FACTORS INFLUENCING THE CONSTRUCTION OF MONUMENTAL ARCHITECTURE: A RAPA NUI (EASTER ISLAND) CASE STUDY

by

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A DISSERTATION

Presented to the Department of Anthropology
and the Graduate School of the University of Oregon
in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy

June 2020

DISSERTATION APPROVAL PAGE

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Title: Factors Influencing the Construction of Monumental Architecture: A Rapa Nui (Easter Island) Case Study

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Degree awarded June 2020.

DISSERTATION ABSTRACT

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Doctor of Philosophy

Department of Anthropology

June 2020

Title: Factors Influencing the Construction of Monumental Architecture: A Rapa Nui (Easter Island) Case Study

Monumental architecture was an important and widespread component in the emergence and dynamics of many past human societies. These features figure prominently in global dialogues about the evolution of social complexity, as monuments are often seen as manifestations of social inequality, religiosity, labor control, intra-community cooperation, and inter-group competition. Consequently, understanding the various socio-ecological factors underlying the emergence of monument construction is critical for a more complete understanding of the human past and its various trajectories. In this dissertation, I investigate these processes on Rapa Nui (Easter Island, Chile), famous for its monumental religious architecture. The role of monument construction in Rapa Nui society had been persistently debated, with some arguing for a cessation of monument construction, internecine warfare, and cultural collapse in a late pre-contact ‘Huri Moai’ phase. Given recent critiques of this narrative, a new emerging model, drawn from costly signaling theory (CST), proposes that monument construction was instead an adaptive response to the island’s marginal and risky environment that had long-term benefits to Rapa Nui communities. In addition to their well-known religious roles, it is hypothesized that monument construction served as conspicuous displays (i.e., costly signals) of communities' competitive ability to control and defend their limited resources, which resulted in greater intra-group cooperation and limited violent conflict between groups. This dissertation is focused on testing the archaeological predictions of the CST model and critically evaluating some central, yet unresolved aspects of the Huri Moai narrative. This dissertation addresses these issues through a series of quantitative spatial and chronological analyses of monument construction on Rapa Nui as well as the archaeological and ethnohistoric evidence for warfare and monument destruction that define the Huri Moai phase. The results provide support for the CST hypothesis, question the validity of the Huri Moai phase, and offer a revised account of Rapa Nui culture history.

This dissertation includes previously published, co-authored material.

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DiNapoli, R.J., Rieth, T., Lipo, C.P., Hunt, T.L. (2020). A model-based approach to the tempo of “collapse”: the case of Rapa Nui (Easter Island). *Journal of Archaeological Science.* 116: 105094.

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Cochrane, E.E., Tautunu, A.A.M., DiNapoli, R.J. (2019). Hypotheses to explain the few early coastal archaeological deposits in Sāmoa: preliminary evaluations. *Journal of Archaeological Science: Reports*. 26: 101931.

Hixon, S., DiNapoli, R.J., Lipo, C.P., Hunt, T.L. (2019). The ethnohistory of freshwater use on Rapa Nui (Easter Island, Chile). *The Journal of the Polynesian Society*. 128(2): 163-189.

DiNapoli, R.J., Lipo, C.P., Brosnan, T., Hunt, T.L., Hixon, S., Morrison, A.E., Becker, M. (2019). Rapa Nui (Easter Island) monument (*ahu*) locations explained by freshwater resources. *PLoS ONE*. 14(1): e0210409.

Morrison, A.E., Rieth, T. DiNapoli, R.J., Cochrane, E.E. (2018). The Sāmoa Archaeological Geospatial Database: initial description and application to settlement pattern studies in the Sāmoan Islands. *The Journal of the Polynesian Society*. 127(1): 35-54.

Lipo, C.P., DiNapoli, R.J., Hunt, T.L. (2018). Commentary – rain, sun, soil, and sweat: a consideration of population limits on Rapa Nui (Easter Island) before European contact. *Frontiers in Ecology and Evolution*. 6(25): 1-3.

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DiNapoli, R.J., Morrison, A.E. (2017). A spatiotemporal model of risk and uncertainty for Hawaiian dryland agriculture and its implications for *ahupuaʻa* community formation. *Journal of Archaeological Science: Reports*. 15: 109-119.

DiNapoli, R.J. Morrison, A.E. (2017). Human behavioral ecology and Pacific archaeology. *Archaeology in Oceania*. 52(1): 1-12.

ACKNOWLEDGEMENTS

I would like to first thank my mentors, Terry Hunt, Scott Fitzpatrick, and Carl Lipo. Terry introduced me to the study of the Pacific Islands, taught me the value of a critical and theoretically explicit approach to the human past, and gave me the opportunity to work with him and Carl on Rapa Nui. Scott provided invaluable guidance and support throughout the entire dissertation process, has been a guiding force in my professional development, and helped expand my research interests outside of Polynesia. Carl Lipo has been a major part of my doctoral education, and I thank him for his skepticism, candidness, encouragement, and professional opportunities he has given me over the last six years. I would also like to thank my committee members, Jon Erlandson and Patrick Bartlein, who provided vital feedback on a range of substantive and analytical portions of this research. This dissertation would not have been possible without their guidance and mentorship.

This research was supported by National Science Foundation Doctoral Dissertation Research Improvement Grant #1841240, the American Philosophical Society's Lewis and Clark Fund for Exploration and Field Research, The Explorers Club Exploration Fund, as well as internal grants and awards from the Department of Anthropology, College of Arts and Sciences, Global Studies Institute, and Center for Asian and Pacific Studies at the University of Oregon. I thank them for their financial support of this research.

While my name alone appears as the author of this document, it is the result of several years of collaborations with Terry Hunt, Carl Lipo, Alex Morrison, Tim Rieth, Tanya Brosnan, Sean Hixon, Matt Becker, Brian Lane, and Tim De Smet. I thank them for their guidance and contributions to this research. I would also like thank the following individuals who provided valuable conversations, assistance, advice, and criticisms on various aspects of my dissertation project: Melinda Allen, Steve Athens, Aletta Biersack, Chris Bone, Allison Carter, Lisa Clawson, Ethan Cochrane, Enrico Crema, John Dudgeon, Stephen Dueppen, Tom Dye, Leah Frazier, Catrine Jarman, Thegn Ladefoged, Gyoung-Ah Lee, Tom Leppard, Christian Moreno Pakarati, Matthew Napolitano, Jessica Stone, Larry Sugiyama, Robin Torrence, and Monica Tromp.

I would also like to thank my Rapanui friends, Gina Pakarati, Hetereki Huke, and Tiare Aguilera for their guidance, support, and teaching me about the island and its history. Without them the field components of this dissertation truly would not have been possible. I also thank Comunídad Indígena Polínésica Maʻu Henua, the Easter Island Development Commission, the Consejo de Monumentos, and the people of Rapa Nui for allowing us to work on their island.

Numerous family members have supported me and made me happy over the last six years. I especially want to acknowledge my parents, Mark and Joan DiNapoli, and my grandparents, Daisy and Frank DiNapoli, who deserve special recognition. They have always supported and encouraged me in pursuing archaeological research. I also thank Chris and Katie Hall for supporting me in multiple ways. Most of all, I would like the thank my wife, Kelly, for always supporting me, making me happy, and keeping me sane.

For Kelly, Mark, and Joan

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CHAPTER I

INTRODUCTION

1.1. Approaching Monumental Architecture in Human History

Monumental architecture was an important and widespread component in the emergence and dynamics of many past human societies. These features are highly variable, occurring as mounded earthworks, pyramids, statues, stone circles, cathedrals, and several other forms, and were built in many times and places around the world over the last ca. 10,000 years (e.g., Banning, 2011; Finlayson et al., 2011; Notroff et al., 2014). What all these monumental structures have in common is that their "scale and elaboration exceed the requirements of any practical functions that a building is intended to perform" (Trigger 1990:119). Because building these structures necessarily required the collective action of large numbers of individuals, their appearance, elaboration, and cessation at different times and places around the world are useful as archaeological evidence for changes in past social organization and complexity.

The construction of monumental architecture is often argued as an important factor in the evolution and transformation of many past human societies, as these structures are thought to have played a direct role in the emergence and persistence of complex social phenomena, such as religious authority, political power, community cooperation, intergroup competition, and other social processes (e.g., Abrams, 1989; Buccellati et al., 2019; DeMarrais et al., 1996; Dungan and Peeples, 2018; Dunnell and Greenlee, 1999; Fogelin, 2003; Johansen, 2004; Kirch, 1990a; Knapp, 2009; Kolb, 2020; Lawrence and Low, 1990; McCurdy and Abrams, 2019; Moore, 1996; Osborne, 2014;

Scarre, 2011; Trigger, 1990). Consequently, understanding the various socio-ecological factors underlying the spatial and temporal dynamics of monument construction remains one of the 'grand challenges' for modern anthropological archaeology (Howey et al., 2016; Kintigh et al., 2014a, 2014b). Meeting this challenge requires the use of general theoretical models that allow us to explain patterns of monument construction across time and space.

Theory is essential to archaeology, as it is to all sciences, because as a coherent collection of concepts theory influences the questions we ask, stipulates the appropriate models and units for addressing those questions, and guides the collection of data to build those units; in other words, theory is what allows us to explain the archaeological record (Dunnell, 1982, 1980, 1971; Hunt et al., 2001, p. 1; Willer and Willer, 1973). Monuments and monumentality have been a central focus of archaeological scholarship since the inception of the discipline, but, on the whole, there have been limited attempts to build general explanatory models for why human communities build monuments (e.g., Dunnell, 1999, 1989; Neiman, 1997). While these various kinds of structures have been studied from several useful explanatory frameworks, the explanations offered are often historically contingent and focused on particular forms of human social organization (e.g., social inequality in hierarchical societies). While these approaches are useful empirical generalizations about common aspects of monumentality, they typically offer multiple proximate accounts for monument construction in particular times and places rather than more ultimate explanations for these common forms of collective human behavior in the archaeological record (e.g., Levenson, 2019).

Human behavioral ecology (HBE) offers a complementary, but underutilized, source of acquiring knowledge about the ecological influences underlying monument construction (DiNapoli and Morrison, 2017). HBE is the study of human behavioral adaptation to environmental constraints (Smith and Winterhalder, 1992). The definition of ‘environment’ in HBE is broad and includes “everything external to an organism that impinges upon its probability of survival and reproduction” (Winterhalder and Smith, 1992, p. 8). The generality of how the environment is conceived in HBE is necessary because models often concern behavior in relation to both the physical environment (i.e., *parametric context*) and the social environment (i.e., *strategic context*) (Winterhalder and Smith, 1992, p. 8). The main assumption of HBE is that natural selection has shaped human behavior to have a high degree of phenotypic plasticity, allowing individuals to respond to environmental pressures in fitness enhancing or socially beneficial ways (Winterhalder and Smith, 1992). HBE attempts to explain a large variety of human behaviors thought to be shaped by selection, ranging from foraging and agriculture (e.g., Kaplan and Hill, 1992; Kennett and Winterhalder, 2006; Weitzel et al., 2020), mobility and habitat selection (e.g., Cashdan, 1992; Cochrane, 2018; Giovas and Fitzpatrick, 2014; Reeder-Myers, 2014; Tremayne and Winterhalder, 2017), to social interaction, cooperation, and communication (e.g., Bliege Bird and Smith, 2005; Codding et al., 2017; Dyson-Hudson and Smith, 1978; Gintis et al., 2001). As these behaviors undoubtedly involve high levels of complexity, one of the hallmarks and most recognizable aspects of HBE is the attempt to reduce this complexity to its essential components through the use of simple models (Winterhalder, 2002).

The two most commonly used general modeling approaches in HBE are optimality models of individual responses to the physical environment (i.e., parametric context) (Krebs and McCleery, 1984; Maynard Smith, 1978), and game-theory models concerning a strategic context that assess optimal decision-making given the frequency-dependence of other behavioral strategies (i.e., the *evolutionarily stable strategy*) (Maynard Smith, 1982). Here, I draw on the latter of these two approaches by employing the HBE model known as *costly signaling theory* (CST).

CST proposes that many supposedly ‘wasteful’ behaviors, such as energetically inefficient hunting or acquisition of exotic goods, can be adaptive in strategic social contexts as they transmit otherwise unobservable information about the signaler, like reproductive fitness, trustworthiness, or competitive ability, to a receiver (Gintis et al., 2001; Grafen, 1990; Johnstone, 1997; Plourde, 2008; Zahavi and Zahavi, 1999). This ‘wasteful’ behavior can benefit both signaler and receiver because it enables each to make quality assessments—and adjust their behavior—in lieu of more costly forms of interaction, such as direct competition and aggression. Numerous ethnographic studies demonstrate that costly signaling is pervasive in human social groups and highlight the power of CST to explain several enigmatic social behaviors, including conspicuous consumption, magnanimity, and religious ritual, under a coherent framework (Bliege Bird and Smith, 2005; Boone, 1998; Bulbulia and Sosis, 2011; Sosis, 2003; Sosis and Alcorta, 2003). Monuments potentially provide one of the clearest examples of costly signaling in the archaeological record (Atran and Henrich, 2010; Bliege Bird and Smith, 2005; Neiman, 1997; Norenzayan et al., 2016; Quinn, 2019). Indeed, the independent appearance of monuments in many places and times over the last ca. 10,000 years suggests a convergent process in their emergence (Trigger, 1990, p. 120). Despite these implications, there have been few applications of CST to monument construction (e.g., Glatz and Plourde, 2011; Joye and Verpooten, 2013; Neiman, 1997; Wright, 2017), which, considering its ubiquity in the past, represents a significant limitation to our understanding of past human communities. Here, I apply this framework in an attempt to explain the patterns of monument construction on the East Polynesian island of Rapa Nui (Easter Island, Chile, Figure 1.1).

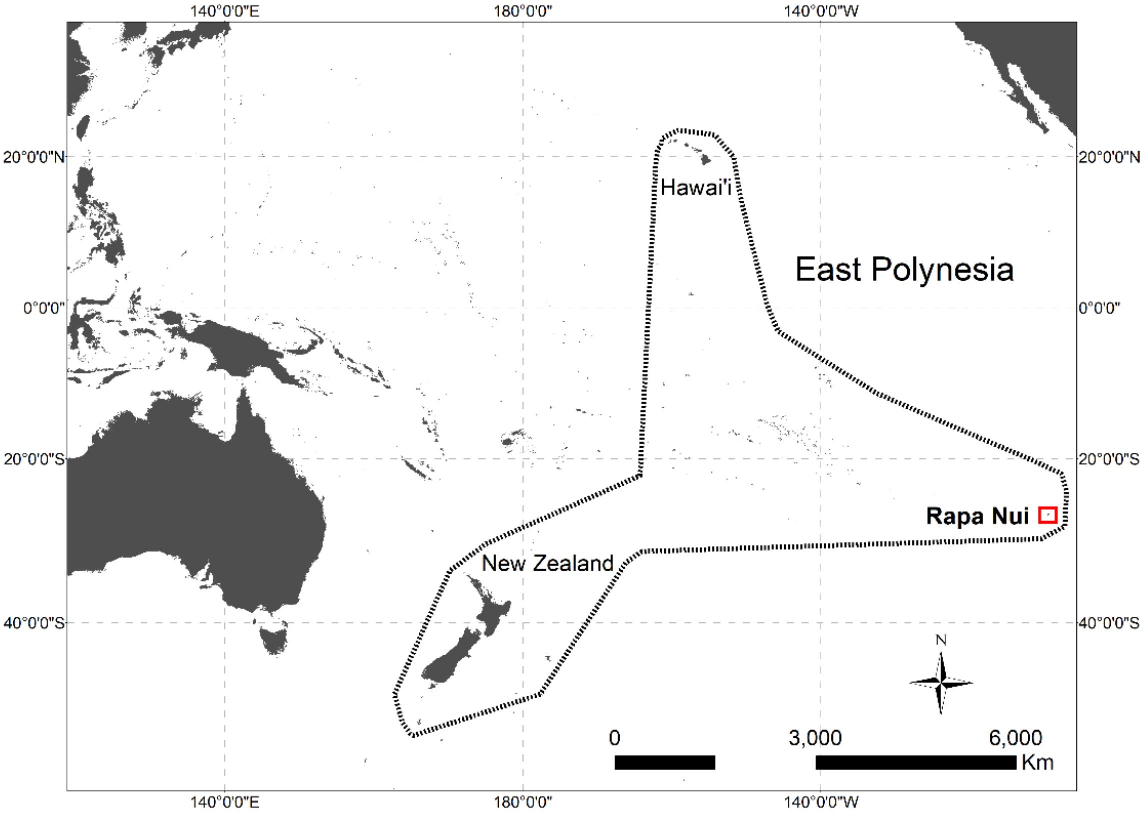

Figure 1.1: Map of East Polynesia.

1.2. Monumental Architecture in Polynesia

One of the most visible aspects of the archaeology of the Pacific Islands is the record of investment in construction projects involving large-scale expenditures of time, energy, and labor, but which often lack clear utilitarian functions (DiNapoli and Morrison, 2017, p. 6; Hunt and Lipo, 2001). These kinds of 'cultural elaboration' (sensus Graves and Ladefoged, 1995; Hunt and Lipo, 2001) often take the form of monumental stone or earthwork features, ranging from the *marae*/*ahu*/*heiau* ceremonial complexes of East Polynesia (e.g., Kahn and Kirch, 2011; Kolb et al., 1994; Wallin, 1993), Yapese *rai* (stone 'money') and Marianas *latte* of western Micronesia (e.g., Carson, 2012; Fitzpatrick, 2001), and smaller megalithic structures in Near Oceania (e.g., Riesenfeld, 1950).

Monumental architecture of one form or another is found on nearly every island and archipelago in Polynesia, the region bounded by the triangle formed by the Hawaiian Islands, Rapa Nui, and New Zealand[1] (Figure 1.1). Of the monuments found in the Pacific, those of East Polynesia are by far the least variable in form, though they vary greatly in elaboration. Based on ethnohistoric accounts, nearly all are ritual in function and tend to share a number of common attributes, including an open space or courtyard, a 'god house', uprights made of either wood or stone, and a raised platform called an *ahu* (Anderson and Green, 2001; Kirch and Green, 2001). In central East Polynesia these features share a high degree of similarity and are called some variation of the word *marae*. This similarity is indicative of homologous origins stemming from the relatively

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[1] The region of Polynesia also includes a number of 'Polynesian Outliers' in island Melanesia and eastern Micronesia (Kirch, 1984a).

recent and rapid settlement of the region as well as prolonged post-colonization interaction (e.g., Cochrane, 2015, 1998; O'Connor et al., 2017; Schmid et al., 2018; Sear et al., 2020; Walworth, 2014; Weisler and Walter, 2017; Wilmshurst et al., 2011).

The highest degree of variability in East Polynesian monuments occurs at the three corners of the Polynesian triangle. Monumental architecture in the Hawaiian Archipelago consists of derived forms of *marae* temples called *heiau*. Since the inception of the earliest archaeological and ethnographic research in the islands, it has been clear that *heiau* are both numerous and highly diverse in style, size, and function (e.g., Stokes, 1991). *Heiau* consist of stone platforms or walled enclosures of various shapes (e.g., rectangular, notched, terraced) and sizes, ranging from a few m^2 to the massive *Piʻilanihale* on Maui, measuring nearly 14,000 m^2 and over 13 m tall (Kirch, 1990a, 1990b; Kolb, 1999, 1992; Kolb et al., 1994; Mulrooney et al., 2005). Aotearoa (New Zealand) and Rapa Iti (Austral Islands) stand out in the East Polynesian archaeological record in that few megalithic ceremonial features occur, though they are known for their massive fortifications (e.g., Best, 1927; Kennett and McClure, 2012). While versions of stone *ahu*, *marae*, and uprights do occur there, these are generally quite small and rare (e.g., Anderson, 2014, 2012a; Anderson et al., 2012a; Mulloy, 1965). Given its small size, Rapa Nui presents perhaps the greatest example of intensified monument construction in the Pacific, whose people constructed hundreds of ritual structures, derivative of *marae* in form where the platform and uprights have been greatly elaborated into the island's iconic *ahu* and *moai* complexes (Lipo et al., 2013; Martinsson-Wallin, 1994; Van Tilburg, 1994). Given that each of these locations, were settled around the same time from similar source populations, this divergence in the degree of monument construction presents a unique opportunity to investigate the origins of intensified monument construction.

1.3. Rapa Nui (Easter Island)

Rapa Nui, one of the most remote and isolated patches of land on Earth, represents a key location where these processes of monument construction occurred (Figure 1.2). Colonized by Polynesian seafarers ca. 800 years ago across thousands of kilometers of open-ocean (Hunt and Lipo, 2006; Sear et al., 2020; Wilmshurst et al., 2011), Rapa Nui remains one of the most interesting, unique, and surprising cases of intensified monument construction in world history. At the time of European arrival in 1722, the island's communities had constructed hundreds of megalithic platforms, called *ahu*, and carved nearly 1000 anthropomorphic stone statues, called *moai* (Hunt and Lipo, 2018; Martinsson-Wallin, 1994; Martinsson-Wallin et al., 2013a; Van Tilburg, 1994; Paul Wallin et al., 2010). Given the island's small size, isolation, and marginal environment, explaining this level of investment in monumental architecture is a significant unanswered question in world archaeology. While there has been much research on Rapa Nui's *ahu* and *moai*, the evolutionary and ecological influences behind the construction of the island's monuments have not been resolved. Though it is a small island that research suggests was completely isolated prior to European contact in AD 1722, a better understanding of Rapa Nui's monumentality will have widespread implications for studies of monument construction elsewhere, as oceanic islands are important model systems for understanding human ecodynamics in variable environments (Allen, 2010; DiNapoli and Leppard, 2018; Kirch, 2007a, 2007b; Vitousek, 2002). Rapa Nui thus offers an ideal opportunity to better understand monumentality using a CST framework.

