughout the pre-contact sequence and into the early historic period [19], with ethnohistoric evidence further indicating the long-term persistence of the *ahu-moai* tradition [41]. Thus, the available archaeological evidence demonstrates that *ahu* and *moai* construction were sustainable cultural traditions (Figure 7).

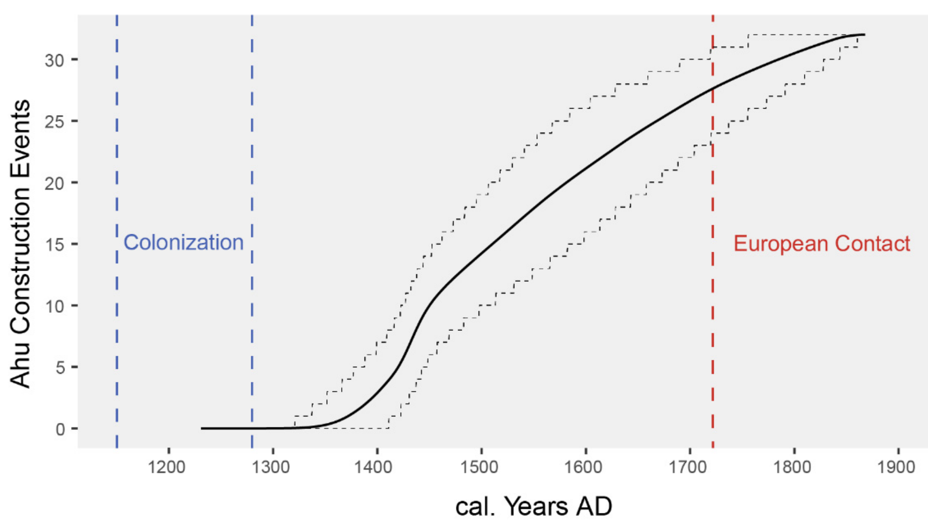

Figure 7. Chronological analyses of *ahu* construction demonstrate the sustainability of religious traditions. The plot shows Bayesian chronological estimates of the cumulative number of *ahu* (statue platform) construction events over time. The dashed black lines represent the 95% Bayesian credible intervals (based on analyses in DiNapoli et al. [19]).

Perhaps most critically, a series of paleodemographic analyses point toward population stability and resilience throughout the pre-contact period. Using summed probability distributions (SPD) of the most reliable radiocarbon dates from settlement sites, Mulrooney [34] demonstrates that the available data are inconsistent with the expectations of the tragedy of the commons narrative, which assumes a major pre-contact population decline. Similar analyses of obsidian hydration dates from several sites also support these results [143–146]. While Lima et al. [30] have argued that SPD analyses of radiocarbon dates show population declines associated with palm forest reduction and climate change, these claims are not robust to the effects of the calibration curve or sampling error, confounding issues that Lima et al. largely ignored [39]. Robust modeling of the radiocarbon and paleoenvironmental records using an Approximate Bayesian Computation approach instead demonstrates patterns consistent with logistic population dynamics on Rapa Nui—i.e., relatively rapid population growth followed by a plateau that lasted until the timing of European arrival in 1722 AD (Figure 8). These results are critical as they demonstrate (1) that the population of approximately 3000 individuals encountered at first contact [38,60,147] is an accurate reflection of pre-contact Rapa Nui communities, and (2) that Rapa Nui communities were sustainable and resilient to the impacts of ecological and climatic changes that occurred over the course of human occupation of this tiny, remote, and environmentally marginal island.