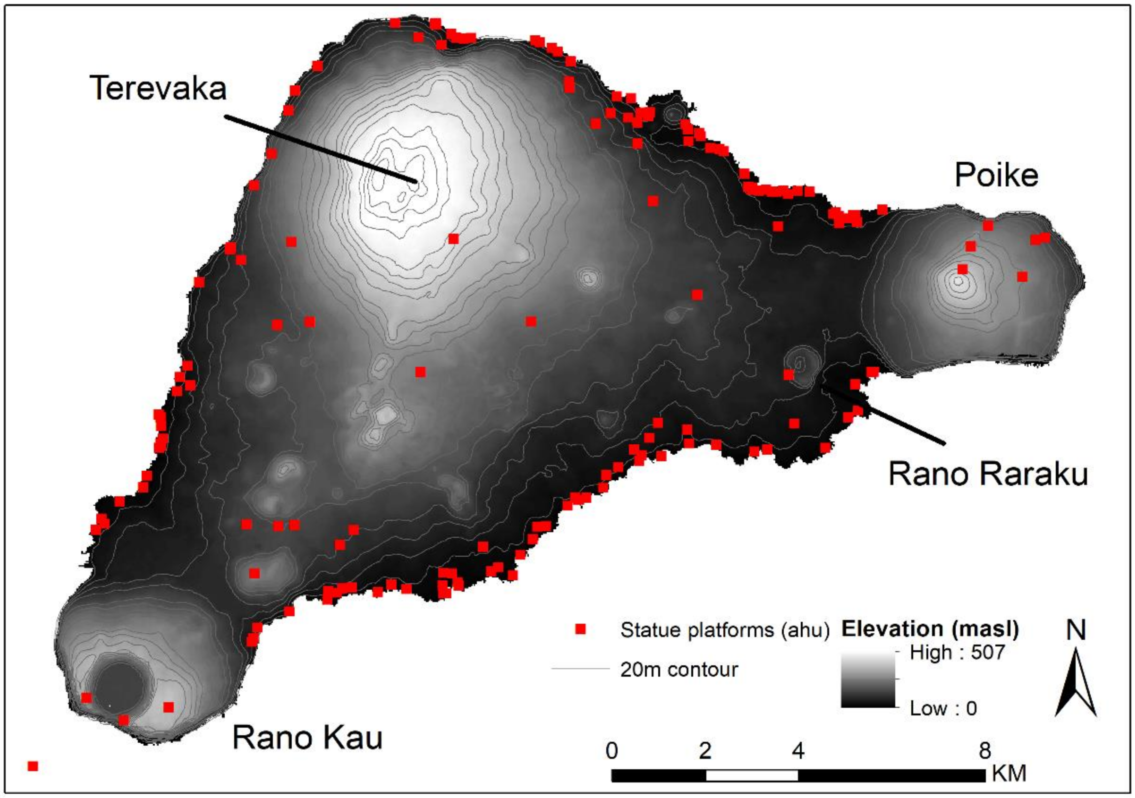

Figure 1.2: Rapa Nui (Easter Island).

Rapa Nui is a small (164 km^2), isolated volcanic island in the eastern Pacific Ocean, situated 3,700 km from South America and nearly 2,000 km from the nearest inhabited island (Pitcairn Island). Current estimates, based on statistical modeling of the most reliable radiocarbon dates, indicate that the island was first colonized by humans as part of the rapid population dispersal into East Polynesia around the 13th century AD (e.g., Fehren-Schmitz et al., 2017; Hunt and Lipo, 2006; Lipo and Hunt, 2016; Schmid et al., 2018; Wilmshurst et al., 2011; cf. Martinsson-Wallin and Crockford, 2002).

Following Polynesian colonization, the islanders (Rapanui) began constructing *ahu* and carving and transporting *moai* (e.g., Lipo et al., 2013; Martinsson-Wallin, 1994; Martinsson-Wallin et al., 2013a; Stevenson, 1986; Van Tilburg, 1994).

Prior to human arrival, the island was home to an extensive palm forest, which disappeared over the ensuing centuries with the impact of the invasive commensal Pacific rat (*Rattus exulans*) and human land-clearing for agriculture (e.g., Flenley et al., 1991; Flenley and King, 1984; Horrocks et al., 2017; Hunt, 2007; Hunt and Lipo, 2009, 2007; Mann et al., 2008; Mieth and Bork, 2010; Orliac and Orliac, 2008; Rolett and Diamond, 2004; Rull, 2020a). The island's soils and marine resources are considered quite marginal compared to elsewhere in Polynesia (e.g., Friedlander et al., 2013; Ladefoged et al., 2010; Louwagie et al., 2006; Vitousek et al., 2014). Cultivation focused on growing sweet potato and other introduced cultigens in rain-fed lithic mulched fields and small walled gardens (e.g., Bork et al., 2004; Ladefoged et al., 2013; Stevenson et al., 2006, 1999; Wozniak, 2018, 1999), and marine resources were also an important dietary component (Jarman et al., 2017; cf. Commendador et al., 2019, 2013; Polet and Bocherens, 2016). Given the limited surface freshwater and often unpredictable rainfall, freshwater was a limited critical resource (Brosnan et al., 2018; Hixon et al., 2019; Hunt and Lipo, 2018; Rull, 2020b). These ecological constraints are thought to have led to intense resource competition, though the particular form of this competition, such as violent warfare or non-violent costly signaling, are still debated and remain unresolved (e.g., Bahn and Flenley, 2017; DiNapoli and Morrison, 2017; Hunt and Lipo, 2018, 2011; Kirch, 2017; Morrison, 2012; Rainbird, 2002).

Rapa Nui's megalithic monuments were the focus of religious and ritual activity and formed the focal points for the precontact settlement pattern, characterized by a series of dispersed communities along the island's coastline (e.g., Hunt and Lipo, 2018; Martinsson-Wallin, 1994; McCoy, 1976; Morrison, 2012; Stevenson, 2002; Stevenson and Haoa, 2008; Van Tilburg, 1994; Vargas et al., 2006), often interpreted as reflecting familial clans or simpler 'open chiefdoms' (e.g., Goldman, 1970; Kirch, 1984b; Stevenson, 1986). At the time of European contact in AD 1722, the island's human population was estimated to be only a few thousand in number, which prompted both early European visitors and later scholars to assume that a much greater population must have existed in the past that subsequently collapsed due to warfare induced by ecological degradation and resource stress (Bahn and Flenley, 1992; Diamond, 2005, 1995; Flenley and Bahn, 2003; cf. Hunt and Lipo, 2011; Mulrooney et al., 2010). Following contact and continuing into the historic era, the focus of ritual activity is thought to have transitioned to *ahu* lacking *moai* (e.g., semipyramidal, *ahu po'e po'e*) and the famous *Tangata Manu* ('bird man') ceremonies held at the site of 'Orongo on Rano Kau (e.g., Ferdon, 1961; Martinsson-Wallin, 1994; Robinson and Stevenson, 2017).

The particulars of Rapa Nui culture history and the role of monument construction in societal change have been the focus of much speculation and debate. For much of the 20th century, the orthodox model for Rapa Nui was that it was the site of major cultural and demographic collapse prior to European contact (e.g., Bahn and Flenley, 1992; Diamond, 2005, 1995; Flenley and Bahn, 2003; Kirch, 2000, 1984b; Mulloy, 1974). According to this perspective, the period following initial Polynesian settlement was a time of unrestricted population growth, expanding cultivation, resource extraction, and monument construction variably termed the ‘Ahu Moai’ phase (Figure 1.3). During the Ahu Moai period, chiefs and priests demanded the construction of increasingly more and larger monuments, requiring more crops to be grown and more tress to be cut down, eventually resulting in an ecological catastrophe. This is said to have marked a major turning point variably asserted to have begun sometime between AD 1500 to 1680, and a critical component of this culture historical scheme is the assertion that monument destruction and warfare followed largely as a consequence the assumed ecological crisis. Common accounts hold that, prior to European contact in 1722, the island’s clan groups ceased making platform *ahu* and *moai*, battled with obsidian spears, sought refuge in fortified caves, and destroyed each other’s statue platforms in a prolonged period of internecine warfare termed the “Huri Moai” phase (Kirch, 2017, 1984b; Smith, 1961a). Within this Huri Moai/collapse narrative, the intensified construction of monumental architecture is seen as the linchpin in the downfall of Rapa Nui society (Rainbird, 2002).

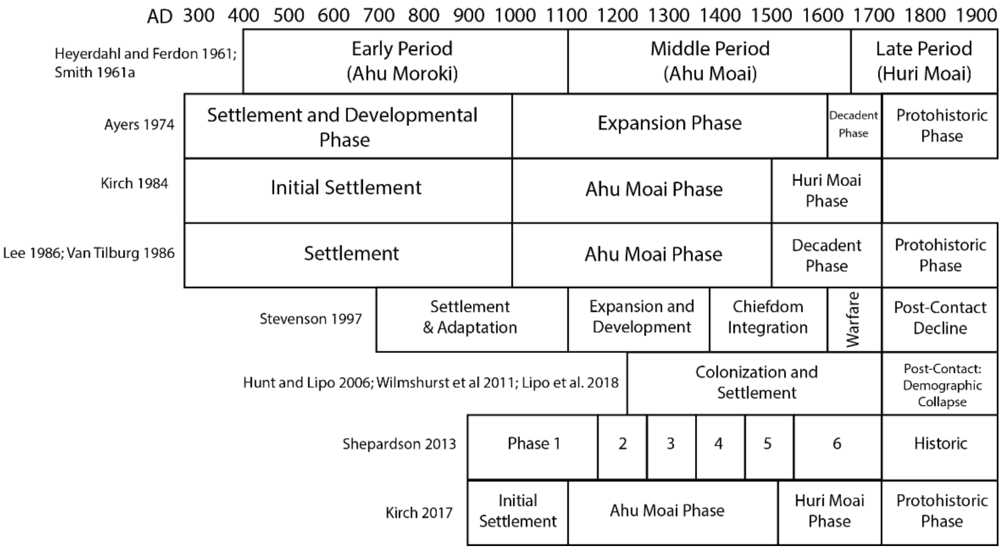

Figure 1.3: Phase schemes that have been proposed for Rapa Nui culture history. Figure adapted from Lee (1986) and Shepardson (2013, p. 211).

New perspectives, however, now see Rapa Nui as an exemplar of resilience in a marginal environment (e.g., Boersema, 2015; Hunt and Lipo, 2018, 2011; Mulrooney et al., 2010; Rainbird, 2002; Simpson and Dussubieux, 2018a; Stevenson et al., 2015). These new perspectives draw from a broad range of empirical archaeological, paleoenvironmental, and historical data. Important revisions to the collapse narrative include: demonstration of a lack of evidence for changes in land-use patterns that should characterize a demographic collapse (e.g., Mulrooney, 2013a; Stevenson et al., 2015), reassessments of the timing, causes, and consequences of deforestation (e.g., Hunt, 2007, 2006; Hunt and Lipo, 2009; Hunter-Anderson, 1998; Orliac and Orliac, 2008; Rull, 2020a; Rull et al., 2010); demonstration that trees were likely not needed or used to transport monuments (e.g., Hixon et al., 2018; Hunt and Lipo, 2011; Lipo et al., 2013); demonstration that agricultural practices improved the island's productivity (e.g., Hunt and Lipo, 2013; Ladefoged et al., 2010; Rainbird, 2002; Wozniak, 2018); lack of evidence for a high degree of settlement/social hierarchy or elite control of resources (e.g., Lipo et al., 2010; Lipo and Hunt, 2005; Morrison, 2012; Simpson et al., 2018a; Simpson and Dussubieux, 2018a); reassessments of the evidence for weapons and lethal skeletal trauma (e.g., Gill and Stefan, 2016; Lipo et al., 2016; Owsley et al., 2016), and critical reexaminations of ethnographic and ethnohistoric accounts (e.g., Boersema, 2018, 2015; Lipo and Hunt, 2009; Mulrooney et al., 2009; Peiser, 2005; Pollard et al., 2010; Rainbird, 2002).

While there is still debate surrounding Rapa Nui's population size and community structure (e.g., Kirch, 2017; Lipo et al., 2019, 2018; Puleston et al., 2018, 2017), this new empirical evidence suggests that Rapa Nui society was divided into several relatively small-scale, autonomous communities that primarily interacted at a local-scale, and with little lethal violence. Recently, hypotheses have been put forth that explain this combination of a localized settlement pattern, high degree of investment in monuments, and limited evidence for violent competition as the result of a costly-signaling strategy (e.g., DiNapoli and Morrison, 2017; Hunt and Lipo, 2018, 2011; Morrison, 2012). This hypothesis proposes that, in addition to their well-known ritual/religious roles, monument construction and transport functioned within Rapa Nui society as conspicuous displays of communities' cooperative and competitive ability to control and defend their limited critical resources, which, while being one manifestation of competition, resulted in reduced lethal violence and a limited interaction between communities. This model could not be more different than the orthodox scenario for Rapa Nui—rather than being the cause of the downfall of society, monument construction was instead a key factor in the long-term persistence, stability, and resilience of Rapa Nui communities (Hunt and Lipo, 2018, 2011). This hypothesis, however, remains to be rigorously tested, and uncertainty remains regarding the empirical validity of the 'Huri Moai' phase in Rapa Nui culture history. In this dissertation, I test the costly signaling hypothesis and critically evaluate the core components of the 'Huri Moai' narrative by examining the factors influencing the construction of monumental architecture. Through a series of quantitative analyses, I endeavor to demonstrate that Rapa Nui provides a kind of model system for understanding the evolutionary ecology of monumentality more broadly.

1.4. Organization of Chapters

In Chapter 2, I present a comparative framework for studying monumental architecture in the Pacific Islands that draws on the insights offered by human behavioral ecology. This discussion focuses on the contrasting culture histories of two marginal East Polynesian islands— Rapa Nui and Rapa Iti. The environments of these islands are quite distinct, and because they were each settled around the same time from similar source populations in central East Polynesia, examining the details of their archaeological sequences provides a unique opportunity to explore the influence of the environment on divergent cultural evolution. I argue that CST potentially explains several unique aspects of Rapa Nui culture history, in particular its record of intensified monument construction and seeming lack of evidence for lethal conflict. The chapter ends with a discussion of additional quantitative modeling needed to empirically evaluate this hypothesis, such as spatially explicit analyses of the relationship between investment in monument construction and contested subsistence resources on the island. This chapter was previously published with A.E. Morrison, C.P. Lipo, T.L. Hunt, and B.G. Lane (DiNapoli et al., 2018).

Chapter 3 tests the CST model prediction that the locations of monument construction are spatially correlated with some contested resource. This is approached using spatially explicit statistical models, in particular point process modeling (Baddeley et al., 2015), and multi-model selection (Burnham et al., 2011; Burnham and Anderson, 2010, 2004) that explore whether the spatial distribution of *ahu* construction locations is explained by the distribution of three critical subsistence resources on Rapa Nui: agricultural land, marine resource locations, and/or fresh water. The results of this statistical modeling indicate that the distribution of *ahu* is best explained by proximity to freshwater sources. The interpretation of this result is that if Rapa Nui's *ahu* did in part serve a signaling function, then the island's limited, but critically important freshwater sources were likely the focus of this signaling competition. Methodologically, the statistical modeling presented in Chapter 3 highlights the strengths of multi-model selection over the more common archaeological approach of null hypothesis significance testing. This chapter was previously published with C.P. Lipo, T. Brosnan, T.L. Hunt, S. Hixon, A.E. Morrison, and M. Becker (DiNapoli et al., 2019).

Chapter 4 presents a revised chronology for *ahu* construction. For this I built a series of Bayesian chronological models for the timing of *ahu* construction events on Rapa Nui, including estimates for both the initial construction dates and tempo of later construction events throughout the island's culture history. As discussed in the chapter, building these Bayesian models requires an accurate estimate for the timing of the island's initial Polynesia colonization, which is used as a prior to constrain the posterior estimates for *ahu* construction. The results of this Bayesian colonization model support previous chronologies of a ca. 12th - 13th century colonization event (Hunt and Lipo, 2008, 2006; Lipo and Hunt, 2016; Schmid et al., 2018; Wilmshurst et al., 2011). The results of this revised chronology have important implications for the overall culture history of the island. In particular, the results suggest that a pre-European contact 'collapse' of statue platform construction did not occur, but that *ahu* construction began very quickly after initial colonization, increased rapidly, and was likely continuous up to and beyond the point of European arrival. These results suggest that Rapa Nui's widely accepted culture historical sequence, in particular the validity of the 'Huri Moai' phase, are in need of reevaluation. The implications of these results for the CST model are discussed in more detail in Chapter 6. This chapter was previously published with T.M. Rieth, C.P. Lipo, and T.L. Hunt (DiNapoli et al., 2020).

Chapter 5 critically evaluates the archaeological and historical evidence for warfare on Rapa Nui. One of the central components of the CST model for Rapa Nui is the hypothesis that competitive signaling through monument construction was beneficial in that it led to limited violent conflict between the island's communities. However, many scholars continue to argue for the occurrence of the 'Huri Moai' phase in late pre-contact Rapa Nui, a period defined by internecine warfare and destruction of *ahu* and *moai*, whose construction subsequently ceased. In Chapter 5, I systematically review and critically evaluate the culture historical framework long proposed for the island, specifically focusing on the archaeological and historical evidence for warfare and monument destruction. I argue that there is currently no unambiguous archaeological or historical basis for these claims about warfare or a pre-contact cessation of statue platform construction.

Chapter 6 presents a model and formal test of the CST hypothesis for Rapa Nui monument construction. This model predicts the construction location and magnitude of investment in monuments be spatially associated with contested subsistence resources and landscape visibility. Given that CST requires there be a dynamic system of signalers and receivers communicating contemporaneously, one prediction of the CST model is that *ahu* construction occurred simultaneously at different locations around the island and was relatively continuous over time. These predictions are assessed using a series of quantitative analyses of the spatial-temporal patterns of investment in monumental architecture relative to resource constraints and visibility. The results offer support for many of the core predictions of the model, suggesting that CST helps explain the factors that influenced the construction and investment in monumental architecture across Rapa Nui culture history.

Chapter 7 concludes with a brief synthesis of the findings of this dissertation. The results call for a re-evaluation of the still widely accepted cultural chronology of Rapa Nui, in particular the notion of a late pre-contact Huri Moai phase. I then end with a discussion of areas for future research.

CHAPTER II

EAST POLYNESIAN ISLANDS AS MODELS OF CULTURAL DIVERGENCE: THE CASE OF RAPA NUI AND RAPA ITI

This chapter was previously published as:

DiNapoli, R. J., Morrison, A. E., Lipo, C. P., Hunt, T. L., & Lane, B. G. (2018). East Polynesian Islands as Models of Cultural Divergence: The Case of Rapa Nui and Rapa Iti. *The Journal of Island and Coastal Archaeology*, *13*(2), 206–223.

2.1. Introduction

The diverse histories of the islands of Polynesia can be usefully compared using comparative evolutionary models that explore the causes and consequences of divergent evolution (Allen, 2010; Kirch, 2007a, 2007b, 1997, 1986). The human populations of the remote islands of East Polynesia (Figure 2.1) are descendants of a set of common ancestors from central East Polynesia about 800 years ago (Allen and Kahn, 2010; Wilmshurst et al., 2011). Thus, many of the cultural traits that spread throughout the remote parts of the Pacific share a common origin from within a parent population. Yet, East Polynesian islands vary widely in their size, geology, climate, marine resources, species richness and so on, providing dramatically different landscapes in which founding populations entered and evolved over time. As a consequence of these similarities and differences, the archaeological record documents human populations which, while initially sharing many traits in common, quickly diverge due to historical contingencies and the varying environmental constraints of individual islands. Together with shared traditions and local innovations, these factors are central components of explanations for the region's widely varying subsistence practices, settlement patterns, style and degree of investment in monumental architecture, and the form and intensity of competition.

Explaining these differences and the variation that emerges between islands requires tracing features that derive from common ancestry and modeling how the effects of marked environmental differences influenced the historically divergent paths of evolution in the cultural dimensions of their human populations.

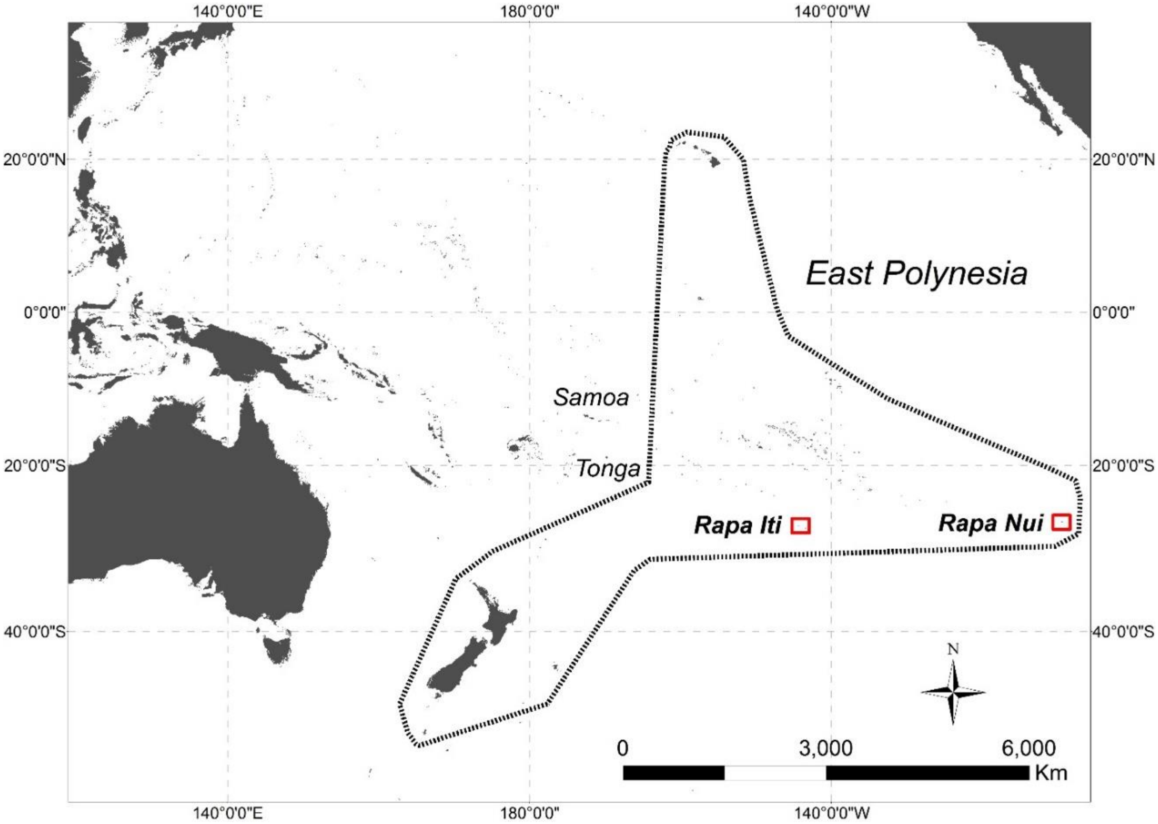

Figure 2.1: East Polynesia and Rapa Nui and Rapa Iti

Rapa Nui and Rapa Iti[2] (Figure 2.2) provide excellent case studies that can be analyzed under this framework. Comparing their histories and environments, we can explore the influence of the environment on shaping each island's independent cultural evolution. While both islands are relatively small and isolated, they differ markedly in the spatiotemporal structure of several key environmental parameters, such as usable land-

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[2] Although there is little ethnohistorical support for the name "Rapa Iti" (Anderson, 2012a), we use the name here rather than simply "Rapa" for ease of comparison.

area, freshwater availability, and agricultural productivity. Although derived from historically-related populations, the islands have distinct archaeological records where one, Rapa Nui, is dominated by the construction of large ritual monuments (*ahu*) and statuary (*moai*), while the other, Rapa Iti, is marked by fortresses and signs of intergroup conflict. The cultural features of these two islands could not be more distinct: while both involve group-level cooperation, Rapa Nui was dominated by populations who directed efforts to community-scale ritual architecture while Rapa Iti's communities directly engaged in violent conflict as evidenced by extensive fortifications.

In brief, Rapa Nui and Rapa Iti provide a case of two populations initially sharing a high degree of similarity who then diverge in several ways in different environments. Here, we describe the similarities and differences between their environments and archaeological histories and offer an evolutionary account for their divergence. Specifically, we compare how differences in usable land-area, freshwater availability, and agricultural productivity affected their settlement patterns, degree and form of investment in monumental architecture, and frequency of lethal conflict. We explicitly draw on two evolutionary ecology models: economic defendability and costly signaling. By examining the details of each island and comparing their divergent histories, we argue that the variation between Rapa Nui and Rapa Iti can best be explained as different forms of competition and cooperation among and between communities in varying local environments. We conclude with a discussion of future research avenues to further test these hypotheses, in particular through quantitative spatial analysis and simulation modeling.

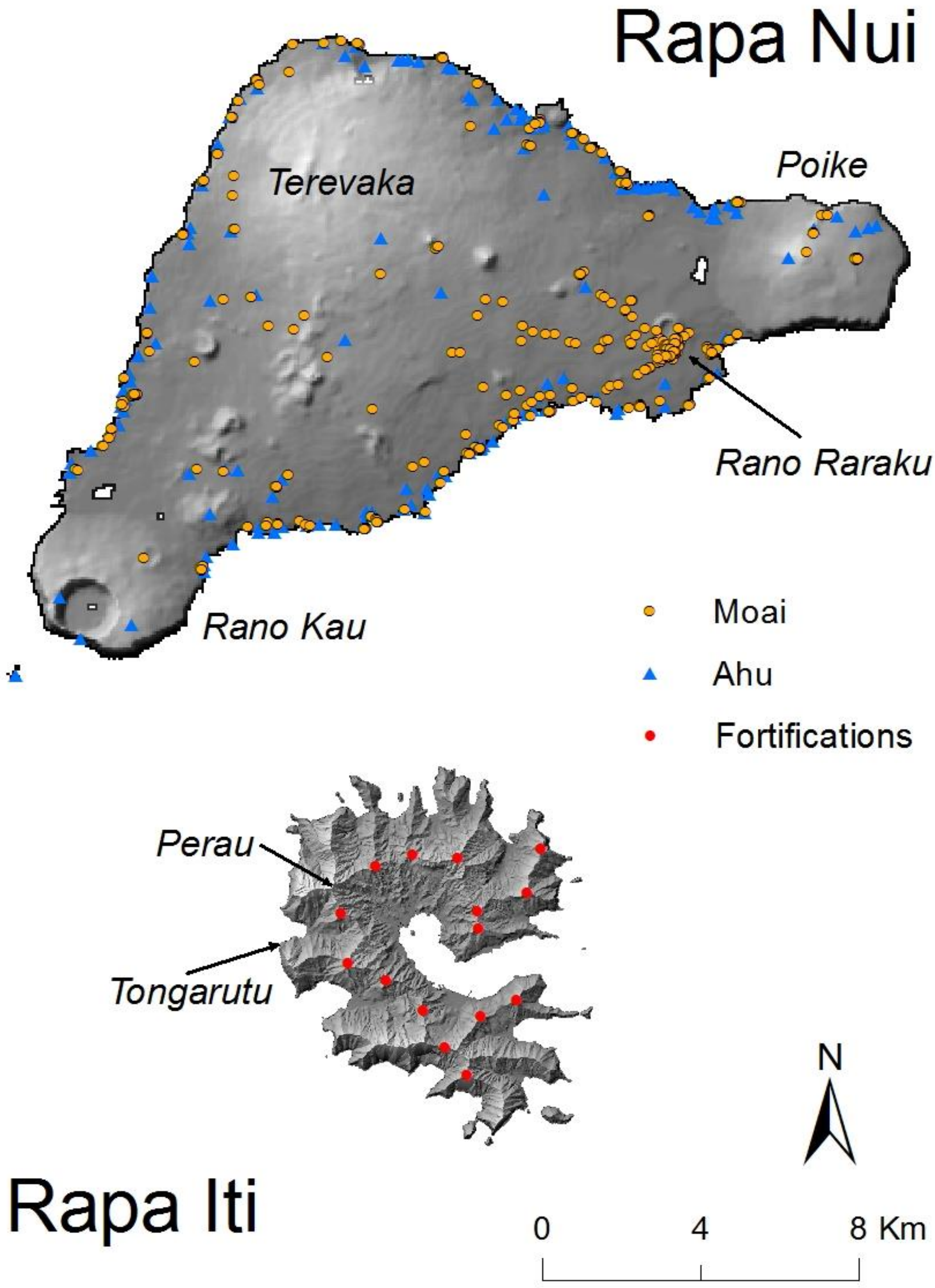

Figure 2.2: Rapa Nui and Rapa Iti

2.2. Island Environments

Rapa Nui, located in easternmost Polynesia and Rapa Iti, located in the southernmost end of the Austral islands, serve as a useful comparison given their similarities and differences. Geographically, both are small and isolated volcanic islands, with Rapa Iti more than 500 km from the nearest inhabitable island, Ra‘ivavae. Rapa Nui is located some 3,500 km from the coast of South America and over 2,000 km from Pitcairn Island to the west. Both islands lie at similar latitudes (~27°) just south of the tropics and are characterized by relatively cool and windy climates unsuitable to many tropical Polynesian cultigens. Anderson and colleagues (2012a, p. 245) argue that this southerly geographic position makes these islands distinct and produces a "‘subtropical depriment’, i.e., the depression in resource opportunity for human settlement that resulted from subtropical geography and climate." Biogeographically, the degree of marginality, small sizes, and relative isolation of these islands contributed to the presence of a restricted subset of domesticated plants and animals common in more tropical Polynesian islands and led to environments with relatively impoverished terrestrial and marine faunas (Anderson, 2001; Anderson et al., 2012a). Beyond these similarities, there are marked contrasts between Rapa Nui and Rapa Iti in several key environmental parameters, such as topography, freshwater availability, and agricultural productivity (Table 2.1).

Table 2.1: Environmental parameters

Ecological Parameter	**Rapa Iti**	**Rapa Nui**
Land area (km^2)	38	164
Geologic age (ma)	4.75	0.78 – 0.10
Max. elevation (masl)	650	500
Reef biotic diversity	Low	Low
Reef biomass	Moderate	Low
Annual rainfall (mm)	2500-3000	600-2000
Drought frequency	Low	Very high
Freshwater availability	Very high (ubiquitous)	Very low (spatially restricted)

2.2.1. Rapa Nui and Rapa Iti Environmental Characteristics

Rapa Nui is substantially larger than Rapa Iti, with a total land area of 164 km^2. The island was formed as a result of several volcanic events (0.78-0.11 Ma) that created the main topographic features on the island, Rano Kau, Poike, and Terevaka shield volcanoes, and several smaller calderas and cinder/scoria cones (Vezzoli and Acocella, 2009). Overall, the island is low in elevation, with Terevaka reaching just above 500 masl, and gently sloping. Compared to many other Polynesian islands, Rapa Nui lacks surface freshwater, with no permanent streams, frequent droughts, and seasonal rainfall varying unpredictably from highs of ca. 2,000 mm/y to lows of ca. 600 mm/y (Morrison, 2012; Stevenson et al., 2015). Freshwater is available in temporary rainwater basins, the island's crater lakes, inland wells, and coastal seeps. The primary sources of water used by prehistoric people appear to have been seeps, a source that can be brackish (Herrera and Custodio, 2008). In addition, freshwater availability could have further been reduced by a possible prolonged drought during the 16th to 18th centuries AD (Cañellas-Boltà et al., 2013). The island's soils are also heavily nutrient-depleted compared to elsewhere in Polynesia (Vitousek et al., 2014). Soil sampling across the island suggests that, while low in general, available nutrients decrease with elevation due to rainfall leeching and substrate age (Ladefoged et al., 2010). Significantly, the island's low soil-productivity was an inherent constraint for even the first colonists, and not the consequence of deforestation (Hunt and Lipo, 2011).

At just 38 km^2, Rapa Iti is considerably smaller than Rapa Nui. The island originated as a breached caldera (ca. 4.75 Ma) and topographically is composed of numerous valleys and peaks, the largest of which (Perau) rises 650 masl (Anderson et al., 2012b; Brousse and Gelugne, 1986). The island's steep terrain exacerbates its smallness by further limiting available land for cultivation and habitation. Unlike Rapa Nui, Rapa Iti has abundant freshwater, receiving upwards of ca. 3000 mm of rainfall per year which in turn yields favorable conditions for constant stream-flow (Prebble et al., 2013). This combination of peak-valley topography and high rainfall/streamflow brings nutrients into the valleys as sediment deposits, a process that occurs elsewhere in Polynesia (e.g., Palmer et al., 2009). With ample rainfall, this process makes the more limited landscape of Rapa Iti far more productive for cultivation than Rapa Nui.

In summary, Rapa Nui and Rapa Iti differ in several key environmental parameters, such as usable land-area, freshwater availability, and agricultural productivity. Rapa Nui's relatively flat, open terrain provided substantially more land-area available for cultivation and habitation. In contrast, the small size and steep, incised topography of Rapa Iti results in a limited subset of its mere 38 km^2 available for subsistence and domestic activity. What Rapa Iti lacks in usable land-area, however, is ameliorated by the potential productivity of its streamlined valleys, which provided ideal locations for irrigated taro agriculture (Bartruff et al., 2012; Kirch, 1984b; Lane, 2017).

While Rapa Nui potentially has more land-area available for cultivation, its soils are marginal in productivity and exceedingly well-drained. Due to the island’s climate, hydrology, and geology, natural resources are marginal, dispersed, relatively homogenous, and temporally unpredictable. In contrast, Rapa Iti is virtually the opposite – it is an environment where the crucial resources for survival, although limited, are high quality, spatially dense, and temporally predictable. As will be elaborated below, these differences provided radically different constraints for colonizing populations.

2.3. Archaeology of Rapa Nui and Rapa Iti

Human colonization of both islands occurred ca. 800 BP from similar parent populations in central Polynesia (Hunt and Lipo, 2006; Kennett et al., 2012; Wilmshurst et al., 2011). The founding populations likely shared a high degree of similarity in terms of biological (Kayser, 2010; Matisoo-Smith, 2015), cultural (Kirch and Green, 2001), linguistic (Walworth, 2014), technological (O’Connor et al., 2017), and architectural traditions (Cochrane, 2015; Martinsson-Wallin et al., 2013a). In terms of subsistence, while both groups arrived with edible and utilitarian cultivars such as taro, bananas, *ti* (*Cordyline fruticosa*), and gourd, due to the southerly latitudes of the islands, other common tropical Polynesian crops, such as coconut, breadfruit, and kava were not cultivated. In addition, the important staple crops of Rapa Nui, sweet potato and yam, were evidently not grown on Rapa Iti (Anderson et al., 2012a). In terms of domesticated animals, neither population successfully introduced the pig or dog, but rats (*Rattus exulans*) were abundant[3]. Rapa Nui differs from Rapa Iti with the presence of the

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[3] In addition to human land-clearing for agriculture, the introduction of rats contributed to the massive deforestation of both islands (Hunt, 2007; Prebble et al., 2013).

chicken, which was an important protein source (Commendador et al., 2013). In sum, the location of the two islands resulted in a lack of many of the features common to the tropical Polynesian ‘transported landscape,’ which forced prehistoric populations to depend on a restricted subset of plant and animal foods. While each island’s colonizing population shared a high degree of similarity, almost immediately after colonization the populations diverged in unique ways. The following sections outline specific ways in which Rapa Nui and Rapa Iti differed according to subsistence, settlement patterns, form of investment in monumental architecture, and frequency of lethal violence.

2.3.1. Rapa Nui Subsistence

Rapa Nui populations relied predominately on food resources gathered from small family-scale walled gardens (*manavai*) as well as labor intensive but marginally yielding lithic mulch cultivation (Bork et al., 2004; Ladefoged et al., 2013; Stevenson et al., 1999; Wozniak, 1999). Recent plant microfossil analyses suggest sweet potato and yam as the primary food crops (e.g., Horrocks and Wozniak, 2008; Tromp and Dudgeon, 2015), with other cultigens, such as dryland taro, supplementing the diet. In contrast to elsewhere in Polynesia, stable isotope analyses indicate a considerable reliance on terrestrial protein sources, such as rats and chickens, with less marine contribution to the Rapanui diet (e.g., Commendador et al., 2013; Polet and Bocherens, 2016). There is currently no archaeological evidence for food storage features. Soil studies (e.g., Ladefoged et al., 2010) and recent modeling (e.g., Louwagie et al., 2006; Morrison, 2012; Stevenson et al., 2015) indicate that Rapa Nui agricultural productivity was likely unpredictable, marginally yielding, and relatively homogeneous across the island (Hunt and Lipo, 2011).

2.3.2. Rapa Nui Monumental Architecture: Ritual Structures

On Rapa Nui, populations heavily invested in monumental architecture in the form of the island’s famous *ahu* and *moai* complexes (Lipo et al., 2013; Martinsson-Wallin, 1994). Erecting carved anthropomorphic statues atop stone altars is a derived form of ritual construction that is widespread in East Polynesia, including the Marquesas, Australs, and Pitcairn Island. On Rapa Nui, however, the practice was remarkably widespread and elaborated upon, with near 300 *ahu* constructed and almost 1000 *moai* statues erected, many of them donning colossal red scoria ‘hats’ (*pukao*). While there is considerable variability in the size and shape of these monuments and statues, many are massive, with some *ahu* being several meters tall and the largest *moai* ever transported from Rano Raraku quarry (> 5km) stood roughly 10 m tall and weighs over 70 tons (Lipo et al., 2013). While dating stone architecture with radiocarbon dating is problematic on Rapa Nui (Lipo and Hunt, 2016; Mulrooney, 2013a), it is likely that investments in monumentality began soon after the island’s settlement and appear to be widespread by ca. 500 BP (Martinsson-Wallin et al., 2013a). In addition, *ahu* constructions were not single events, as many exhibit signs of multiple construction episodes (Martinsson-Wallin, 1994). Clearly, this shows immense amounts of energy invested into the construction of ritual architecture. Significantly, as we outline below, these massive investments in monument construction were undertaken by relatively small-scale, dispersed communities.

2.3.3. Rapa Nui Settlement Pattern, Social Interaction, And Frequency of Lethal Conflict

Several lines of evidence suggest that the pre-contact population of Rapa Nui lived in small, dispersed communities who largely interacted at locally restricted scales. Reliable estimates of the island's population at contact range from ca. 3,000-5,000 (Hunt and Lipo, 2011), which, with a total land-area of 164 km^2, works out to roughly 20-30 individuals per km^2. Recent settlement pattern analyses by Morrison (2012) support these estimates and indicate a dispersed population organized around redundant sets of functionally differentiated domestic activity zones. Dispersed settlements appear to have been focused on communal religious structures, such as *ahu* and *moai* (McCoy, 1976; Morrison, 2012; Stevenson, 2002). There is also some evidence for specialized use of inland areas, however the chronology for inland use is poorly understood (Mulrooney, 2013a).

Several lines of evidence suggest that Rapa Nui intercommunity interaction occurred primarily at a local-scale. For example, stylistic analyses of the island's ubiquitous stemmed obsidian tools (*mata'a*) indicate that the cultural transmission of information about how to make these tools occurred primarily within, rather than across local communities (Lipo et al., 2010). These findings are also supported by biological evidence, such as stable isotope analyses (Commendador et al., 2013; Polet and Bocherens, 2016), the spatially restricted occurrence of several congenital skeletal anomalies (Gill et al., 1983; Gill and Owsley, 1993) and aDNA analyses indicating highly localized gene-flow (Dudgeon, 2008).

Rapa Nui communities did, however, interact at a larger-scale in some respects. For example, craniometric analyses suggest some intercommunity gene-flow (Stefan, 1999). In addition, the spatially restricted availability of a few key resources would have necessitated large-scale interaction. Obsidian artifacts, for example, are ubiquitous across Rapa Nui but obsidian sources only occur in four locations in the southwest corner of the island (Stevenson et al., 2013). Similarly, the raw material used for most *moai* carving (volcanic tuff) is restricted to Rano Raraku crater. Access to these resources meant that populations were required to interact and negotiate with other groups from around the island. This intercommunity interaction, while likely involving a high degree of competition (discussed below), appears to have been largely nonviolent (Hunt and Lipo, 2011). While previous accounts for Rapa Nui argue that the island experienced widespread warfare (e.g., Bahn and Flenley, 1992; Diamond, 2005, 1995; Flenley and Bahn, 2003; Kirch, 2000, 1984b), there are limited osteological instances of lethal injuries (Owsley et al., 2016, 1994), no evidence for the systematic production of lethal weapons (Lipo et al., 2016), and no evidence for fortified structures (Hunt and Lipo, 2011). In contrast, the archaeological evidence from Rapa Iti, while considerably less than Rapa Nui, reveals a very different situation (Table 2.2).

2.3.4. Rapa Iti Subsistence

Colonized ca. 800 BP (Kennett et al., 2012), the founding populations of Rapa Iti initially occupied several rockshelters along the island’s coast (Anderson, 2012b). The most intensively investigated of these, Tongarutu rockshelter, has yielded abundant archaeological and faunal remains, in particular rat (*R. exulans*), native birds, marine shell, and fish bones (Anderson, 2012b). The large amounts of marine fauna excavated from these rockshelters indicates a greater reliance on marine protein in the Rapan diet, likely a response to the absence of pigs, dogs, and chickens (Anderson et al., 2012b; Szabó et al., 2012). Although the number of cultivars introduced to Rapa Iti was quite limited, a heavy reliance on agriculture is evident early in the Rapan sequence. A series of wetland sediment cores and subsequent palynological analyses document a concomitant decline of the native palm forest and a sharp rise in charcoal particles and taro pollen shortly following human arrival (Kennett et al., 2006; Prebble et al., 2013; Prebble and Dowe, 2008), indicative of intensive land-clearing for agriculture.

The central component of Rapan subsistence was wetland taro (*Colocasia escualenta*), which was cultivated in the island's extensive irrigated terrace systems. These cultivation features are similar to those found elsewhere in Polynesia and consist of a series of terraced rectangular stonewalled pondfields with ditch irrigation (Bartruff et al., 2012; Prebble and Anderson, 2012). These features are expansive and cover much of the low-lying areas on the island, and recent geospatial modeling (Bartruff et al., 2012; Lane, 2017) suggests that while these pondfields would have provided a high and predictable crop yield, due to differences in cultivable land-area between different valleys, there was likely a high degree of variability in their productive capabilities.

2.3.5. Rapa Iti Monumental Architecture: Fortifications

Also emerging in concert with these vegetation changes and increased expansion of terraced agricultural systems was perhaps the defining feature of Rapa Iti's prehistory, its numerous hilltop fortifications (*pare*) (Kennett et al., 2012; Kirch, 1984b). Current archaeological evidence suggests that within one to two centuries of colonization populations began to construct two fortified hilltop settlements, and by European contact the number of fortifications had expanded to more than 15 (Kennett et al., 2012). These features are systematically located at high elevations along the island's ridgeline, a position that offers natural defensibility but also perhaps views of agricultural land. Rapan fortifications are characterized by modifications to the hilltop, including a central tower, terraces, ditches, embankments, stone walls, and likely a wooden superstructure (Kennett and McClure, 2012, p. 204). In addition, Vancouver's observations in 1791 indicate these features were palisaded (Anderson, 2012a, p. 29). The fortifications range in size from ca. 3,000 m^2 to over 25,000 m^2 (Kennett and McClure, 2012, p. 204), and while they are indeed monumental in size it is unclear to what degree they served in a ritual capacity in addition to their defensive function (cf. Walczak, 2003). Limited evidence for at least a partial ritual function occurs at the largest fortification, Morongo Uta, in the form of a few small upright stones characteristic of Polynesian ritual sites (Anderson et al., 2012a, p. 253; Mulloy, 1965). Interestingly, aside from this there is currently little evidence that Rapans ever constructed ritual architecture (e.g., *marae, ahu*) so common elsewhere in East Polynesia (Anderson, 2012a, p. 44). Instead, available evidence overwhelmingly suggests these hilltop features functioned as fortified settlements.

2.3.6. Rapa Iti Settlement Pattern, Social Interaction, And Frequency of Lethal Conflict

European accounts and excavations within Rapan fortifications suggest that they were permanent habitations. European visitors such as Vancouver and others observed that the fortifications were inhabited (Anderson, 2012a). Targeted excavations within several of the fortifications have yielded clear evidence of long-term domestic activity in the form of earth ovens, abundant charcoal, storage pits, marine shell, fish and rat bone, adzes, and taro pounders (Kennett and McClure, 2012). Archaeological evidence for weapons from fortifications is limited to surface collections of possible sling stones (Mulloy, 1965). Early European observations (Anderson, 2012a, p. 28) and ethnographic fieldwork by Stokes (n.d.; cited in Anderson, 2012a, p. 43; and Mulloy, 1965, p. 58), however, indicate the presence of wooden spears and clubs, slings, darts, a fighting axe/adze, and possibly a garrote. There is very little prehistoric osteological data available from Rapa Iti (but see Smith, 1965), so the frequency of lethal skeletal trauma remains unknown.