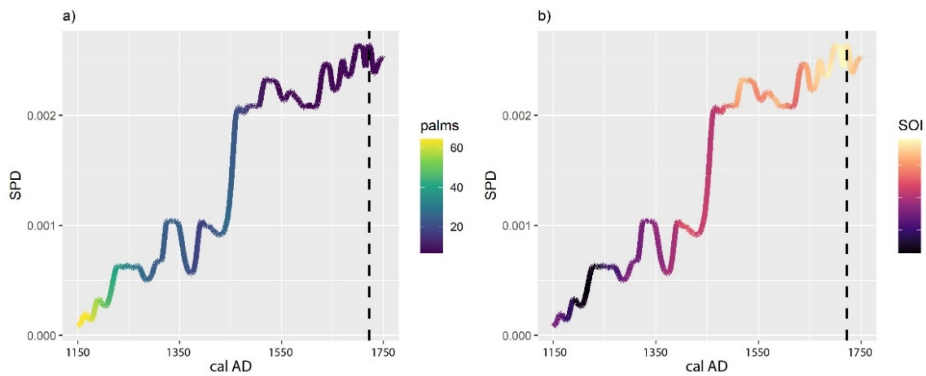

Figure 8. Summed probability distribution (SPD) of reliable radiocarbon dates associated with settlement sites on Rapa Nui in relation to changing vegetation and climate: (**a**) Rapa Nui SPD, in relation to changing palm forest cover (paleoecological data from [96]); and (**b**) climate change, based on Yan et al.'s [148] reconstruction of the Southern Oscillation Index (SOI). The patterns in the SPD are consistent with a process of logistic population growth, whereby populations were resilient to the effects of forest decline and climate change. The vertical dashed lines show the timing of European contact in 1722 AD. This figure is based on analyses from DiNapoli et al. [39].

4. Overcoming the Tragedy

This new evidence presents a very different picture of Rapa Nui. Rather than a catastrophic tragedy of the commons, Rapa Nui's history is better seen as a case of success on a remote, resource-poor island. Polynesians colonized Rapa Nui between the 12th and 13th centuries, bringing with them a suite of plants (e.g., sweet potato, yams, banana, taro, etc.) and animals (rats, chickens), along with a variety of knowledge about subsistence strategies (e.g., fishing, cultivation), economic practices (e.g., lithic tool quarrying and manufacture), and cultural traditions (e.g., monument construction). Starting with these components, Rapa Nui communities quickly grew in size and transformed the island from a palm forest to an anthropogenic landscape [26,39,149]. From the available archaeological evidence, populations resided in multiple, functionally redundant dispersed communities (e.g., [150–152]), which appear to have cooperatively managed common-pool resources at both local (e.g., agricultural land, fishing locations, water sources) and island-wide scales (e.g., lithic quarries) in a resilient and sustainable way for multiple centuries (Figure 9).

Given the marginality of the island's environment and extreme isolation, how was such a group-level social dynamic achieved?

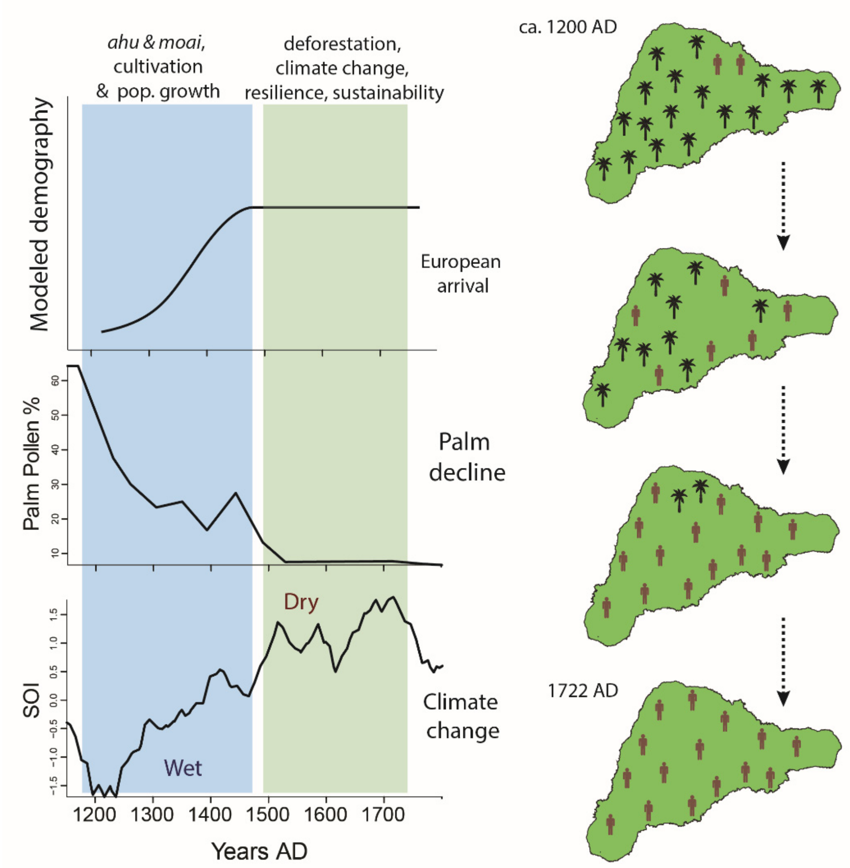

Figure 9. Human–environment interactions on Rapa Nui. Populations were stable, resilient, and sustainable despite their isolated location, marginal environment, and changing climatic and ecological conditions.

One problem for group-level cooperative behavior is the fact that it is often most beneficial to behave selfishly. If, for example, there is a benefit to everyone in a group involved in statue construction, then those individuals who can receive that benefit without paying the cost of cooperating will have an advantage relative to those who must pay the cost. As a result, while a cooperative group can be initially established, over time the "cheaters" or "free-riders" tend to increase in frequency, leading to the ultimate failure of the group as a whole.

Ostrom's Nobel Prize-winning research in economics on the conditions favoring group-level cooperation over common-pool resources provides a framework to explain the emergence of groups that overcome this problem [42]. In the context of traditional economic thinking, the selfish tendencies that lead to a tragedy of the commons are avoided through the imposition of top-down regulatory structures or the privatization of resources [27]. Ostrom's work, which assembled a worldwide array of examples of communities that successfully and sustainably used shared resources, demonstrated that regulation and privatization are not necessary conditions for sustainable use of common-pool resources—resources can be reliably conserved under social conditions lacking top-down structures. Ostrom's research revealed that all successful cases of cooperative self-governance over common-pool resources have several "core design principles" in common. A recent generalization of these design principles is offered by Wilson et al. ([43] (p. 2)):

1. The group identity and its shared resource(s) should have clearly defined boundaries.
2. Individuals must not receive benefits from the group that are disproportionate to the contribution costs they have incurred, i.e., high status or inequality must be earned.
3. Decisions must be made by consensus, collective-choice arrangements.
4. There must be monitoring by group members to deter free-riding and/or rule-breaking.
5. The severity of punishment for rule-breaking should be gradual.
6. There must be fair and collectively agreed-upon conflict resolution mechanisms.
7. Groups should be relatively autonomous and be able to conduct their own affairs.
8. Larger-scale interaction requires appropriate coordination among sub-groups.

These principles characterize numerous historical cases of cooperative social groups, and indeed may be foundational functional aspects of the evolution of cooperation in general—"when a group possesses the core design principles, the opportunities for some members to benefit at the expense of others become extremely limited" ([43] (p. 6)). The design principles point to conditions favoring the emergence of sustainable community practices (e.g., [153–157]). A sustainable community is one that strategically shares resources among its members and institutions to support the community's well-being, while not negatively affecting future generations' or other communities' use of these resources. Since one of the biggest challenges for any community is to offer equitable and sustainable sharing of the resources upon which everyone in the community relies, communities that are unable to solve the problem of common-pool resources will quickly fail. The core design principles offer a governance structure that can provide solutions to managing these resources and provide a solid basis for sustainable communities.

These design principles potentially help us explain the success of Rapa Nui communities. Given the environmental context of Rapa Nui—small, marginal, extremely isolated—cooperation mattered to a critical degree. Communities on the island depended on marine foraging locations, suitable agricultural land, freshwater sources, and lithic quarries comprising common-pool resource areas. Yet, for each of these common-pool resources, as discussed in the previous section, Rapa Nui communities avoided a tragedy of the commons scenario and sustainably used them for several centuries. What was it about Rapa Nui community practices and governance that produced such sustainable communities despite the obvious challenges posed by the island itself? If the island's communities were sustainably persisting up to the point of European contact, we would expect the record and early ethnohistoric accounts to reflect features that would be consistent with many of Ostrom's principles. In this way, Ostrom's principles offer significant hypotheses that can be evaluated regarding these communities.

4.1. Design Principle 1. Clearly Defined Boundaries

While strong territoriality like that seen in some other parts of Polynesia does not appear to have been present on Rapa Nui [158], archaeological and ethnohistoric evidence provides a clear picture of relatively small-scale delineated communities on the island [152]. The archaeological settlement pattern is characterized by multiple redundant sets of domestic feature classes, such as house features, earth ovens, and garden areas, which are centered around ceremonial platforms (*ahu*) (e.g., [150,151]). There are several hundred *ahu* of various types on the island, with image-*ahu*—those with *moai* statues—numbering around 150 [159]. Archaeological, genetic, and biological data show relatively clear boundaries between these communities, and that interaction between these groups was highly localized [152].