In contrast to Rapa Nui, the available data from Rapa Iti indicates that populations lived within dense and nucleated settlements. While rockshelters were clearly used as dwellings early in Rapan prehistory (Anderson, 2012b), later settlements appear to have been mostly restricted to fortifications and smaller adjacent hilltops (Anderson et al., 2012a; Kennett and McClure, 2012). Though there is currently limited data on the degree to which these communities interacted, their heavily fortified nature suggests significant territoriality, and likely violent, intercommunity conflict (Anderson et al., 2012a; Kennett et al., 2006; Kirch, 1984b). Competition over the island’s agricultural resources is implied, especially when population density is taken into account. Recent demographic modeling suggests a contact-era population of ca. 2000-3000 (Bartruff et al., 2012), yielding an estimated population density of ca. 50-80 individuals per km^2. When we consider that much of Rapa Iti's land-area is either of limited use (due to steep topography) or under cultivation, this estimated density becomes even greater.

Table 2.2: Archaeological characteristics

Characteristic	**Rapa Iti**	**Rapa Nui**
Estimated contact population	2000-3000	3000-5000
Population density / km^2	~50-80+	~20-30
Settlement pattern	Nucleated	Dispersed
Monumental ritual architecture	Few if any	200+, ~1000 statues
Fortifications	15+	None
Skeletal evidence of lethal trauma	Unknown	Limited
Weapons	Likely	Limited

While this comparison of the two islands is brief, there are clear differences between the historical outcomes of the founding populations. Although the two islands were settled by populations with a common ancestor at roughly the same time, they soon diverged in terms of settlement patterns, investment in ritual architecture, and intergroup aggression. The question remains as to *why* each of these populations underwent such divergent historical paths. For example, why did the Rapanui invest so significantly in large ritual monuments whereas Rapans devoted their construction efforts to defensive fortifications? One potential explanation for these differences may be in the structure of the resources available to the human populations on each island. To evaluate the potential explanatory relevance of these ecological differences, we draw on two well-known evolutionary ecology models: economic defendability and costly signaling.

2.4. Discussion: Models for Explaining Competition and Cooperation

As we have noted, the histories of both Rapa Nui and Rapa Iti are characterized by vast investments of time and energy into community-level construction activities. A key difference between them, however, concerns the role that these construction activities play in the form and scale of competition and cooperation. On Rapa Nui, intracommunity cooperation and intercommunity competition was negotiated through the construction and maintenance of monumental ritual architecture. While intra- and intercommunity interaction on Rapa Iti also involved large construction projects, the focus was largely not ritualistic in nature but instead for the prevention of lethal interactions through the maintenance of fortified settlements. Considered from an evolutionary ecological framework, these seemingly disparate community dynamics can in part be explained as the result of different forms of competition and cooperation among local populations in different kinds of environments. Here, we explore two models of particular relevance to this issue: the economic defendability model (EDM) and costly signaling (CS).

2.4.1. Economic Defendability on Rapa Nui and Rapa Iti

The EDM specifies how different ecological conditions are expected to influence the way in which individuals compete for and defend contested resources (Dyson-Hudson and Smith, 1978). A resource's *economic defendability* depends on the relationship between the benefit an individual receives from resource access and the cost of its defense (Brown, 1964). The form and intensity of competition are influenced by two key parameters in the spatiotemporal structure of resources: density and predictability (Dyson-Hudson and Smith, 1978). Density defines both a resource's quality (e.g., caloric returns) and its available quantity per unit area, such as degree of clustering or dispersion. Predictability is more nuanced, but in general defines a resource with a detectable pattern or constancy over time (Cashdan, 1992). The EDM predicts a number of resource utilization strategies for different combinations of these density and predictability parameters (See Table 2.3; Davies and Houston, 1984; Dyson-Hudson and Smith, 1978). For example, when resources are dense and predictable the model predicts high degrees of intergroup competition and a territorial settlement pattern, whereas when resources are unpredictable and scarce, we predict settlement systems to be dispersed with little violent competition. The empirical predictions of the EDM for archaeological studies suggest the following: (1) Environments with spatially restricted, dense, and predictable resources are likely to be highly defendable, and evidence for defense in the form of fortifications and other forms of warfare such as weaponry and lethal trauma is likely to be present. (2) Fortified settlements should be spatially associated with dense and predictable patches of subsistence resources and the concomitant settlement pattern should reflect a nucleated form of social organization.

Table 2.3: Predictions of the EDM under different resource parameters. Adapted from Dyson-Hudson and Smith (1978)

Resource structure	**Economic defendability**	**Predicted resource utilization**
Unpredictable and dense	Low	*Information sharing*
Unpredictable and scarce	Low	*Dispersion*
Predictable and dense	High	*Territoriality*
Predictable and scarce	Fairly low	*Home ranges*

Applying the logic of the EDM to our two case studies potentially sheds light on why the islands see such divergent forms of competition and territoriality over time. When considered in terms of density and predictability, the environments of Rapa Nui and Rapa Iti fall at opposite ends of the economic defendability spectrum. For example, the environment of Rapa Iti provided populations limited, but high-quality irrigated agriculture, a resource structure reflecting the island’s limited cultivable land-area, high rainfall, and reliable streamflow. Given that the relationship between population density and the density of available resources is of particular importance to economic defendability and ensuing conflict, such an outcome is not surprising (Boone, 1992; Field, 2008; Mattison et al., 2016). Rapa Iti, in fact, can be conceived as a prime example of this relationship, as its population density and the economic defendability of its resource base were high, and in turn the settlement pattern was nucleated and strongly territorial. Competition between communities and cooperation within them took the form territorial defense through the construction of fortifications. In addition, although there are currently limited osteological data from Rapa Iti, the logic of the EDM leads us to predict a high frequency of lethal skeletal trauma, which could be tested in future research.

Though this connection between the EDM and Rapa Iti's prehistory has been discussed (e.g., Bartruff et al., 2012; Kennett et al., 2006), its reciprocal connection to Rapa Nui is also of significant explanatory relevance (DiNapoli and Morrison, 2017). The resources necessary for subsistence were distributed in a low-density fashion across the landscape, and the pattern of agricultural activities and community structure on Rapa Nui were also dispersed (McCoy, 1976; Morrison, 2012). This result is explicable as the consequence of populations that are strongly constrained by the island's homogeneously poor soils and unpredictable low rainfall. Thus, Rapa Nui is characterized by populations living in dispersed communities with unpredictable and relatively low-quality resource potential, a situation that results in low economic defendability. With a lack of defendability, there is no strong payoff from territoriality or direct community conflict. Therefore, the construction of fortifications would be ineffective in resolving competition over resources because the location of these resources would not be dense nor predictable over time or space. In this way, the EDM helps to illuminate the lack of evidence for violent intercommunity aggression on Rapa Nui, such as developed weapons, fortifications, or much lethal skeletal trauma. Territorial defense and violent intergroup conflict, however, are but one of several resolutions to competitive contexts.

2.4.2. Costly Signaling on Rapa Nui and Rapa Iti

In both human and animal competition, contests often occur in the form of non-violent displays or ritualized fighting through the use of costly signals (Bliege Bird and

Smith, 2005; Maynard Smith and Harper, 2003; Zahavi and Zahavi, 1999). A costly signal is a behavior or feature of an individual that functions to communicate an unobservable quality about the sender to a receiver (Maynard Smith and Harper, 2003). These signals provide benefits to both parties: CS is adaptive for both sender and receiver because it allows individuals to assess each other's unobservable qualities, such as resource holding potential (RHP) or cooperative ability, in less risky ways. This kind of interaction, however, can only be evolutionarily stable if the signals are honest, i.e., accurately relate to the unobservable quality of the individual or group broadcasting the signal (Grafen, 1990). In cases where the signals are deceptive, receivers will detect the fraud over time and begin to ignore the signals. For this reason, signals are often "costly" and involve the use of energy and time since it is this aspect of the signal that helps ensure it is an honest representation of the trait being advertised. Costly signals often take the form of elaborate displays, such as peacock's tails (Maynard Smith and Harper, 2003). Though there are many examples of this form of behavior in human populations, ranging from costly hunting to the origins of prestige goods (Bliege Bird and Smith, 2005; Plourde, 2008), the construction of monuments is a particularly strong example of how CS can be used to explain archaeological phenomena (e.g., DiNapoli and Morrison, 2017; Glatz and Plourde, 2011; Hunt and Lipo, 2011; Joye and Verpooten, 2013; Kantner and Vaughn, 2012; Neiman, 1997).

The construction and display of monumental architecture can be understood as the outcome of competition between groups, as well as a means to maintain cooperation. For example, if two individuals competing over a resource are able to accurately determine the outcome of a fight by signaling an underlying quality related to competitive ability, such as RHP, then each individual benefits by avoiding inevitable physical injury or death. The regularity of competitive signaling is tied to local ecological conditions, in particular the heterogeneity in resources. For example, if there are marked differences in RHP between groups, then information about differences in competitive ability is readily apparent such that there is little benefit from CS. When there is a high degree of homogeneity in the distribution of resources, however, differences in competitive ability between groups are uncertain and signaling is predicted to become frequent and intense (Glatz and Plourde, 2011, p. 39). CS can evolve, and more importantly remain stable, under these ecological conditions because the signal serves as an honest communication of a group's competitive ability in lieu of more uncertain and costly violent conflict. CS can thus be a powerful force in structuring the form of both competition and cooperation (Gintis et al., 2001). The empirical predictions of such a model are similar to those of the EDM discussed above, but under different environmental parameters: (1) In environments where critical resources are relatively homogeneous, the locations of monumental signals should be spatially correlated with the locations of these resources or in contested liminal spaces between communities (DiNapoli and Morrison, 2017; Glatz and Plourde, 2011). (2) The magnitude of monument investment should covary with the quality or availability of critical resources.

Applying the logic of CS to Rapa Nui and Rapa Iti helps to illuminate the drastic differences in the form of monumental construction these populations invested in. While fortification construction on Rapa Iti may also have a signaling component (Kennett et al., 2006, p. 351), the presence of ditches, banks, palisades, and weapons strongly suggests the prevalence of violent conflict. The relevance of CS for explaining the extreme degree of investment in monumental architecture on Rapa Nui is especially salient (DiNapoli and Morrison, 2017; Hunt and Lipo, 2011; Morrison, 2012). While we have already highlighted the relatively low economic defendability of Rapa Nui's agricultural resources, in terms of competition, another critical resource – water – was likely in high demand and a focus of competition. However, due to the relative homogeneity in agricultural RHP potential across the island, CS through the construction of movement of *moai* served as a means by which competitive ability was displayed between the different communities. The signaling of a community's competitive ability to defend its limited resources, in particular water, may have been an adaptive solution to avoid risky physical conflict.

The investment in massive monument construction requires high degrees of community cooperation. One powerful way that cooperation can be maintained is through CS (Boone, 2000; Gintis et al., 2001), in particular CS involving a religious component (Bulbulia and Sosis, 2011) or synchronized, coordinated behaviors (Fessler and Holbrook, 2016). The carving and transport of *moai* and the construction and maintenance of *ahu* required a strong degree of intracommunity cooperation and involved both a major religious component and synchronized, coordinated activity (Lipo et al., 2013). On Rapa Nui, cooperation in ongoing monumental construction activities was possibly a way in which other forms of crucial community cooperation were maintained in such an uncertain environment. Given our model relating behavior and configurations of RHP, the risky and uncertain environment of Rapa Nui was likely a major influence on why cooperation and sharing was so important (Hunt and Lipo, 2011, 2001). In times of drought or scarcity community cooperation in the form of information sharing and pooling of resources would have likely been crucial to survival. The magnitude of investment in *moai* and *ahu* in the archaeological record of Rapa Nui, in this sense, is a direct reflection of the degree to which cooperation within communities mattered to survival on this particular island.

In summary, the differences between Rapa Nui and Rapa Iti in terms of settlement patterns, form of investment in monumental architecture, and degree of lethal conflict were strongly influenced by local ecological conditions. The divergent evolution of these population characteristics represent adaptive strategies to varying ecological constraints, such as usable land-area and the density and predictability of critical resources. Approached using evolutionary models designed to trace these forms of divergence, we can partially explain the central attributes of Rapa Nui and Rapa Iti prehistory – their forms of monumental construction. One form is ritual architecture whereas the other is fortified settlements, but they are each manifestations of different resolutions to competition and cooperation in varying ecological contexts.

2.5. Discussion

Although the explanations presented here are intriguing and suggest the potential for evolutionary explanations of the histories of these two islands, the individual hypotheses remain to be rigorously tested. My focus here has been to build a qualitative, comparative framework to guide descriptions of these two islands for further quantitative analyses. Nonetheless, this approach provides a useful comparative and explanatory framework for exploring how evolutionary ecological models can provide the basis for explaining the cultural divergence seen among populations, and in particular, for East Polynesia. In the preceding section, I laid out some empirical predictions of the EDM and CS concerning the ways in which the locations and attributes of fortifications or monuments should vary under different environmental parameters. One straightforward way that these model predictions could be evaluated is through quantitative analyses of the relationship between the spatial structure of subsistence resources and the patterning in fortifications and monuments. In particular, it is possible to confirm or, importantly, falsify these model hypotheses through the use of geospatial statistics and point-pattern analysis (Bevan et al., 2013; Howey et al., 2016). These spatial statistics could allow us to estimate to what degree variation in the characteristics of each islands' environment help explain variation in the placement and attributes of monumental ritual or fortified architecture, which can then lead to avenues for additional quantitative modeling.

As Lewontin (1974) has argued, the key to building explanations is to describe the empirical record using measurements that are defined and made meaningful from an explicitly explanatory framework. In our case, we use evolutionary ecological models as a basis to make our comparisons, which then allows us to account for the differences we observe in each of our case studies. This approach also provides a solid basis for developing research designs in order to generate additional descriptions that are suitable for specific hypothesis testing as well as more precise models to derive empirical expectations. One promising avenue along these lines makes use of comparative simulation such as agent-based modeling (ABM). An ABM allows us to formalize a series of decision rules into a population of autonomous individuals (i.e., agents) who interact with the environment and each other over time and across a simulated space. We can then use these models to observe population-scale outcomes of behavioral strategies, such as economic defendability or costly signaling, as they are shaped under the consequences of historical contingencies and different environmental parameters. In addition, this ABM approach could potentially also allow us to estimate if, and to what degree, both models explain some part of the variation seen in the archaeological record; in particular, the issue of a signaling component in Rapa Iti fortifications (Kennett et al., 2006, p. 351). Such an approach could also prove valuable elsewhere in the Pacific where fortifications and ritual monuments co-occur, such as on Palau (Liston, 2009). In this way, ABMs can serve as 'behavioral laboratories' that enable archaeologists to explore their ideas in terms that are potentially measurable in the archaeological record (Cegielski and Rogers, 2016; Premo, 2006). The available environmental and archaeological data from Rapa Nui and Rapa Iti offer a prime opportunity for this kind of comparative analysis, which is currently underway (e.g., DiNapoli et al. 2016; Morrison and Lipo 2015).

While we have just begun the process of constructing these explanations, we argue that the archaeological histories of Rapa Nui and Rapa Iti represent a comparative case study in which two populations who initially shared a high degree of similarity ultimately evolved independent histories along several dimensions of variability including settlement structure, degree of intergroup aggression, and form of investment in monumental architecture. Here, we have argued that key influencing factors in initial similarity leading to divergent historical outcomes lie in the substantial differences between island environments that constrain the options available to islanders as well as the competitive and cooperative strategies employed by their human populations. In this way, the case of Rapa Nui and Rapa Iti exemplifies the utility of islands as models for studying human cultural evolution.

CHAPTER III

SPATIAL MODELING OF MONUMENTAL ARCHITECTURE

This chapter was previously published as:

DiNapoli, R. J., Lipo, C. P., Brosnan, T., Hunt, T. L., Hixon, S., Morrison, A. E., & Becker, M. (2019). Rapa Nui (Easter Island) monument (ahu) locations explained by freshwater sources. *PLOS ONE*, 14(1), e0210409.

3.1. Introduction

Explaining the temporal and spatial patterns of monument construction as they relate to social complexity is a ‘grand challenge’ for contemporary archaeology (Howey et al., 2016; Kintigh et al., 2014b, 2014a). Despite considerable research on this subject, formal analyses of the role that environmental factors play in the emergence of monument construction have been largely underdeveloped. Recent studies, however, have begun to employ spatially explicit modeling to explore how distributions of resources relate to monuments (Carrero-Pazos and Rodríguez-Casal, Forthcoming; Howey and Clark, 2017; e.g., Howey et al., 2016; McMichael et al., 2014). These studies provide key insights into the degree to which ecological constraints shape the location and function of monuments in past societies.

Rapa Nui (Easter Island, Chile, Figure 3.1) provides one of the most dramatic cases of prehistoric monument construction where, in a span of only about 500 years, from the 13th century AD to European contact in AD 1722 and into historic times, the islanders (Rapanui) constructed over 300 megalithic platforms (*ahu*) and nearly 1000 multi-ton anthropomorphic statues (*moai*) (Hunt and Lipo, 2018, 2006; Lipo and Hunt, 2016; Martinsson-Wallin, 1994; Van Tilburg, 1994). The achievements of the Rapanui are even more impressive when one considers the island's ecological marginality, including low and unpredictable rainfall, nutrient-poor soils, lack of large coral reefs or abundant sources of surface freshwater (Hunt and Lipo, 2011). The island's ecology greatly constrained the range of options available for subsistence to the island's inhabitants (Hunt and Lipo, 2018; Louwagie et al., 2006), and many consider these environmental constraints to be a key factor in the emergence of monuments on Rapa Nui, such as their role as adaptive responses to environmental uncertainty (e.g., Graves and Ladefoged, 1995; Hunt and Lipo, 2001) or as territorial signals of control over limited resources (DiNapoli et al., 2018; DiNapoli and Morrison, 2017; e.g., Hunt and Lipo, 2018; Kirch, 2017; McCoy, 1976; Simpson, 2009).

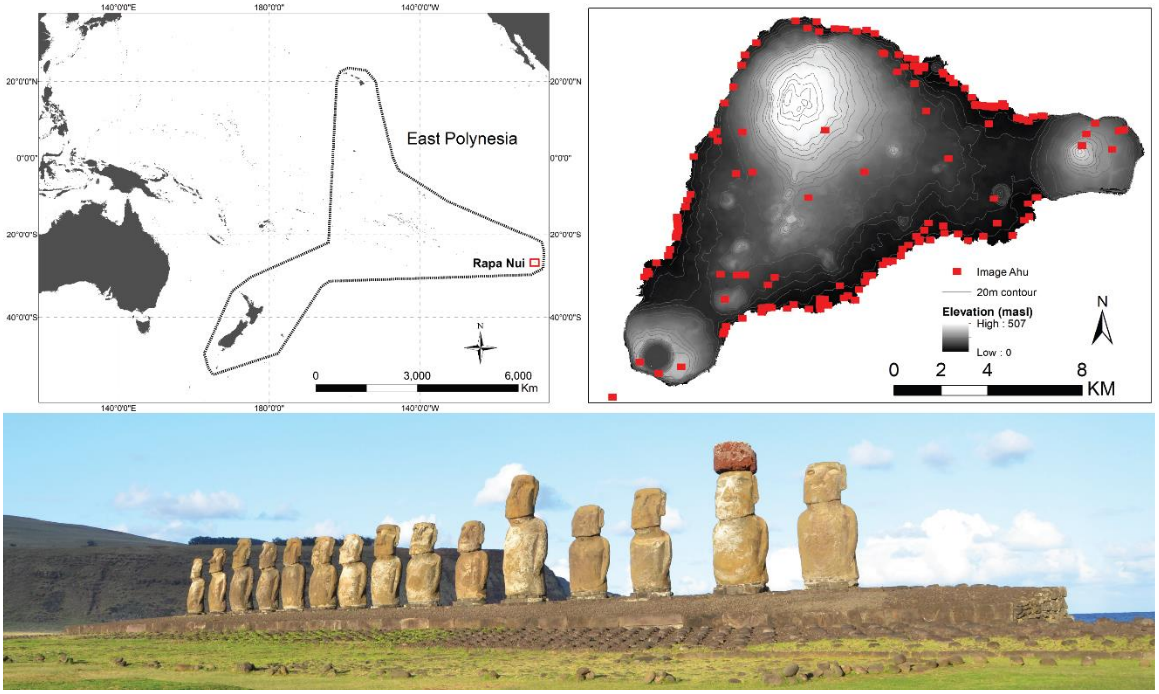

Figure 3.1: Rapa Nui. (Top left) Rapa Nui in East Polynesia, (top right) locations of image-*ahu* on Rapa Nui, and (bottom) *Ahu Tongariki* with *moai*.

The relationship between the island's subsistence resources and temporal and spatial patterns of monument construction, however, remain largely untested, which represents a significant limitation in our understanding of Rapa Nui's history. Yet, like other oceanic islands, Rapa Nui can offer a model system for understanding human-environment interactions, including the ecological factors underlying monument construction (DiNapoli et al., 2018; Kirch, 2007a, 2007b; Vitousek, 2002). Accordingly, the current work is concerned with beginning to test the hypothesis that Rapa Nui's monumental architecture served as territorial signals of control over subsistence resources. As a starting point for evaluating this hypothesis, we quantitatively model how the spatial distribution of *ahu* is explained by different resources thought to be the focus of competition in precontact times. Tests are conducted through spatially-explicit modeling of the relations between *ahu* and the three critical subsistence resources on Rapa Nui: rock mulch agricultural gardens, marine resource locations, and freshwater sources. The expectation is that if Rapa Nui's monuments were built, in part, to signal territorial resource control, then there should be a spatial association between *ahu* and the resources they are signaling control over (DiNapoli et al., 2018). In our work, we follow an information criteria model-selection approach using point-process models (Baddeley et al., 2015; Bevan and Wilson, 2013; Eve and Crema, 2014; Spencer and Bevan, 2018). Our analyses combine existing data for the coverage of agricultural fields (Ladefoged et al., 2013), marine resource locations, and include data from our ongoing study of the island's freshwater sources (Brosnan et al., 2018; Zeferjahn, 2016). For the purposes of this study, we restrict our spatial analysis of *ahu* to the eastern portion of the island where we have near-complete coverage documenting the distribution of these three resources.

The results of our point-process modeling indicate that the spatial locations of *ahu* are most parsimoniously explained by proximity to freshwater sources. Our findings offer an explanation for the primarily coastal distribution of these monuments as well as for *ahu* found inland. These results provide key information on the conditions that contributed to the unprecedented investments in monument construction on Rapa Nui.

3.2. Rapa Nui Environment

Rapa Nui is a small (164 km^2), isolated island in the southeastern Pacific that is about 3500 km from South America and nearly 2000 km from the nearest inhabited island (Figure 3.1). The island is volcanic in origin with three main shield volcanoes (Rano Kau, Terevaka, and Poike) and a number of smaller scoria and cinder cones (Vezzoli and Acocella, 2009). With Terevaka at just over 500 meters above sea-level (MASL), the island is relatively low-lying and lacks incised valleys common on other Pacific islands. Rapa Nui's climate is seasonal and windy, given its subtropical latitude, and it receives relatively low and unpredictable annual rainfall ranging from ca. 600-2000 mm/year (Louwagie et al., 2006; Stevenson et al., 2015). While paleoecological studies demonstrate a once extensive palm forest (e.g., Cañellas-Boltà et al., 2013; Flenley et al., 1991; Flenley and King, 1984; Mann et al., 2008), over the period of human occupation the island lost its forest with the combined effects of human land-clearing for cultivation and the invasive commensal Pacific rat (*Rattus exulans*) (Horrocks et al., 2017; Hunt, 2007; Hunt and Lipo, 2009, 2007). Compared to elsewhere in Polynesia, Rapa Nui's soils are excessively-drained, leached, and poor in available nutrients (Ladefoged et al., 2010; Louwagie et al., 2006; Vitousek et al., 2014). Although there are freshwater lakes within the volcanic craters, given the very porous nature of the underlying substrate (Herrera and Custodio, 2008), the island lacks other sources of surface freshwater, such as permanent streams, common on other islands. As it rises steeply from the ocean floor, Rapa Nui also has a relatively impoverished marine environment and lacks large coral reefs or a lagoon (Friedlander et al., 2013). These environmental characteristics imposed considerable constraints on the subsistence options available to precontact inhabitants.

3.3. Rapa Nui's Monuments

The inherent environmental constraints make the achievements of human populations who persisted on this small island for more than 500 years all the more remarkable. Not only did Rapanui people manage to live successfully in a small, resource-poor, and isolated location, they collectively manufactured nearly one thousand massive stone statues (*moai*) and more than 300 megalithic platforms (*ahu*).

While a precise overall chronology for Rapa Nui's monuments has not been fully established, radiocarbon dating indicates that construction of the island's megalithic platforms, known collectively as *ahu*, likely began shortly after colonization in the 13th century and intensified over time (Hunt and Lipo, 2006; Martinsson-Wallin et al., 2013a; Mulrooney, 2013a; Stevenson, 1986; Paul Wallin et al., 2010; Wilmshurst et al., 2011). *Ahu* represent a derived form of ritual architecture found elsewhere in East Polynesia (Cochrane, 2015; Green, 2000; Kirch, 1984b; Martinsson-Wallin, 1994), though both the quantity and magnitude of investment on Rapa Nui are distinct. While many *moai* (ca. 400) remain at the statue quarry at Rano Raraku, hundreds of *moai*, weighing several tons each, were transported along statue roads and erected upon *ahu* (Lipo et al., 2013; Lipo and Hunt, 2005; Richards et al., 2011). In addition, many *moai* were also adorned with large red-scoria ‘hats’ called *pukao* (Hixon et al., 2018, 2017). Rectangular platform *ahu* with a dressed-stone sea-wall, and which often support one or more *moai*, are referred to as “image-*ahu*” (Martinsson-Wallin, 1994). Image-*ahu* are precontact features, whereas other *ahu* forms, such as semi-pyramidal *ahu*, *ahu po‘e po‘e*, and *ahu avanga* are considered largely post-contact in age (Martinsson-Wallin, 1994). Here, we focus our discussion and analyses on the distribution of image-*ahu* (Fig 1).

Image-*ahu* were the focal points of Rapa Nui’s precontact communities (Martinsson-Wallin, 1994; Stevenson, 2002, 1986). Overall, the Rapanui settlement pattern is characterized by relatively dispersed communities distributed along the coastline as redundant sets of domestic features ca. 100-200 m inland from *ahu* (McCoy, 1976; Morrison, 2012; Stevenson, 1984, p. 47). While image-*ahu* have a primarily coastal distribution and, based on limited historical accounts, were community gathering locations for ritual activity, questions about why they occur in their specific locations or additional social roles these monuments may have served remain largely unanswered.

Many have debated whether *ahu* served as territorial displays of control or hereditary ownership over the island’s limited subsistence resources (e.g., Barber, 1996, pp. 877–878; Kirch, 1984b; Kolb, 2012; McCoy, 1976; Sahlins, 1955; Shepardson, 2005; Simpson, 2009; Stevenson, 2002; Van Tilburg, 1994, p. 94; Wallin and Martinsson-Wallin, 2011), and while there is general agreement that competition and territoriality were centered around limited and predictable resources (see Dyson-Hudson and Smith, 1978), there is disagreement over which resources were most critical. Van Tilburg (1994, p. 94) has argued that,

> the archaeological evidence illustrates clearly that the control of subsistence production in agriculture and marine resources was intimately and strongly linked to the typical Polynesian scheme of hereditary land use rights…The need constantly to restate that ownership, generation after generation and in the context of a growing population and a changing natural environment, seems to have been one of the driving forces of *ahu* construction, although other social and religious motivations obviously existed.

Similarly, Kirch (2017, p. 236) has argued that image-*ahu*, "are found at the best embayments around the island," which served as a means of, "visually 'controlling' access to the limited marine resources." Others (DiNapoli et al., 2018; e.g., Hunt and Lipo, 2018; McCoy, 1976) suggest that freshwater would have been a significant critical limited resource and the focus of intense competition, whereby *ahu* served as costly signals of community competitive ability. In addition, many assume that surplus sweet potato yields from lithic mulch gardens would have been necessary to support *ahu* construction and *moai* transport and that monuments served to broadcast elite control of these resources (e.g., Simpson, 2009; Stevenson et al., 2006, 2002, 1999; Wallin et al., 2005). Stevenson and colleagues (Stevenson et al., 2006, 2002, 1999; Wallin et al., 2005) have consistently argued for an association between *ahu* and rock mulch gardens, that the development of intensified agriculture closely tracks the tempo of monument construction, and that "[t]hese repeated associations indicate that ranked persons were most likely ritually involved with agricultural production and used the position to manage the field systems under their authority" (Stevenson et al., 1999, p. 810). To date, however, rigorous tests of these hypotheses are lacking, as are any attempts to construct formal models of *ahu* spatial patterns (but see Beardsley, 1996 for exploratory analyses). If image-*ahu* served as territorial markers of control over subsistence resources, as a majority of archaeologists who have worked on the island suggest, then the empirical expectation is a spatial association between *ahu* and the resources for which they mark control.

3.4. Rapa Nui Subsistence Resources

Access to raw materials for architectural construction and tools seems to be unrelated to image-*ahu* locations. Obsidian used for cutting and scraping tools known as *mataʻa* (Ayres et al., 2000b; Church and Ellis, 1996; Church and Rigney, 1994; Lipo et al., 2016) was derived from several discrete locations near their source volcanic vents away from *ahu* activity (Mulrooney et al., 2014; Stevenson et al., 2013). Basalt, on the other hand, which was used to create adzes and other tools, had many sources around the island, but there is no clear pattern suggesting localized control (Simpson et al., 2018a; Simpson and Dussubieux, 2018b). Stone for large *moai* and red scoria for *pukao* come primarily from single quarries at Rano Raraku and Puna Pau (respectively), and there do not appear to have been limits to the access of these materials by any particular group (e.g., Hamilton et al., 2008; Routledge, 1919; Seager Thomas, 2014). Thus, on Rapa Nui there are three broad classes of resources to consider that might potentially relate to the choices made for constructing image-*ahu*: locations suitable for agriculture, sources of marine food, and freshwater.

3.4.1. Agriculture

Like Polynesians across the Pacific, the precontact Rapanui were agriculturalists, although, overall, Rapa Nui's growing conditions are considered marginal when compared to elsewhere (Louwagie et al., 2006; Vitousek et al., 2014). A substantial fraction of subsistence, however, depended upon agricultural crops that included sweet potato (*Ipomoea batatas*), yams (*Dioscorea alata*), dryland taro (*Colocasia esculenta*), bananas (*Musa* sp.), sugar cane (*Saccharum officianarum*), and other cultigens. Of these, plant microfossil analyses of soils and human dental calculus indicate that sweet potato was the primary plant food source (Horrocks et al., 2017; Horrocks and Wozniak, 2008; Tromp and Dudgeon, 2015). The island's cool climate and lack of streams or incised valleys meant that irrigated taro cultivation common elsewhere in Polynesia was not possible (Kirch, 1994). Instead, sweet potato, along with yams and dryland taro, were grown in lithic mulch gardens. In these gardens, a collection of basalt pebbles, cobbles, and boulders were placed on the ground to add nutrients, trap moisture, protect plants from wind, and stabilize temperature (Bork et al., 2004; Ladefoged et al., 2013, 2010; Stevenson et al., 2006, 1999; Vitousek et al., 2014; Wozniak, 1999). Apart from Poike and Rano Kau, mulch gardens are found across the island (Ladefoged et al., 2013). Cultivation also took place within small, circular-walled garden enclosures (*manavai*) that are thought to have been used primarily for taller cultigens such as bananas or sugarcane (Stevenson et al., 2002, 1999). *Manavai* were likely of secondary importance to mulch gardens (Ayala-Bradford et al., 2005; McCoy, 1976; Wozniak, 2018). Terrestrial protein was available from domesticated chickens (*Gallus gallus*), rats (*Rattus exulans*), and potentially birds (Ayres et al., 2000a; Rorrer, 1998; Steadman et al., 1994).

3.4.2. Marine Resources

The relative importance of marine resources in the precontact Rapanui diet has been the subject of some debate. The first detailed ethnographies conducted in the early 20th century (Englert, 1948; Métraux, 1940; e.g., Routledge, 1919) suggested that marine resources were a relatively unimportant dietary component at this time, though Métraux (1940, p. 22) suggested that fishing was more important in precontact times. These ethnographies documented a range of near-shore techniques used to target several eel and fish species, including netting, snaring, and hook and line fishing with stone, bone, and wooden fishhooks. These different kinds of fishhooks, netting needles, and stone net-sinkers are also found in archaeological contexts (e.g., Ayres, 1979; Heyerdahl and Ferdon, 1961). Due to the paucity and small size of marine shellfish on Rapa Nui, shell fishhooks are unknown (Ayres, 1979). Near-shore foraging for invertebrates, such as octopus, crabs, lobsters, and urchins, was also practiced, though these were possibly of lower importance (Arana, 2014; Ayres, 1979).

The available zooarchaeological data for Rapa Nui marine resource use are limited but also suggest the importance of near-shore fishing in the precontact times. Ayres (1985; Ayres et al., 2000a) excavated several deposits on the north and south coasts and found that fish and shellfish remains comprised a relatively low percentage (< 30%) of the overall food remains and suggested a greater importance of near-shore fish taxa. Ayres (1985) also found slight geographic differences in fish remains, with a higher proportion on the north coast, though these were balanced by a larger proportion of invertebrate remains on the south coast. However, a later analysis of additional remains from these sites found a much higher percentage (~85%) of fish remains and less geographic differences between the north and south coast (Ayres et al., 2000a). Similarly, Rorrer (1998) excavated two cave sites on the southwest coast which yielded abundant fish remains and small amounts of marine shell, with the assemblage being predominantly comprised of snapper, wrasse, and moray eel. Steadman et al.'s (1994) excavations at Anakena beach also yielded an assemblage of fish and dolphin remains that were more or less evenly distributed through the deposit. While some have suggested that the presence of dolphin in these deposits implies that the Rapanui fished in the open ocean (Diamond, 2005, e.g., 1995), it is more likely that dolphins were hunted in the shallows of Anakena bay as was done on other Polynesian islands (Cressey, 1998). Similar results from Anakena excavations are reported by Martinsson-Wallin and Crockford (Martinsson-Wallin and Crockford, 2002) and Hunt (Hunt, 2007), though with a much higher abundance of fish remains. Apart from Steadman et al.'s (1994) large assemblage of dolphin remains, these studies indicate the importance of nearshore taxa in precontact times. It should be noted that many of these studies used relatively large mesh screens (⅛ inch) during excavation (though Steadman et al. (1994) subsampled material and screened with 1/16th inch mesh for one square of their 1×4 m unit), thus potentially biasing our knowledge about marine resources against smaller fish and shell remains (Allen, 2014). In sum, these studies all indicate the importance of nearshore taxa in precontact times.

Relative to terrestrial resources, marine resources were once thought to make only a small contribution to subsistence (Commendador et al., 2014, 2013; Polet and Bocherens, 2016). A recent reanalysis of the stable isotope evidence (Jarman et al., 2017), however, indicates that marine resources composed at least 50% of dietary protein. In conjunction with the zooarchaeological evidence, these findings demonstrate that marine resources played a significant role in the Rapanui diet. Thus, while Rapa Nui's marine resources are limited when compared to other Polynesian islands, they nonetheless comprised an important part of the precontact subsistence system. In addition, recent surveys of Rapa Nui's marine ecosystem indicate that overall fish biomass is relatively high (e.g., Friedlander et al., 2013). Rapa Nui's relatively marginal marine environment, however, restricted opportunities for prehistoric populations to intensify reef foraging (especially for shellfish), a practice important elsewhere in Polynesia (e.g., Allen, 2017; Lambrides and Weisler, 2016).

3.4.3. Freshwater

Freshwater is a limited resource of critical importance that is infrequently discussed for Rapa Nui. As noted above, the island receives a moderate amount of rainfall but also experiences frequent droughts and, due to soil and bedrock permeability, has no permanent streams. The highly permeable bedrock allows water to rapidly transfer to the island's unconfined aquifers, and the water table is generally only a few MASL near the coast (Herrera and Custodio, 2008, pp. 1331–1333). Herrera and Custodio (2008) have suggested that groundwater may be perched on less permeable geologic features inland, but except where a few springs occur, the island's geology makes inland groundwater inaccessible without the aid of modern drilling equipment. While there are a few isolated instances of landforms that give the impression of once being fluvial ravines (Bahn and Flenley, 2017, p. 216; Heyerdahl and Ferdon, 1961, p. 26), these are likely volcanic features such as collapsed lava tubes (Métraux, 1957, p. 65).

Freshwater is also available in the island's many lava tubes, found mainly on the western end of the island, where groundwater and rainwater can collect (Ciszewski et al., 2009; Herrera and Custodio, 2008, p. 1333; Heyerdahl and Ferdon, 1961, p. 26; Routledge, 1919, p. 272). The only large perennial bodies of freshwater are lakes and springs resting atop impermeable portions of volcanic cores in Rano Kau, Rano Raraku, and Rano Aroi. However, there is a curious lack of evidence for these lakes being primary water sources in either pre- or post-contact times (Métraux, 1940, p. 12; Routledge, 1919, p. 137; Rull, 2018; cf. Rull et al., 2018), likely due to their inaccessibility or distance from the majority of habitation areas. The highly permeable substrate and absence of perched aquifers led to the primary challenges faced by the Rapanui in procuring freshwater.

Early European visitors were quick to note the scarcity and brackish quality of freshwater on Rapa Nui, and their reports also provide key insights into the primary sources of freshwater. At first European contact in AD 1722, Bouman, a captain in Roggeveen's Dutch expedition, noted that the Rapanui had "calabashes [i.e., gourds, *Lagenaria* sp.] in which they kept water which I tasted and found to be quite brackish." (von Saher, 1994, p. 99). Later visitors also describe the use of gourds for water storage and transport (e.g., Dos Pasos, 1971, p. 47; Thomson, 1891, p. 29). Due to its ability to retain considerable moisture, sugarcane was also possibly used as a water source (Dos Pasos, 1971, p. 68; Forster and Kahn, 1968, pp. 327–332). However, the historical accounts of sugarcane use are contradicted by the relatively low abundance of their phytoliths in human dental calculus (Dudgeon and Tromp, 2014). Most observations point to the importance of freshwater from coastal areas. Cook, for example, noted that the islanders drank coastal water, commenting that the water given to them by the Rapanui was “brackish and stinking” which was only “rendered acceptable by the extremity of their thirst” and later saying that they were even given “real salt water” and that the Rapanui “drank pretty plentifully” from the sea (Ruiz-Tagle, 2007, pp. 160–162). From these descriptions, it is likely that Cook experienced the Rapanui using coastal groundwater discharge (CGD) whereby groundwater seeps up in many locations along the island’s coastline. There are several additional European accounts of the Rapanui drinking seawater (e.g., Dos Pasos, 1971, p. 61; Forster and Kahn, 1968, p. 343; Richards, 2008, p. 54,75), though, as pointed out by Routledge (Routledge, 1919), these were almost certainly observations of the use of CGD as freshwater sources. These European accounts indicate that CGD was an important freshwater source for the Rapanui (Brosnan et al., 2018).

Archaeologically, evidence for freshwater management occurs mostly in the form of features known as *taheta* and *puna*. *Puna*, sometimes referred to as ‘wells,’ are stone paved and sometimes walled features occurring along the coast that served to trap CGD (Englert, 1948; Métraux, 1940). Métraux (1940, p. 65) recognized the important function of *puna*, noting these features “impounded rain water and perhaps some fresh water springs”, and that the “ruins of ancient settlements are always thick around water holes” (Métraux, 1940, p. 11). In his early ethnographic and archaeological surveys, Englert (1948) also noted the co-occurrence of water sources with both *ahu* and settlements.

In addition to the use of *puna*, the Rapanui also made freshwater features known as *taheta*. *Taheta* are small (i.e., <1 m wide) and shallow rainwater basins carved into basalt bedrock, which, being dependent on rainfall, provided opportunistic and temporary sources of freshwater (Métraux, 1957, p. 66). These features can be found scattered throughout the island, though they appear to be more abundant in inland areas and on the northwest coast (Dudgeon and Tromp, 2014; Morrison, 2012; Shepardson, 2006). Freshwater diatoms extracted from the dental calculus of precontact human remains (Dudgeon and Tromp, 2014) suggest that populations relied on features like *taheta* that would have been habitat for phytoplankton. Many of the diatoms identified in the skeletal remains prefer brackish water (Cocquyt, 1991), indicating the islanders also used other kinds of standing pools located at or near the coast, such as brackish water at locations of CGD or *puna*. In addition to *taheta* and *puna*, Vogt and colleagues (Vogt and Kühlem, 2018; Vogt and Moser, 2010) have identified a unique water basin and possible dam feature at the inland site of Ava Ranga Uka A Toroke Hau. In sum, while Rapa Nui lacks many obvious sources of freshwater, the geology of the island, the distribution of archaeological material, and ethnohistorical accounts suggest a heavy reliance on water from coastal areas, in particular CGD, which was at times impounded through the use of *puna*.

Below, we present a series of spatially-explicit models designed to assess the degree to which image-*ahu* spatial locations are explained by the presence of rock mulch gardens, marine resource locations, and/or freshwater sources to test competing hypotheses about whether monument construction on Rapa Nui is related to subsistence resource constraints.

3.5. Archaeological and Environmental Data

To compare the spatial distribution of *ahu* to subsistence resource locations requires comprehensive spatial coverage of these variables, and we therefore restrict the current analysis to an eastern region of Rapa Nui (Figure 3.2) where we have data on monuments, agricultural plots, marine resource locations, and freshwater sources. The 93 image-*ahu* and their locations derive from the comprehensive *ahu* survey conducted by Martisson-Wallin (1994). We determined *ahu* locations by georeferencing Martinsson-Wallin's (1994) maps and subsequently correcting their locations during field surveys using a Trimble Geo 7x GPS unit and with Google Earth imagery (Figure 3.2a).

Our analyses of agricultural resources focus on the relationship between image-*ahu* and rock mulch gardens, rather than other features like *manavai* or agricultural productivity models (e.g., Morrison, 2012; Puleston et al., 2017), as these features represent known locations of the most intensified agricultural production. The locations of rock mulch gardens derive from the results of Ladefoged et al. (2013), who produced remote-sensing-based documentation of the distribution of mulch gardens across the island. Ladefoged et al. (2013) produced three products from their analyses: minimal, medial, and maximal mulch classifications. We analyzed each of these three mulch classifications. To facilitate the distance-based analyses outlined below, we transformed the rock mulch dataset. First, we converted the data into a binary raster with areas of rock mulch = 1 and non-mulch areas = 0. Next, we created a mulch density estimate by calculating the mean occurrence of rock mulch within a circular neighborhood of 100 m around each cell, and this result was reclassified into a new binary raster with 1 = the upper 90% (Fig 2d-f). This process filtered out potential noise in Ladefoged et al.'s

(2013) rock mulch model that would come from small areas being incorrectly classified as mulch or small isolated areas unlikely to be important resource locations, based on previous hypotheses that only the largest intensified field systems were associated with construction of image-*ahu* (Stevenson et al., 2006, 2002, e.g., 1999). We then created a distance map for rock mulch, i.e., a raster layer where each cell value is equal to its Euclidean distance from rock mulch gardens.

As discussed above, Rapa Nui lacks large coral reefs and has a relatively homogenous rocky shore marine environment. Given these characteristics of the island's marine ecology and archaeological evidence for the importance of near-shore taxa, the most suitable locations for marine resource procurement would have simply been areas with easy coastal access. Using NASA's Shuttle Radar Topography Mission (SRTM) 30 m digital elevation model (DEM), we defined marine resource locations as areas <10 MASL (Figure 3.2c). This choice of 10 MASL is somewhat arbitrary, but captures the locations of low-elevation embayments, which would have provided the best access points for near-shore fishing and other forms of marine foraging (Kirch, 2017, p. 236; Shepardson, 2013, p. 206). To explore the sensitivity of our modeling to this <10 MASL cutoff, we also perform these analyses using a <5 MASL threshold (Appendix A). As for the rock mulch data, we created a Euclidean distance map with cells equal to distance from marine resource locations.