Thus, the archaeological record points to a series of semi-autonomous communities distributed across the island. Ethnohistoric accounts from 18th- and 19th-century European visitors also support this interpretation. La Perouse in 1786, for example, noted, "the conjectures which may be formed respecting the government of these islanders are, that they compose a single nation, divided into as many districts as there are morais {*ahu*]; because it is to be remarked, that the villages are built near these burying places." This social system persisted into the historic era where ethnographers recorded a series of multiple, small-scale, autonomous clan groups (e.g., [160,161]).

4.2. Design Principles 4/5/6. Monitoring, Sanctions, and Conflict Resolution

A key development in recent years is an increased understanding of violence on Rapa Nui. Scholars long treated Rapa Nui as a case where widespread violence and internecine warfare were major contributors to the society's supposed downfall [41]. A series of recent papers, however, have demonstrated that warfare and lethal violence were largely absent on Rapa Nui (e.g., [41,162,163]). A critical line of evidence comes from analyses of trauma in human skeletal remains, which document relatively high levels of interpersonal aggression, but with lethal violence largely absent [162,164]. This arguably corresponds to Ostrom's design principle of "graduated sanctions," whereby punishment through physical violence was used only when other options had been exhausted, and even then, non-lethally. The 19th-century account of Eyraud provides a window into this—"The natives don't often resort to violence. I have seen them have noisy arguments and burn down each other's huts but without, nevertheless, coming to blows" ([165] (p. 26)). While Eyraud's visit occurred more than 100 years after initial contact, there are a plethora of similar historic observations made in the 18th and 19th centuries which note a lack of lethal violence on the island [41].

Other early observations suggest that part of what led to an avoidance of conflict is simply the poor quality of the resources; few resources were worth defending and individuals were free to pursue their own paths [158]. Johann Reinhold Forster ([166] (p. 83)), the naturalist who accompanied Cook during his visit in 1774, noted that "if any young man wants to live on his own, he may simply occupy a [plot of] land and clear it out with a tool made of hardwood, in form of a pointed stake, which is used here instead of spade; his family and friends will not refuse him some sweet potatoes that he will divide into cuttings to multiply them; others will give him some shoots of sugar cane or banana tree, and there he is, ready to become head of a family and to feed himself, his wife and children." While the duration of Forster's stay was limited and occurred ca. 50 years after initial contact, his observations offer a window into the local-scale cooperative use of land and subsistence resources within post-contact Rapa Nui communities.

While the archaeological record demonstrates that individual-level conflicts took place, large-scale conflicts were likely resolved through other means, with physical violence used as a last resort. One possibility is that competition took ritualized forms of costly signals (e.g., [167,168]). Costly signaling is a mechanism whereby some unobservable quality, such as competitive ability, is communicated through displays that are either detrimental or impossible to fake. On Rapa Nui, this is one hypothesized role of monument construction (e.g., *ahu* and *moai* construction and transport) within and between communities, particularly in relation to coastal freshwater sources [25,26,138,150,158,169]. It is also likely that ritual activities associated with *ahu* and *moai* served as a means for community monitoring. At the level of the individual, the success of *moai* transport and *ahu* construction would be physically evident in the success of the endeavor. Free-riders who failed to contribute to the effort would be easily detectable; a failure to participate would be obvious, and fake effort would likely be revealed in structural or transport failure. At the scale of communities, each group has access to the efforts and success of others. The process of moving *moai* from the quarry to their *ahu* locations required parading the monument across the terrain of neighboring groups along the statue roads [170]. In this way, and given the island's relatively open landscape, where large areas are intervisible, the process of statue transport, *ahu* construction, rituals, and other community-scale activities would have facilitated intra- and inter-community monitoring [171].