Our freshwater data derive from previous studies (Cocquyt, 1991; e.g., Herrera and Custodio, 2008; Montgomery & Associates, Inc., 2011) and our ongoing pedestrian and geochemical surveys (Brosnan et al., 2018; Zeferjahn, 2016) designed to locate precontact freshwater sources, such as lakes, springs, ponds, caves with seeping groundwater, *puna*, and coastal seeps (Figure 3.2b). We do not consider *taheta* in our analysis for the same reason we filtered out smaller areas of rock mulch. Specifically, *taheta* would have provided only small and temporary sources of freshwater and thus would have been unlikely sources of competition (Brosnan et al., 2018). Complete survey data on *taheta* are also presently unavailable. Coastal seeps, or coastal groundwater discharge (CGD), locations were identified using EXTECH EC170 salinity meters, which measure the concentration of dissolved ions in coastal water expressed in parts per thousand (ppt). Salinity measurements were taken every 10 m along the coastline within our survey area (Fig 3.2b) and within one hour of low-tide when CGD is at its maximum. Coastal seeps were defined as locations where the salinity of coastal water was substantially less than the average salinity of seawater (ca. 35 ppt), in this case 28 ppt or less. This value represents a 20% reduction in salinity and therefore signals areas of substantial CGD that could be used as freshwater sources (further details in Brosnan et al., 2018). In limited locations we also identified CGD using a Solonist Levelogger conductivity meter based on differences in conductivity between freshwater and seawater (Hem, 1985). Rapa Nui seawater has a mean conductivity value of 55 millisiemens (mS), so any location with a conductivity <50 mS was classified as a high concentration of CGD (Cole et al., 2015). While we have not yet resolved the question of potential temporal variability in discharge rates, given Rapa Nui's hydrogeology, the spatial locations of these water sources have likely remained stable over the time period of human occupation (Brosnan et al., 2018; Herrera and Custodio, 2008). These freshwater data were transformed into a Euclidean distance map where cell values equal distance from freshwater sources.

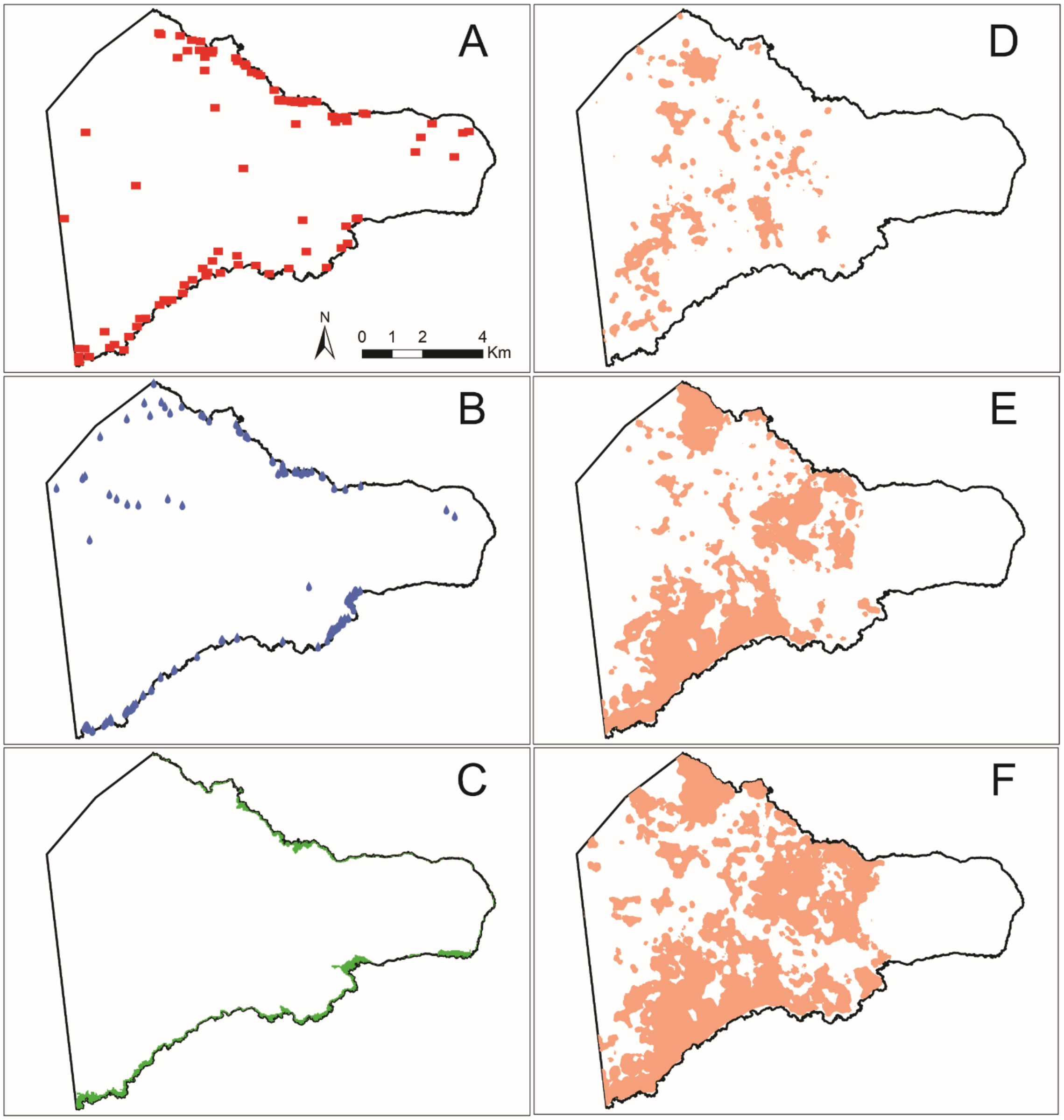

Figure 3.2: Archaeological and environmental data used in our analyses. (A) locations of image-*ahu*, (B) locations of freshwater sources, (C) marine resource locations, (D) minimal rock mulch classification, (E) medial rock mulch classification, (F) maximal rock mulch classification.

3.6. Point Process Modeling

Two fundamental concepts in spatial analysis are the first- and second-order properties of point patterns (Bevan and Wilson, 2013, p. 2416; O'Sullivan and Perry, 2013). The first-order property of a point pattern is its intensity, defined as the number of points per unit area of the study region. The intensity is usually described as being homogeneous (i.e., expected number of points the same across the study area) or inhomogeneous (i.e., spatially varying intensity) (Baddeley et al., 2015, pp. 157–160). The second-order property is the interaction among points, such as clustering (resulting from an attraction process) or dispersion (resulting from some kind of repulsion/spacing). In general, a major goal of point-pattern analysis is to account for what, if any, independent variables explain the intensity of the point pattern and whether aspects of the spatial pattern are accounted for by clustering/dispersion among points. These two properties are analytically important to distinguish, as aspects of first-order intensity may be conflated for second-order interaction, such as a set of points appearing clustered simply due to their tendency to be in one part of a study area. On Rapa Nui, for example, one might assume that the tendency for *ahu* to be dispersed along the coastline is related to settlement spacing (second-order property), though this distribution may be sufficiently accounted for by a dependent relationship with coastal resources (inhomogeneous first-order intensity). It is also possible that *ahu* spatial patterns are explained by both first- and second-order properties. Below, we apply a series of formal techniques for modeling these two properties in an effort to better understand which properties and variables best explain the spatially varying intensity of image-*ahu*.

To test whether geographic patterns of *ahu* construction are explained by resource availability, we evaluate the following hypotheses related to the spatial dependence of *ahu* on distance from subsistence resources locations: (1) image-*ahu* have a homogeneous or inhomogeneous random spatial distribution (null hypothesis), (2) image-

ahu have an inhomogeneous spatial distribution which is simply explained by distance from the coastline; image-*ahu* have an inhomogeneous spatial distribution that is best explained by (3) distance from rock mulch gardens; (4) distance from marine resource locations; (5) distance from freshwater sources; or (6) the spatial distribution of image-*ahu* is explained by some combination of these variables.

We assess hypothesis 1 using homogeneous and inhomogeneous forms of Besag's L-function (Baddeley et al., 2000; Besag, 1977). The homogeneous L-function simply tests for deviations from complete spatial randomness (CSR) in the form of clustering or dispersion in a point-pattern at different spatial scales, whereas the inhomogeneous L-function tests for clustering or dispersion relative to the inhomogeneous intensity of the underlying point-pattern. For example, *ahu* may appear clustered simply because they are predominantly coastal in their distribution, though once we account for this spatial inhomogeneity they may be neither clustered nor dispersed. We assess the statistical significance of these tests using Monte Carlo simulation envelopes of CSR. Areas of the empirical function falling outside this envelope indicate significant departures from CSR, with areas above the envelope indicating clustering and below the envelope indicating dispersion. Here, we use 39 simulations of CSR, which is equivalent to testing at the p=0.05 level.

To test hypotheses 2 through 6, we first explore potential relationships between *ahu* and distance from subsistence resource locations using spatial Kolmogorov-Smirnov (SKS) tests (Berman, 1986). The SKS test works by comparing the spatial empirical cumulative distribution function (CDF) to the expected CDF under the null hypothesis of CSR and thus provides an indication of whether the spatial distribution of a point-pattern is non-randomly patterned according to an underlying spatial covariate. We perform this SKS test for *ahu* spatial relationships with distance from marine resource locations, freshwater sources, and Ladefoged et al.'s (2013) three rock mulch classifications. The alternative hypothesis is that the CDF for *ahu* lies above that expected under CSR, i.e., that *ahu* are closer to these resource locations than is expected for a random spatial pattern. The SKS test, however, is merely an exploratory tool to help guide the choice of spatial covariates to use in more formal models, and here those spatial covariates for which *ahu* are non-randomly constructed near are further evaluated using point-process modeling.

Point-process models (PPM) are a wide class of spatially explicit models that facilitate formal analysis of the relationship between point-patterns and a range of spatial covariates (Baddeley et al., 2015). PPM works by fitting a spatial intensity function to the intensity of an empirical point pattern and finding the values of the predictor variables (i.e., parameters) that best fit the data (Baddeley et al., 2015, p. 305). The technique is similar to geographically weighted regression or maximum entropy modeling but has a number of strengths (Baddeley et al., 2015, p. 299), such as its ability to simultaneously model both first-order (i.e., homogeneity/inhomogeneity) and second-order (i.e., clustering/dispersion) properties in the underlying point-pattern and how these properties may be dependent upon a set of underlying spatial covariates (Bevan and Wilson, 2013; Eve and Crema, 2014). PPM is therefore well-suited to the objectives of this study.

Rather than simply evaluate the likelihood of different models or test for significant effects of different spatial covariates, PPMs allow for the use of formal model-selection tools based on information criteria. Tools like the Akaike Information Criterion

(AIC; (Akaike, 1974)) or Bayesian Information Criterion (BIC; (Schwarz, 1978)) allow for the formal comparison of competing potential models about the formation of archaeological patterns. These tools are based on a principle of parsimony, which penalizes models for additional parameters, so the model chosen as 'best' is the one that explains the most variability in the underlying data in the simplest way. This parsimony criterion is beneficial, because more complex models often will have higher likelihoods simply because of additional parameters, though they may be overfit (Eve and Crema, 2014). The use of information criteria therefore allows us to evaluate the tradeoff between model complexity and likelihood in selecting the best model. One convention is to choose the model which has the smallest change in information criterion score (e.g., ΔAIC or ΔBIC) and the highest weight, which provides a measure of the relative strength of different candidate models (Burnham and Anderson, 2004; Eve and Crema, 2014).

To accomplish this task, we built a series of inhomogeneous Poisson PPMs that model the log-linear relationship between an empirical point pattern and different spatial covariates, in this case how the spatial trends in *ahu* construction are predicted by subsistence resource locations. Our initial model simply considers the inhomogeneous relationship between *ahu* locations and their distance from the coastline, i.e., based on the possibility that *ahu* are not related to subsistence resources but simply occur in coastal areas (hypothesis 2). We then built additional models which consider the spatial dependence of *ahu* on distance from different combinations of subsistence resource locations (hypotheses 3-6). Following the suggestion of Kuha (2004), we then use both ΔAIC and ΔBIC to formally compare these models, for when used in tandem these two information criteria can be powerful tools for selecting the best-fitting model.

Once the best-fitting model was selected, we evaluated the fit between the model and the data using a number of techniques. First, we used the residual L-function, which compares whether the L-functions of simulated realizations from the best-fitting model are statistically indistinguishable from the L-function of the empirical point-pattern (Baddeley et al., 2015). Regions of the empirical function falling outside the envelope of the L-function for the model indicate a poor fit between the model and the data. For example, if the L-function of the empirical pattern falls above the envelope for the model, then the empirical pattern is likely more clustered than was accounted for in the model. We also assessed the fit between the L-function of a PPM and empirical point-pattern by implementing the maximum absolute deviation (MAD) and Diggle-Cressie-Loosmore-Ford (DCLF) tests using 39 Monte Carlo simulated realizations of the model (Baddeley et al., 2014). For these latter two tests, high p-values indicate good fit between the model and data while low p-values suggest significant deviations between them. In the event of poor fit, the models can be re-parameterized to include second-order properties such as clustering or dispersion. We also present visualizations of simulated realizations of the best-fitting PPM using the Metropolis-Hasting algorithm (Geyer and Møller, 1994). We performed our analyses with R (R Core Team, 2019), using the spatstat package for PPM (Baddeley et al., 2015) and the MuMIn package for multi-model selection (Bartoń, 2018). All data and R code necessary for running these analyses are available in Appendix A.

3.7. Point Process Modeling Results

Figure 3.3 shows the results of the homogeneous and inhomogeneous L-function, which tests for deviations from CSR in the *ahu* point pattern. In the figure, the black line is the empirical L-function for *ahu*, the red line is the expectation under CSR, and the grey regions are the *p*=0.05 significance envelopes. Fig 3.3a shows that when compared to CSR *ahu* appear highly clustered at nearly all spatial scales, though when accounting for the spatial inhomogeneity of *ahu* (Figure 3.3b) they are neither clustered nor dispersed, except for dispersion at distances greater than ca. 1500 m. As expected, these results indicate that *ahu* have an inhomogeneous spatial distribution but little evidence for clustering or dispersion at distances less than 1500 m. Next, we model whether this inhomogeneous spatial distribution is explained by one or more environmental variables.

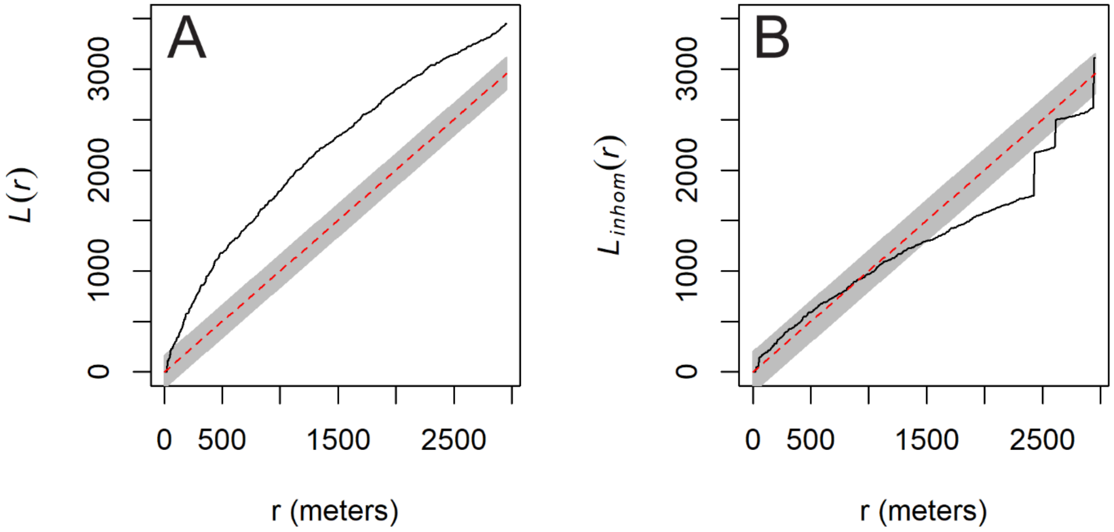

Figure 3.3: Test of hypothesis 1. (A): L-function of *ahu* compared to 39 simulated realizations of CSR; (B): inhomogeneous L-function of *ahu* compared to 39 simulated realizations of CSR. Y-axes are the values of the L-functions at separation distances (r) in meters (x-axes). Results indicate that image-*ahu* have an inhomogeneous intensity lacking second-order properties, though there is some evidence for dispersion at distances >1500 m. Black lines are the empirical L-functions, red dashed lines are the theoretical expectations under the null model, and the grey-shaded region is the envelope of 39 Monte Carlo simulations of the null model.

Figure 3.4 shows the results of the SKS tests on the relationship between *ahu* and marine resource locations, freshwater sources, and rock mulch gardens. The results indicate that *ahu* are not significantly closer to the minimal rock mulch classification than expected under CSR ($D^+ = 0.083$, $p = 0.26$); however, there is a significant spatial association for both the medial ($D^+ = 0.20$, $p = 0.0004$) and maximal classifications ($D^+ = 0.24$, $p < 0.0001$) from Ladefoged et al. (2013). *Ahu* are significantly closer to both marine resource locations ($D^+ = 0.65$, $p < 0.0001$) and freshwater sources ($D^+ = 0.59$, p-value < 0.0001) than expected under CSR. Based on these findings we then formally explored the relationship between *ahu* and marine resource locations, freshwater sources, the maximal rock mulch classification, and the coastline using PPM and multi-model selection. We also applied the same PPM procedure using the medial rock mulch classification and a <5 MASL threshold for marine resource locations and obtained similar results (see Appendix A).

Table 3.1 shows the different candidate models with their ΔAIC, ΔBIC, and weights. Both model selection tools indicate that *ahu* spatial patterns are poorly explained by just distance from the coastline, suggesting that some additional spatial covariate is needed to explain the distribution of *ahu*. Both AIC and BIC indicate that *ahu* locations are best explained by an additive model with the combined effects of distance from the coastline and distance from freshwater sources (model 5) with a ΔBIC of 0 and a BIC weight of 0.675 and a ΔAIC of 0 and an AIC weight of 0.35.

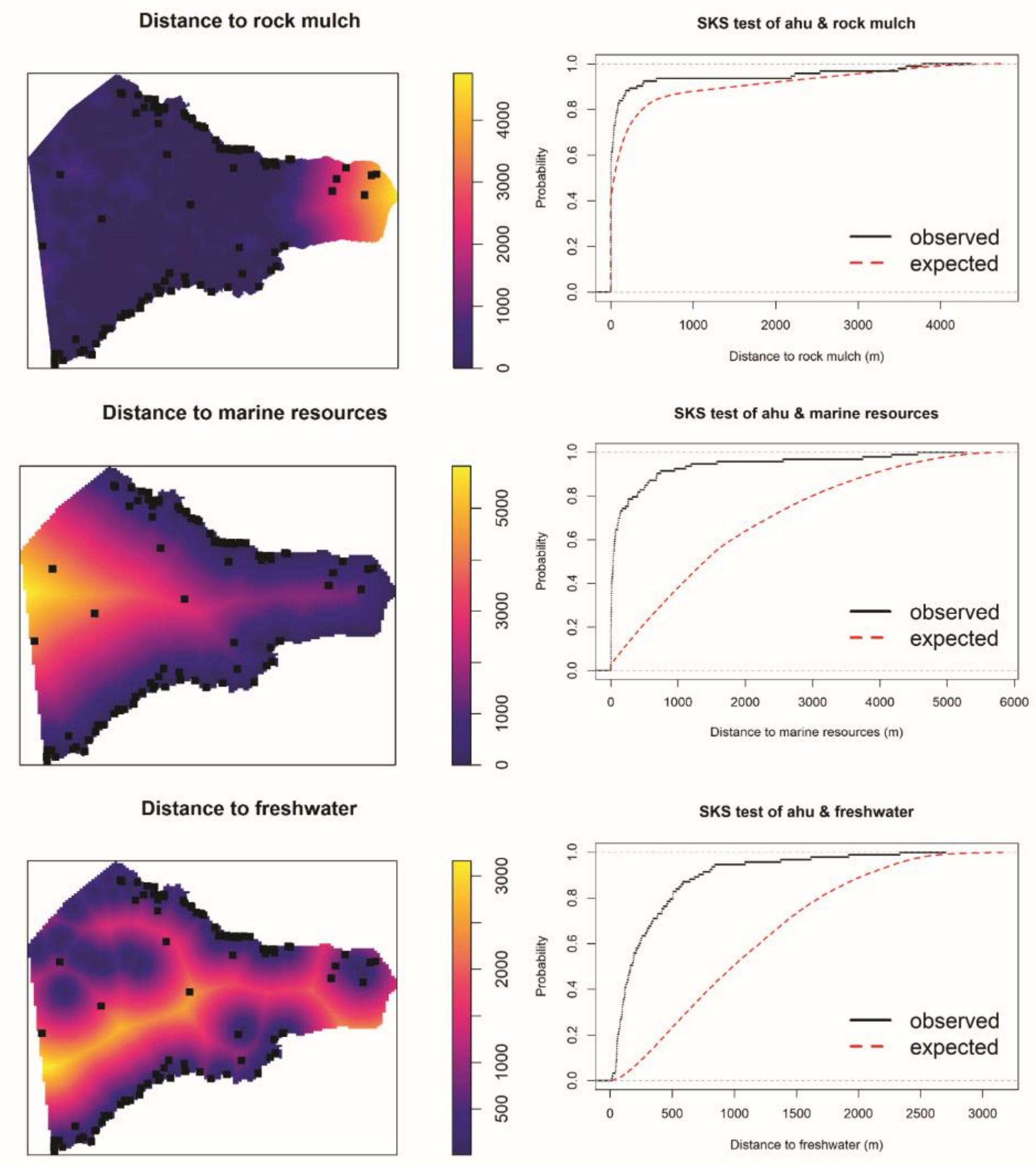

Figure 3.4: Spatial Kolmogorov-Smirnov (SKS) tests. SKS tests for the relationship between image-*ahu* (black squares) and distance (m) from subsistence resource locations (choropleth maps). Observed distribution (black lines) is compared to the expected distribution under CSR (dashed red lines) with the alternative hypothesis being that *ahu* are nearer to these resources than random. Results suggest *ahu* are significantly clustered near freshwater sources ($D^+=0.59$, $p<0.0001$), marine resource locations ($D^+=0.65$, $p<0.0001$), and the maximal rock mulch garden classification ($D^+=0.24$, $p<0.0001$). Results for minimal and medial mulch classifications can be found in Appendix A.