4.3. Design Principles 7/8. Groups Should Conduct Their Own Affairs and Larger Scale Interaction Requires Coordination among Groups

While much social interaction appears to have occurred at highly localized scales, there were of course larger-scale interactions on the island. While agricultural land, marine foraging locations, and freshwater sources were likely managed at local scales, lithic quarries were a common-pool resource that necessitated larger-level coordination. A variety of lithic materials provided important resources for a range of economic and social activities on Rapa Nui. Basalt was widely used as a construction material for domestic and subsistence architecture (e.g., houses, ovens, chicken coops, lithic mulch gardens), ritual structures (e.g., *ahu*, *avanga* (burial features)), and implements (adzes, chisels, flakes, etc.). Volcanic tuff was used to create most of the island's famous *moai* statues (a limited number were carved from red scoria, trachyte, and basalt) [172]. Red scoria was also used to create *pukao* (*moai* "hats") and *paenga* (rectangular construction stones), and obsidian was widely used for creating small lithic tools (e.g., *mata'a*). Given the volcanic origins of the island, it is perhaps unsurprising that the evidence shows continuous and sustainable use of these resources over time. What is notable, however, is what the use of these resources implies about the nature of larger-scale interactions.

With the exception of coarser-grained basalt used as architectural stone [173], most lithic resources were quarried from one or only a few source locations. Volcanic tuff for creating *moai* derives from highly localized outcrops at Rano Raraku [172], as does *pukao* scoria from Puna Pau [174,175]. Obsidian is available from four different source locations (Orito, Motu Iti, and two sources on Rano Kau), though these all occur at the southwestern sector of the island, and Orito seems to be the predominant source [176]. Fine-grained basalt for creating adzes also comes from a limited number of sources [177–179]. Despite the spatially restricted nature of these raw material sources, the artifacts manufactured from them are found in archaeological contexts throughout the island. There is no evidence of walls or other restrictions to accessing these sources—they were available for all communities to use. At the statue quarry of Rano Raraku, for example, many have noted distinct quarry areas that appear to have been used by different groups working contemporaneously (e.g., [161,172,180,181]). While the specific details of how this interaction was mediated are poorly known, the nature of lithic raw material use points to some mechanism of larger-scale coordination in the use of these common-pool resources among Rapa Nui communities.

5. Conclusions: The Triumph of the Commons

Rather than experiencing a tragedy of the commons, Rapa Nui communities lived successfully on the island for over 500 years despite its extreme isolation, limited resources, and changing environmental conditions. Here, we offer a new model that captures the key features of what we now know of the island's success: the triumph of the commons.

In this account, Polynesians first arrived on the island during the late 12th to early 13th century AD and found an environment dominated by a mixed palm forest ecology. These colonists began to clear the forest to grow crops and, as part of their Polynesian traditions, build ceremonial platforms (*ahu*) and carve and transport *moai* statues to honor their ancestors. Working cooperatively in small kin-related groups, these communities thrived with the benefits associated with cooperation, sharing, and conflict avoidance. In this resource-limited environment, those groups that worked better together differentially outperformed those that did not. Access to common-pool resources such as drinking water, agricultural land, and marine foraging locations was managed at a local level by small, relatively autonomous groups with governance structures that likely featured key aspects of Ostrom's design principles (Figure 10). Over time, the palm forest was replaced by lithic mulch gardens, other agricultural infrastructure (e.g., *manavai*), and human settlements, and while the loss of forest did cause large-scale ecological changes and local extinctions, the available evidence shows that palms offered few economic benefits, and thus their disappearance resulted in negligible negative impacts on the persistence of human communities. Group membership and privileges were reinforced through physical contributions to monument construction and transport, and between-group conflicts were mediated through cooperative, group-level signals: *ahu* and *moai*. When aggressions did escalate to physical violence, the vast majority of cases appear to have been non-lethal. While population growth was initially rapid, it peaked at around 3000, a number that can be successfully sustained by the island's available resources. This pattern of logistic population growth occurred despite the changing ecological and climatic conditions that emerged in late pre-contact times, facilitated through resilient and adaptive cultivation, marine foraging, and freshwater management strategies that increased the productivity of the island. Investment and elaboration in monuments persisted since the act of bringing people together for cooperative activities strengthened the communities. Consequently, the sustainable communities of Rapa Nui thrived until the arrival of Europeans; the introduction of disease, slave raiding, and new kinds of economic resources resulted in the gradual abandonment of some long-standing traditions.