Table 3.1: Point-process model selection for the relationship between ahu and subsistence resources. Smaller change in information criteria score (ΔBIC and ΔAIC) and higher weight indicate best-fitting model.

Model	***Covariates***	***df***	***ΔBIC***	***ΔAIC***	***BIC weight***	***AIC weight***
1	Coastline	2	49.61	52.14	0	0
2	Freshwater	2	54.62	57.16	0	0
3	Marine resources	2	61.36	63.89	0	0
4	Rock mulch	2	231.19	233.72	0	0
5	**Coastline + freshwater**	**3**	**0**	**0**	**0.675**	**0.350**
6	Coastline + marine resources	3	51.91	51.91	0	0
7	Coastline + rock mulch	3	35.28	35.28	0	0
8	Freshwater + marine resources	3	5.51	5.51	0.043	0.022
9	Freshwater + rock mulch	3	58.94	58.94	0	0
10	Marine resources + rock mulch	3	50.51	50.51	0	0
11	freshwater + marine resources + rock mulch	4	10.02	7.49	0.005	0.008
12	Coastline + freshwater + marine resources	4	2.66	0.13	0.178	0.328
13	Coastline + freshwater + rock mulch	4	4.36	1.83	0.076	0.140
14	Coastline + marine resources + rock mulch	4	34.88	32.34	0	0
15	Coastline + freshwater + marine resources + rock mulch	5	6.75	1.68	0.023	0.151

Table 3.2 shows the covariate estimates, standard errors, 95% confidence intervals, and Z values for the best fitting model 5. Negative values of the covariate estimates indicate that *ahu* intensity decreases with distance from the coast and freshwater sources, i.e., the inhomogeneous intensity of image-*ahu* is greatest near these resources. Figure 3.5 graphically displays the inverse relationship between the effect of distance from water sources on the intensity of *ahu*.

Table 3.2: Covariates for best-fitting Model 5. Negative covariate estimates indicate that *ahu* intensity decreases with distance from the coast and freshwater sources.

Covariate	**Estimate**	**Standard error**	**95% Confidence interval, low**	**95% Confidence interval, high**	**Z-test**	**Z-value**
(Intercept)	-11.2	0.16	-11.6	-0.1	<0.0001	-70.06
Distance from coastline	-0.001	0.0003	-0.002	-0.0007	<0.0001	-4.7
Distance from water	-0.003	0.0004	-0.003	-0.002	<0.0001	-5.9

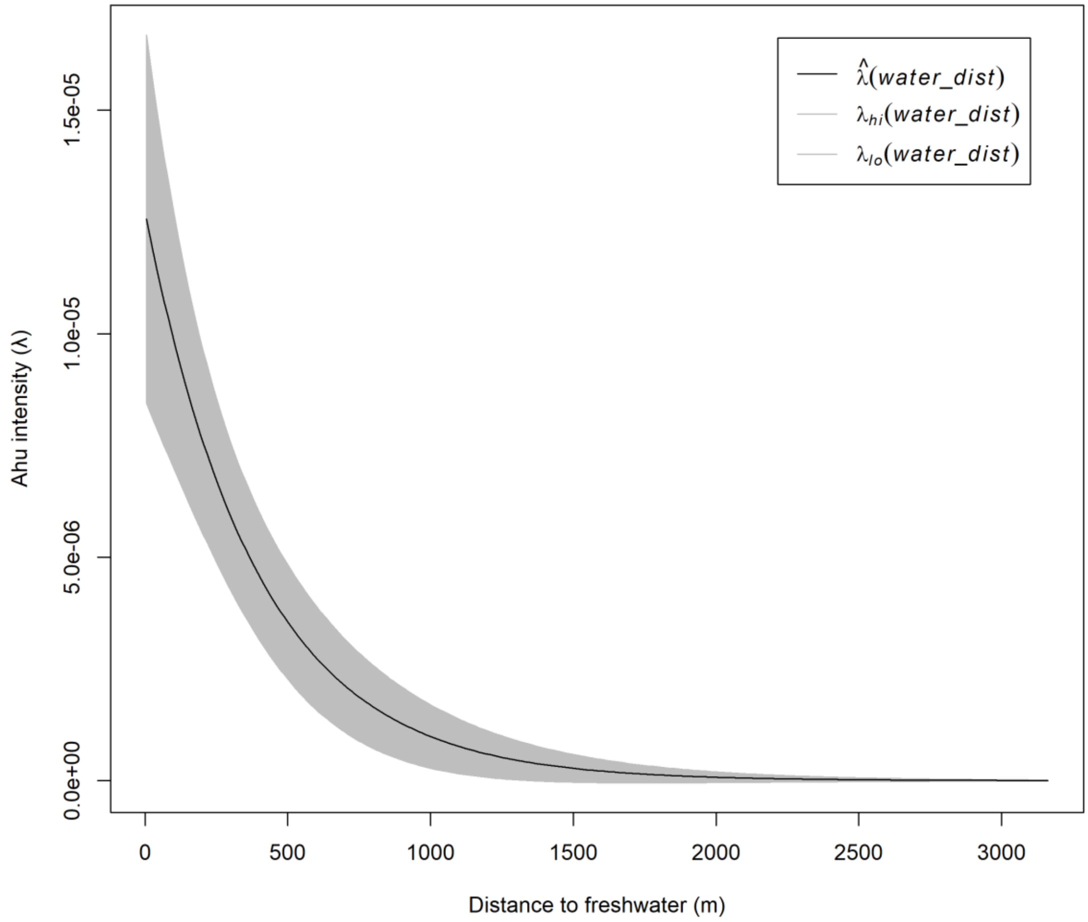

Figure 3.5: Effect of distance from freshwater sources on the spatial intensity of image-ahu. *Ahu* spatial intensity declines with distance from freshwater sources. Grey-shaded region represents the 95% confidence interval.

Figure 3.6 shows the result of the residual L-function test, which serves as a form of model validation. The results indicate no significant deviations between model 5 and the data. To further validate the model, we also used a MAD and DLCF test (Baddeley et al., 2014). The results of these tests indicate that model 5 is a good fit to the data (MAD=171.91, p=0.22; U=41528000, p=0.18). This finding indicates that the inhomogeneous spatial intensity of image-*ahu* is sufficiently explained by the model 5 covariates and that no second-order interaction parameters (e.g., clustering/dispersion) are warranted, thus pointing to the significance of freshwater sources and their association with *ahu* locations.

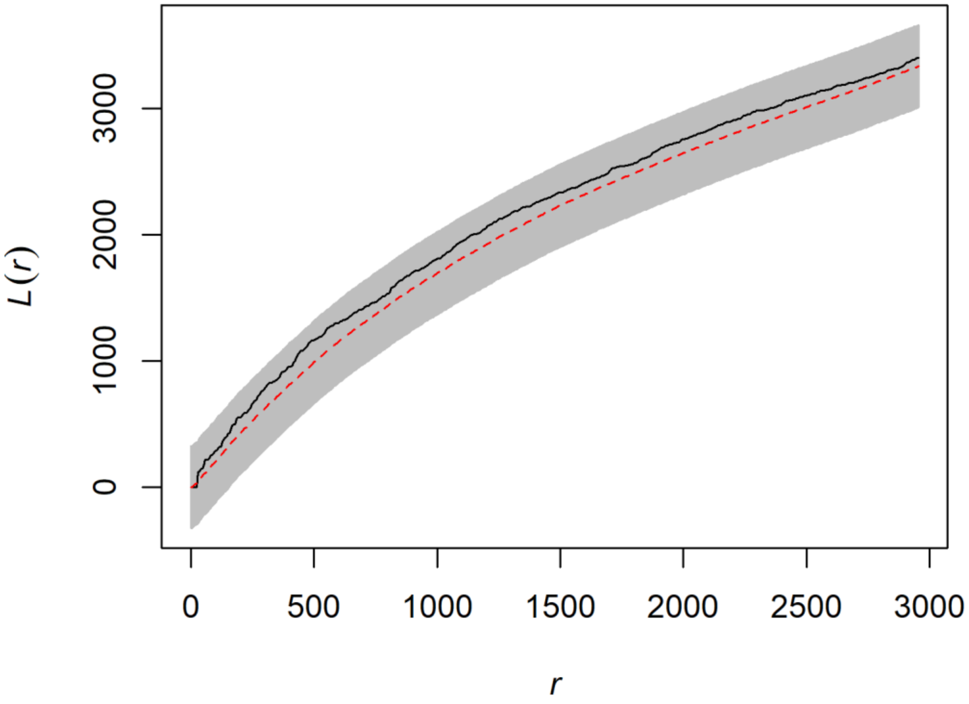

Figure 3.6: Residual L-function for best-fitting model. Red dashed line is the theoretical L-function of the model, grey shaded region represents the upper and lower bounds of 39 Monte Carlo simulated realizations of the model (*p*=0.05), and the black line is the L-function for *ahu*. Y-axis is the value of the L-function at distances (r) in meters (x-axis) Results indicate no significant deviation between model 5 and the data.

A final step in model validation is to visually compare simulated realizations of the best-fitting model 5 against the empirical point pattern using the Metropolis-Hasting algorithm (Geyer and Møller, 1994). Figure 3.7 shows 20 simulated realizations of the best-fitting model. The results show that the model produces point patterns that are primarily coastal in distribution but with a few scattered points inland, similar to the empirical distribution of image-*ahu* (Figure 3.2a).

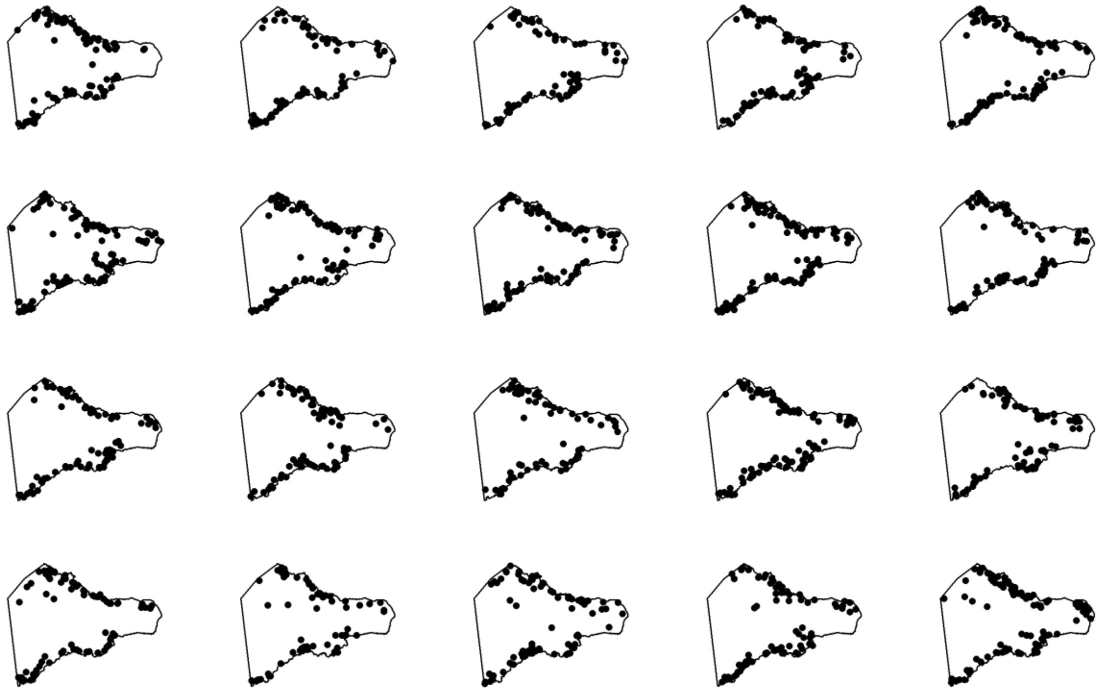

Figure 3.7: Simulated realizations of the best-fitting model. 20 simulated realizations of the best-fitting model 5 incorporating distance from the coastline and distance from freshwater sources.

3.8. Discussion

The results indicate that the image-*ahu* point-pattern exhibits neither clustered nor dispersed second-order properties but that their inhomogeneous coastal distribution is sufficiently explained by a dependent relationship with some subsistence resources, though not others. Our findings do not support the claims that *ahu* are related to competition over or monitoring of agricultural resources, at least in the sense that the distribution of image-*ahu* are not explained by the locations of rock mulch gardens, which were the source of intensified sweet potato production (e.g., Stevenson et al., 2006, 2002, 1999; Wallin et al., 2005). While the construction of Rapa Nui's monuments may be coeval with the establishment of rock mulch field systems, image-*ahu* do not appear to be built in locations to mark control or territoriality over these resources. This result is supported by other evidence indicating a lack of control over other resources, in particular fine-grained basalt, *moai* tuff, and red scoria (e.g., Simpson and Dussubieux, 2018b; Simpson et al., 2018a; cf. Stevenson et al., 2013).

While our exploratory SKS analyses suggest a strong and significant spatial association between *ahu* and marine resource locations, our PPM and multi-model selection suggests this variable is not particularly meaningful. It is likely that marine resource locations appear correlated with image-*ahu* due to their geographic proximity to the more meaningful explanatory variables (coastline, freshwater). That is, because marine resource and freshwater locations tend to occur in similar locations, significance tests show that *ahu* are significantly related to both. It is in this kind of situation where multi-model selection is useful. Based simply on summary statistics and significance tests, image-*ahu* appear to be located near prime marine resource access points; however, marine resource locations are not necessary to explain the spatial patterns of *ahu*. These results highlight the strengths of formal model selection over the more common method of significance testing in archaeological analyses (e.g., Beheim and Bell, 2011; Bell et al., 2015; Eve and Crema, 2014). Significantly, our results offer little support to recent claims that *ahu* were preferentially built at locations that mark control over marine resource locations (e.g., Kirch, 2017, p. 236). As emerging lines of evidence indicate that marine resources were likely not as limited in the past as once thought (e.g., Jarman et al., 2017), they may not have been the focus of inter-community resource competition.

Our multi-model selection indicates that, in addition to their primarily coastal distribution, image-*ahu* spatial patterns are most parsimoniously explained by an inhomogeneous Poisson PPM that models the spatial trend using distance from freshwater sources. Our multiple model validation procedures show that, when accounting for these covariates, no second-order properties are needed to explain the spatial intensity of image-*ahu*. Overall, simulated realizations of the model (Figure 3.7) produce patterns that are remarkably similar to the empirical *ahu* pattern, with most points occurring near the coast but with a few scattered inland. This suggests that our model 5, which incorporates distance from the coastline and freshwater sources, captures the underlying spatial patterns of *ahu* well.

This result is significant, as it likely explains the previously unresolved issue of why Rapa Nui's monuments occur primarily along the coast – one the most abundant sources of freshwater, coastal seeps, occurs primarily in coastal locations. The fact that our model 5 is a much better fit than the simpler model 1, which only includes distance from the coastline, offers compelling support for the claim that *ahu* are related to freshwater locations.

While one might argue that these results are unsurprising given that human settlements tend to be associated with freshwater sources, this would not account for important characteristics of the settlement pattern on Rapa Nui, which, like elsewhere in Polynesia (e.g., Graves and Ladefoged, 1995, p. 154; Graves and Sweeney, 1993, p. 109), is characterized by ritual architecture being spatially distinct from domestic settlement clusters. Specifically, areas of domestic activity are slightly disassociated from *ahu* and tend to occur 100-200 m inland (McCoy, 1976; Morrison, 2012; Stevenson, 1984). While these separation distances between domestic and ritual activity are not great in an absolute sense, what is notable here is the non-random relative patterning in the topology of domestic features and monument locations. For example, Morrison (2012) found that clustered sets of co-occurring domestic activity areas were spatially segregated from the locations of *ahu.* However, at larger spatial scales, groups of these redundant sets of domestic features, while located further inland, are generally clustered around one or more *ahu.* In other words, while *ahu* were indeed the focal points for the settlement pattern, they are spatially offset from them, and directly adjacent to freshwater sources. These patterns suggest a link between freshwater locations and the factors underlying the emergence of ritual monument construction on the Rapa Nui landscape.

One interpretation of these results is that *ahu* were preferentially built near freshwater sources to demarcate community access/control over these resources. This interpretation draws on the logic of costly signaling theory, whereby Rapa Nui's monuments are hypothesized to serve as conspicuous displays of community access/control over the island's limited subsistence resources. Recently, such a costly signaling model for *ahu* has been proposed (DiNapoli et al., 2018; DiNapoli and Morrison, 2017; e.g., Hunt and Lipo, 2018, 2011), which predicts that, if Rapa Nui's monuments did serve a costly signaling function, then there should be a spatial association between them and the underlying quality they are potentially signaling, such as the limited and vitally important, freshwater resources. These predictions are quantitatively supported by our present results. Such an interpretation is not unique. McCoy (1976), who conducted the first large-scale settlement pattern analysis on Rapa Nui, suggested that warfare in precontact times would have likely been over freshwater. It is interesting to note that McCoy (1976, p. 130) also suggested a signaling function for *ahu* and argued that, "[e]laboration of…ahu…would, from present knowledge, provide a rough index of success in competition between lineages…based ultimately on the free time that could be allotted to such non-vital activities." Several emerging and independent lines of evidence show that there is little empirical support for violent warfare, including little evidence for the production of lethal weapons (Lipo et al., 2016; Stevenson and Williams, 2018), limited instances of lethal skeletal trauma (Owsley et al., 2016), and a lack of fortifications (DiNapoli et al., 2018; Lipo and Hunt, 2009; Mulrooney et al., 2010, 2009). Given this lack of evidence for warfare, it is possible that inter-community competition took the form of territorial displays, or costly signals, through the construction of monumental architecture directly adjacent to the island's limited freshwater locations. However, additional formal analyses to specifically test these ideas are needed to evaluate this scenario.

One limitation of our analysis is the lack of explicit spatio-*temporal* analyses of *ahu*. Unfortunately, such a comprehensive temporal analysis is not possible at this time given the overall lack of secure and high precision radiocarbon dates for Rapa Nui (Lipo and Hunt, 2016; Mulrooney, 2013a). We can say, however, that the construction of *ahu* likely began shortly following colonization and within ca. 500 years they numbered in the many hundreds. Temporal changes in the island's environment and resources have been the subject of intensive research and prolonged debate. Regarding changes in freshwater availability, several researchers have suggested that the loss of the island's palm forest severely degraded the amount of available surface freshwater (Bahn and Flenley, 2017, p. 216; Mieth and Bork, 2018, p. 52; Rull, 2018; e.g., Steadman et al., 1994; Vogt and Kühlem, 2018); however, little in the way of hydrologic rationale nor data have been presented to suggest this would be the case. Lake-core sediment data suggest a possible prolonged period of drought from the 16th to 18th centuries (e.g., Cañellas-Boltà et al., 2013; Rull, 2016) that would have reduced available freshwater from precipitation. These potential climatic and landscape changes would have only increased the vital importance of freshwater coastal seeps. Given the island's hydrogeology, the locations of these freshwater sources (and also marine resource locations) have likely remained stable over time, and as many have argued, the growth of the island's lithic mulch field systems is coeval with the construction of monumental architecture (Stevenson et al., 2006, e.g., 1999; Wallin et al., 2005). Therefore, we see our spatial analyses as an investigation of the processes that led to the formation of Rapa Nui's monumental landscape – a spatial pattern which appears best explained by the location of freshwater sources. However, an extension of our analysis to the western portion of Rapa Nui, once freshwater data from that region become available, will be necessary to more fully explore these spatial patterns of monument construction.

The contrast between Rapa Nui's marginal environment and the degree of investment in monumental architecture has puzzled researchers since first European contact. The long held orthodox view assumed that the island must have supported a larger and more complex society under more prosperous environmental conditions that then 'collapsed' following a self-imposed 'ecocide' (Diamond, 2005). In recent years, nearly every major component of this narrative has been shown to lack empirical sufficiency (e.g., Hunt and Lipo, 2011; Mulrooney, 2013a; Mulrooney et al., 2010; Simpson and Dussubieux, 2018b). A key finding is that the construction and transport of the island’s *moai* and *pukao* (red scoria ‘hats’) required neither large numbers of individuals nor trees (Hixon et al., 2018; Lipo et al., 2013). The implications of this are far-reaching, particularly in that they question the common assumptions that monument construction necessarily involved complex social organization and labor management or that it necessarily led to environmental degradation (e.g., deforestation, erosion, etc.). Major unresolved issues, however, concern the labor invested and choices made in constructing *ahu*, in particular why *ahu* (and the *moai* and *pukao* upon them) were built where they were and how monument construction might relate to territorial signaling of control over subsistence resource availability. Here, we have presented a series of formal models which indicate that if Rapa Nui’s monuments did indeed serve a territorial display function (in addition to their well-known ritual roles), then their patterns are best explained by the availability of the island’s limited freshwater.

CHAPTER IV

A BAYESIAN CHRONOLOGY FOR RAPA NUI MONUMENT CONSTRUCTION

This chapter was previously published as:

DiNapoli, R. J., Rieth, T. M., Lipo, C. P., & Hunt, T. L. (2020). A model-based approach to the tempo of “collapse”: The case of Rapa Nui (Easter Island). *Journal of Archaeological Science*, 105094.

4.1. Introduction

Monumental architecture, such as earthen mounds, massive stone circles, burial complexes, and temples trace the history of collaborative achievements by human communities over the last ca. 10,000 years. Because building these structures necessarily required group-level cooperation, their appearance, elaboration, and cessation at different times and places around the world are useful as archaeological evidence for changes in social organization and complexity (Abrams, 1989; DeMarrais et al., 1996; Kirch, 1990a; Marcus and Flannery, 2004; Trigger, 1990). Yet, given the wide range of environmental and social conditions under which these phenomena emerge, explaining the dynamics of monument construction in different world regions remains a central challenge to archaeologists (DiNapoli et al., 2019; Howey et al., 2016). One step toward progress in this effort requires the establishment of reliable chronologies that provide probabilistic estimates for when monumentality begins, the timing of investments in these features made over the duration of their use, and the point at which construction activities cease. It is through such information that archaeologists can document events associated with increases in organizational complexity, cultural resilience in the face of environmental or demographic changes, or societal collapse.