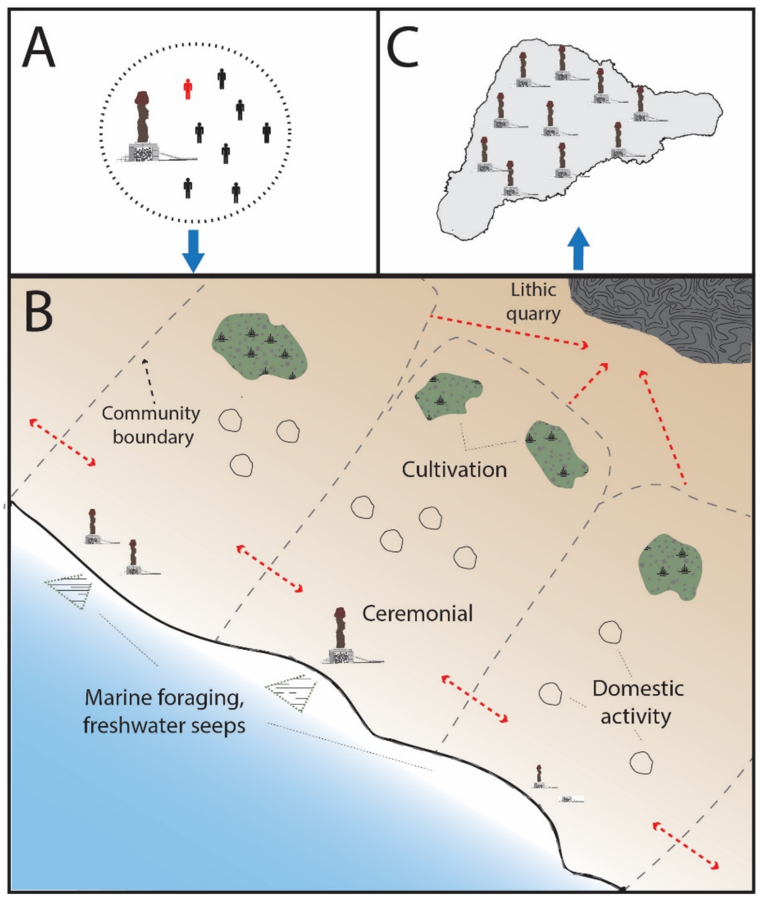

Figure 10. A simplified model for the Triumph of the Commons on Rapa Nui. At the scale of the individual (**A**), demonstrable participation in group-level activities ensures access to common-pool resources. At the scale of groups (**B**), those groups that work more effectively to manage common-pool resources via aspects of the Ostrom Design Principles outperform those that do not. Individuals participating in successful groups receive benefits. Group interaction is mediated through cooperative constructed signals (*moai* and *ahu*). At the scale of the island (**C**), groups persist at levels within the resource constraints of the island. Over the transformation of the island from a forest to a mulch-garden landscape, human populations reach equilibrium and communities are sustainable through to the arrival of Europeans in the 18th century. Note that the model is simplified: interaction and coordination likely took place on a continuous set of scales from small groups to island-wide interactions.

Rapa Nui has long been argued to provide lessons about the nature of human interactions with the environment and the potential fate of current and future human communities. While long seen as a potential warning for the future, of how selfish actions and overconsumption might lead to collapse, a range of interdisciplinary research conducted over the last ca. 20 years now clearly shows that Rapa Nui communities were resilient and sustainable. In this way, Rapa Nui does provide an important source of knowledge on human–environment interactions, though in quite different ways than has long been assumed. While human populations did cause profound changes to the island's environment, these human impacts were accompanied by land-use practices that ultimately improved the island's productivity and helped ensure the long-term sustainability of Rapa Nui communities. This pattern of anthropogenic ecological transformation of island environments into landscapes that sustainably supported human communities is widespread across the Pacific (e.g., [7,113,119,120,182–189]). While the social and environmental configurations that comprise these transformations greatly vary by island location, due to historical contingencies and island-specific resource constraints (e.g., [132,158,190,191]), a common outcome is how these practices increased the natural productivity of these environments. In this way, the current empirical evidence shows Rapa Nui to be an example of sustainable communities, not unlike other areas of the Pacific. Rapa Nui's triumph of the commons suggests that common-pool resources can be successfully managed in remote and resource-limited environments in the long run, through governance and cooperative activities that align with Ostrom's design principles. We suggest that the ecological economics framework offered by Ostrom can potentially provide a useful approach for archaeologists seeking to examine the factors influencing the sustainability of communities elsewhere in the Pacific, as well as island and coastal regions around the world.

Supplementary Materials: The following are available online at www.mdpi.com/article/10.3390/su132112118/s1, Table S1 History of numbers cited for pre-European population sizes.

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