Though the definition and process of ‘collapse’ have long been debated (e.g., Butzer and Endfield, 2012; Kirch and Rallu, 2007; McAnany and Yoffee, 2010; Middleton, 2012; Scheffer et al., 2012; Schwartz and Nichols, 2006; Strunz et al., 2019; Tainter, 1988, 2006; Yoffee and Cowgill, 1988), most scholars agree that these kinds of events commonly involve the end or decline in some kind of activity, whether it be changes in settlement patterns, like depopulation of political centers, declines in focal aspects of religious and social activity, such as the end of monument construction, or other factors (e.g., Dunnell and Greenlee, 1999; Middleton, 2017; Turner and Sabloff, 2012). In a recently proposed series of ‘grand challenges’ for archaeology, Kintigh et al. (2014a, 2014b) highlight collapse as a central issue in the discipline and stress the need for broadly applicable ways of characterizing societal declines or transitions. One basic, but critical, component for resolving these issues concerns the chronology of these events in absolute and relative terms (Butzer and Endfield, 2012; Scheffer, 2016; Scheffer et al., 2012). Some recent studies have approached this issue using summed probability distributions of radiocarbon dates (e.g., Downey et al., 2016; Hoggarth et al., 2016; Shennan et al., 2013). Here, using the hypothesized ‘collapse’ of Rapa Nui (Easter Island) monument construction as a case study, we present an alternative approach that makes use of Bayesian model-based testing of hypotheses for collapse that considers the onset, tempo, and cessation of archaeological events. Our Bayesian approach combines radiocarbon determinations, relative chronological information from architectural stratigraphy, and ethnohistoric accounts with the recently developed ‘tempo plot’ technique (Dye, 2016) to provide rigorous, model-based estimates for when monument construction begins, the rate of change in monument construction events, and the most likely timing for the cessation of these activities.

Our results provide a key line of evidence contradicting the collapse narrative for Rapa Nui and thus calls into question a broad range of interdisciplinary research that uses the island as a model for societal decline more generally. Though we approach the issue of collapse on Rapa Nui with reference to chronologies of monument construction, we discuss how our methodological approach to testing hypotheses regarding the chronology of collapse can be extended to other case studies around the world where similar debates remain difficult to resolve.

Rapa Nui (Easter Island, Chile, Figure 4.1) presents a quintessential case in world history where the tempo of intensified monument construction is central to debates regarding societal collapse. This small (164 km^2) and isolated island is situated in the southeastern margin of East Polynesia, some 3000 km from South America and nearly 2000 km from the nearest inhabited island. Current estimates suggest that Polynesian voyagers initially colonized the island around the 13th century AD (e.g., Hunt and Lipo, 2008, 2006; Lipo and Hunt, 2016; Wilmshurst et al., 2011). At some point after this event, islanders began constructing megalithic platforms (*ahu*) and carving and transporting multi-ton statues (*moai*). These monuments subsequently served as a major focal point for social and ritual activity of Rapa Nui's pre-contact communities (Martinsson-Wallin, 1994; Métraux, 1940; Morrison, 2012; Stevenson, 2002). Despite its size and remote location, the present archaeological record of Rapa Nui boasts hundreds of *ahu* and nearly 1000 *moai*.

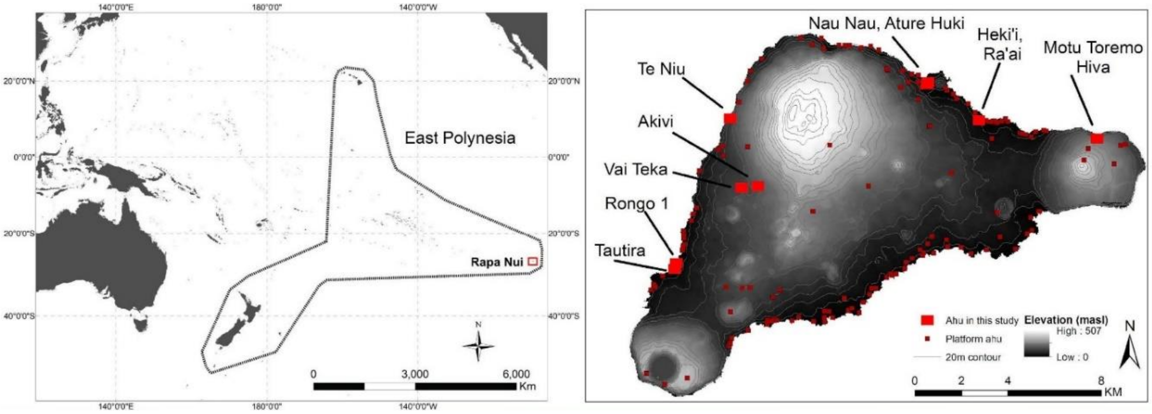

Figure 4.1. Rapa Nui and East Polynesia. East Polynesia (left), and Rapa Nui showing the locations of all documented platform *ahu* as well as those analyzed in this study (right).

The role of monument construction over the course of Rapa Nui's culture history has been the subject of prolonged speculation and debate. *Ahu* construction and elaboration is commonly used as evidence for increasing social complexity and fission-fusion patterns among Rapa Nui's social groups (Stevenson, 2002, 1997, 1986; Wallin and Martinsson-Wallin, 2008). In addition, numerous archaeological narratives for the island posit that an accelerated pace of monument construction, during the "Ahu Moai" phase, led to an environmental and demographic collapse around the 17th century. A core component of this narrative is the rapid destruction of monuments and end of *ahu* and *moai* construction, a time period termed the "Huri Moai," literally 'statue toppling,' phase (Bahn and Flenley, 2017, 1992; Diamond, 2005; Flenley and Bahn, 2003; Kirch, 2017, 1984b; Smith, 1961a). While a popular account, the lack of empirical evidence for many aspects of this narrative (Hunt, 2007; Hunt and Lipo, 2011; Mulrooney, 2013a; Mulrooney et al., 2010, 2009) has led some to argue that monument construction was instead a key factor in the long-term persistence of pre-contact communities that only terminated as a consequence of changes following the arrival of Europeans (Boersema, 2015; DiNapoli et al., 2019, 2018; Hunt and Lipo, 2018, 2011; Lipo et al., 2018; Mulrooney et al., 2010; Peiser, 2005). Despite these criticisms, the notion that the late pre-contact period on Rapa Nui was a time of severe cultural and demographic changes remains popular (e.g., Bahn and Flenley, 2017; Kirch, 2017; Puleston et al., 2017; Rull, 2018, 2016; Rull et al., 2018; Scheffer, 2016). Indeed, the narrative of collapse on Rapa Nui is still persistently used in fields outside archaeology as a model for societal collapse, treating the supposed events of the 'Huri Moai' phase as historical fact (e.g., Akhavan and Yorke, 2019; Anderies, 2000; Basener and Ross, 2004; Basener and Basener, 2019; Bologna and Flores, 2008; Brander and Taylor, 1998; Brandt and Merico, 2015; Cazalis et al., 2018; D'Alessandro, 2007; Dalton et al., 2005; Dalton and Coats, 2000; de la Croix and Dottori, 2008; Dockstader et al., 2019; Erickson and Gowdy, 2000; Pezzey and Anderies, 2003; Reuveny, 2012; Reuveny and Decker, 2000; Roman et al., 2017; Takács et al., 2019; Uehara et al., 2010).

Monumental architecture is central to explanations of Rapa Nui culture history and the proposed collapse of its pre-contact society. Yet, the chronology of *ahu* construction remains poorly resolved, leading to uncertainty in evidence such that debates are difficult to settle. For example, while we can currently say that monument construction was widespread during some component of Rapa Nui's history, further details about the onset, rate, and duration of these activities are ambiguous. Moving past this generalization requires developing chronological models for these events involved in monument construction activities. Like with many chronological issues in archaeology, formal Bayesian models provide a useful tool to better resolve temporal patterns of monument construction (e.g., Carter et al., 2019; Chirikure et al., 2013; Culleton et al., 2012; Dye, 2016, 2012; Schulz Paulsson, 2019).

4.2. Previous Chronologies for *Ahu* Construction

Heyerdahl and Ferdon's (1961) Norwegian archaeological expedition to Rapa Nui in the 1950s provided the first modern attempts to build an absolute chronology for *ahu* construction. They built their chronology based on stratigraphic evidence derived from the excavation of numerous *ahu* complexes as well as ^{14}C dates from *ahu* Vinapu, Te Peu, and several other important sites on the island. Based on this evidence, they argued that the island experienced an early period of *ahu* construction around ca. AD 800 and that this activity continued until AD 1600s (Smith, 1961b). Following Heyerdahl and Ferdon, Ayres (1971) offered the next absolute chronology based on ^{14}C dates from excavations at *ahu* Tahai and Ko te Riku. Evidence from his excavations suggested that initial *ahu* construction activities began around AD 700. Mulloy and Figueroa (1978) later proposed that the initial construction of *ahu* Akivi and Vai Teka did not begin until ca. AD 1450. Using a large suite of obsidian hydration dates from several south coast *ahu*, Stevenson (1986, pp. 74–76) argued that the initial construction of *ahu* Vaihu, Akahanga, and Ura Uranga te Mahina took place between AD 1301-1400, with additional platform *ahu* construction and rebuilding episodes continuing into the late 1600s. Stevenson (1997, pp. 8–13) later altered this chronology using a different hydration rate constant to argue that initial construction occurred as early as ca. AD 1000, with platform construction limited after ca. AD 1500-1600. In their reviews of early ^{14}C dates from several *ahu* across the island, including *ahu* Nau Nau and Ature Huki (Skjølsvold, 1994), Heki‘i (Martinsson-Wallin, 1998; Martinsson-Wallin and Wallin, 1998), Ra‘ai (Martinsson-Wallin and Wallin, 2000), Viri o Tuki (Huyge and Cauwe, 2005), Motu Toremo Hiva (Cauwe et al., 2010, 2006), Vinapu (Martinsson Wallin, 2004), Rongo (Huyge and Cauwe, 2002), and Tautira (Martinsson-Wallin and Crockford, 2002), Wallin and colleagues (P. Wallin et al., 2010, p. 43; Wallin and Martinsson-Wallin, 2008, p. 154) suggest that initial construction of these complexes likely occurred around AD 1250-1400, but possibly as early as AD 1100-1200. In a later analysis of a select sample of ^{14}C dates from *ahu*, Martinsson-Wallin et al. (2013b) used summed probability distributions (SPD) to estimate the onset and cessation of *ahu* construction. In their visual interpretation of the *ahu* SPD, they suggest that *ahu* complexes “were securely in place on Rapa Nui by ca. AD 1300-1400” and claimed that a ‘destruction phase’ for large platform *ahu* occurred around AD 1600 (Martinsson-Wallin et al., 2013b, pp. 417, Figure 7). This argument for a “[d]egeneration of ceremonial sites” (Wallin and Martinsson-Wallin, 2008, p. 154) during a destruction phase for platform *ahu* around AD 1600 assumes a transition from the “Ahu Moai” phase to the “Huri Moai” phase in Rapa Nui culture history (Kirch, 1984b, 2017; Smith, 1961a; cf. Mulrooney et al., 2009; Lipo and Hunt, 2009).

These previous dating programs have provided valuable data and working hypotheses for monument construction and testing the collapse narrative on Rapa Nui. These estimates for initial *ahu* construction are limited, however, given that they are not based on formal statistical models but on *ad hoc* visual approximations of the calibrated date lists, or in the case of Martinsson-Wallin et al.(2013b), visual approximations of an SPD. Given contemporary concerns over choices of samples for generating radiocarbon dates (Hunt and Lipo, 2006; Wilmshurst et al., 2011; Allen and Huebert, 2014; Rieth and Athens, 2013; Spriggs and Anderson, 1993; cf. Schmid et al., 2018), the now well-understood uncertainties with visual interpretations of dates, and a multitude of issues with simple visual inspection of SPD curves (Bayliss et al., 2007; Contreras and Meadows, 2014; Crema et al., 2016; Dye, 2016; Timpson et al., 2014), these chronologies for initial *ahu* construction are in need of re-evaluation. Previous syntheses of ^{14}C data from *ahu* have also not included the rigorous dating program by Wozniak (2003) at *ahu* Te Niu. Furthermore, the timing of the cessation of platform *ahu* construction is poorly understood, given the lack of formal modeling and sporadic and limited historical accounts from the 18th century. Bayesian chronological modeling provides a promising alternative for examining the chronology of *ahu* on Rapa Nui given the island's short chronology and highly overlapping radiocarbon probability distributions, as well as the approach's explicit aim of incorporating prior information about relative construction components from the dated sequences and ability to formally model the timing of events that are otherwise not directly dated (Dye, 2016, 2012; Schulz Paulsson, 2019).

4.3. Chapter Objectives

Here, we use a sample of previously published ^{14}C determinations in concert with relative *ahu* construction events to build a series of Bayesian models to estimate the onset and later tempo of *ahu* construction. I construct these models using OxCal v.4.3.2 (Bronk Ramsey, 2017a). For clarity, we capitalize and italicize OxCal commands (e.g., *Phase, Sequence,* etc.). We use the ArchaeoPhases package (Philippe et al., 2019) to create a tempo plots of *ahu* construction activity. Our primary objectives are: (1) to estimate how soon after the colonization of Rapa Nui initial monument construction began; and (2) to estimate the duration of *ahu* construction events, including initial platform construction and the timing of later investments, such as how far they extend into the pre-contact and/or early historic eras as a means of testing the claim that *ahu* construction ceased following a pre-contact collapse. These objectives require that we have a reliable estimate for initial colonization and select samples that most closely relate to *ahu* construction and use.

4.4. Sample Selection, Radiocarbon Calibration, and Bayesian Modeling Procedures

We use OxCal v 4.3.2 (Bronk Ramsey 2017) to create all Bayesian models. We calibrated terrestrial samples using the SHCal13 southern hemisphere calibration curve (Hogg et al., 2013). For the few human and rat (*Rattus exulans*) bone dates we used a mixed curve of 50% terrestrial (SHCal13) and 50% marine (Marine13; Reimer et al. 2013) based on recent estimates of the marine component of the pre-contact Rapa Nui islander diet and the assumption of a rat diet similar to humans (Jarman et al., 2017; Swift et al., 2018). For the marine calibration, we use a marine reservoir correction (ΔR) of -83±34 (following Beck et al., 2003; Burr et al., 2009; Commendador et al., 2014; Jarman et al., 2017) and also incorporate a ±10 error term for the percentage of the marine component to account for uncertainties in marine diet (following Cook et al., 2015). All modeled results are presented as 95.4% highest posterior density (HPD) estimates. While less precise than the 68.2% HPD, we focus on the 95.4% HPD to give a more accurate chronological estimate. In addition to the documentation provided below, all data and OxCal files are available in Appendix B.

We exclude ^{14}C samples from bulk soil, those with unclear stratigraphic relationships with *ahu* features, those from the Gakushuin lab (GaK) (e.g., Ayres, 1971; Esen-Baur, 1983) known to be problematic (Blakeslee, 1994; Spriggs, 1989; Spriggs and Anderson, 1993) and samples with unknown relations between the target and dated events. For example, we exclude a number of ^{14}C determinations on abraded coral artifacts from Ahu Nau Nau at Anakena given the unknown time lag between coral harvesting and deposition at the *ahu* (Beck et al., 2003, p. 100). We also exclude obsidian hydration dates given long-standing, unresolved issues with the method (see section 4.4.1 below). Given the general lack of short-lived samples from *ahu* contexts, we must rely on unidentified charcoal samples, which may have inbuilt age (Allen and Huebert, 2014). We apply a *Charcoal Outlier* parameter to these unidentified charcoal samples whereby all samples have a 100% probability of being outliers, which can help produce more accurate results in simulated and real-world case studies, especially when paired with multiple *Phases* (Bronk Ramsey, 2009; Dee and Bronk Ramsey, 2014). We also apply a *General* “t” type *Outlier* parameter to all identified charcoal samples to statistically assess potential poor fit between the model and radiocarbon determinations, using an outlier probability=0.05 (Bronk Ramsey, 2009). With these uncertainties and potential issues in mind, the majority of our models for *ahu* construction are best described as TPQs for initial construction.

We present modeled results as 95.4% highest posterior density (HPD) estimates in calibrated years AD. Estimates are rounded out to nearest 5 years. ^{14}C samples used in the colonization models are included in Table S1 and samples for the *ahu* models are in Table S2. We created tempo plots in R (R Core Team, 2019) using the ArchaeoPhases package (Philippe et al., 2019). Full descriptions for each model and tempo plot, including calibration procedures, contextual information, OxCal and R code necessary for reproducing this analysis are available in Appendix B.

4.4.1. A Note on the Exclusion of Obsidian Hydration Dates

Rapa Nui remains one of the few places where obsidian hydration dating (OHD) is still considered by some to be a reliable dating technique, and it has been widely used in determining chronological events and trends for the island (e.g., Stevenson, 1986, 1997, 2000, 2013, 2015; Vargas et al., 2006; cf. Anovitz et al., 1999). For most researchers, the technique has proven to be problematic not for lack of precision in the measurements, but because the conditions under which the hydration process occurs can vary over time and significantly affect the results (Ridings 1996; Stevenson et al. 2000). Temperature, in particular, changes the rate of hydration and thus obsidian artifacts exposed in slightly different locations that vary in their sun exposure or burial depth may produce different dates despite their simultaneous manufacture (Ridings 1996). This general problem is addressed through two means. First, through careful measurement the burial conditions of a deposit can be characterized and average values derived (Rogers 2006; Stevenson et al. 2000, 2013; Stevenson and Williams 2018). While more recent efforts have attempted to measure the potential conditions of buried samples, many samples come from surface conditions or within different *ahu* components and thus their environmental history is unknown (Stevenson, 1984, 1986, 1997). For example, according to Stevenson et al. (2013), the effective temperature between different depth of burial has a tremendous impact on age: between 15cm and 40cm the difference is 0.42 microns squared/1000 years. This means small differences in the depositional location can have 100s of years impact on the calculated date. Though average values used to characterize the conditions of depositional environments may produce a suite of dates that have an overall accurate chronological distribution, one cannot rely upon the date for any particular object. As a consequence, individual dates have error terms of unknown magnitude and direction.

Thus, unlike radiocarbon dates from unidentified charcoal samples that may have uncertainty associated with the relation between the dated event and the target event, the uncertainty associated with OHD is the basic clock used to calculate the date. In terms of radiocarbon dating, this situation would be equivalent to having unknown rates of radioactive decay. Thus, strategies that allow unidentified charcoal dates to be combined in analyses (e.g., Schmid et al 2018, 2019) are likely not equally applicable to OHD dates where the dated event itself is uncertain.

As a consequence of this problem in the case of Rapa Nui, the basic value calculation used by analysts to determine the dates - the rate of hydration - has varied over time. Shifts in the rate values (Table 4.1) seem to have occurred not as a function of increased knowledge about the fundamental physics of hydration on the island but by the perceived “mismatch” of OHD values with perceptions about the then current chronologies reached by radiocarbon dates. Thus, the degree to which OHD “works” on Rapa Nui is largely due to the changes made to keep the values consistent with other forms of dating: a somewhat circular rationale. To give a case in point, Stevenson’s

(1984, 1986) original OHD chronology for south coast *ahu* suggested initial construction activities beginning around AD 1300-1400, but these OHD dates are then re-calibrated for unclear reasons in Stevenson (1997) using a different hydration rate suggesting initial construction possibly as early as AD 1000, consistent with the accepted radiocarbon chronology for Rapa Nui at the time. It is worth noting, however, that Stevenson's (1986) original OHD chronology for south coast *ahu* is consistent with the results of our Bayesian models. Construction of large platform *ahu*, such as *ahu* Akahanga, Ura Uranga te Mahina, and Vaihu, are suggested to begin around AD 1300-1400 with platform *ahu* construction continuing into the late AD 1600s (1986). Stevenson's (1997) revised hydration rate chronology, however, is incompatible with both our estimate for initial colonization of Rapa Nui and Bayesian models for the tempo of *ahu* construction activities.

Table 4.1. A sample of obsidian hydration rates used for Rapa Nui.

Citation	**OHD rate**
Evans 1965	11 microns squared/1000 years
McCoy 1973	2.25 microns/1000 years
Ayers 1975:98	2.7 microns/1000 years
Stevenson 1984, 1986	6.29 microns squared/1000 years for Rano Kau obsidian 7.30 microns squared/1000 years for Motu Iti obsidian
Stevenson 1997	5.67 microns squared/1000 years for Orito and Rano Kau
Stevenson 2013	5.07 microns squared/1000 years

4.4.2. Colonization Models

I use existing radiocarbon determinations from the published literature to provide refined Bayesian estimates for Rapa Nui colonization. We start by using ^{14}C samples with a conventional radiocarbon age (CRA) ≥ 650 BP not from *ahu* contexts (see Appendix B). Our use of a ≥650 BP threshold provides a focus on samples that conceptually relate to the early pre-contact/colonization era, such that the colonization estimate is not biased by younger ^{14}C samples that are unrelated to colonization (Mulrooney et al., 2011). We do not include samples from monumental architecture contexts in the colonization models as these determinations are included in the *ahu* models. We group the ^{14}C samples into a single *Phase*, with the start *Boundary* providing the colonization estimate. We built two colonization models using ^{14}C samples from archaeological contexts: one with only short-lived plant remains (*n*=9), and a second with these nine short-lived samples and 19 unidentified charcoal samples. For the second model, we apply a *Charcoal Outlier* parameter to assess the influence of unidentified charcoal samples on the precision of our colonization estimate (Bronk Ramsey, 2009; Dee and Bronk Ramsey, 2014; Schmid et al., 2018).

We built two single-phase models for the initial colonization of Rapa Nui designed to constrain the *Phases* in the *ahu* models. Our first colonization model contains samples from short-lived plant remains (n=9), and our second model includes these nine short-lived samples and 19 unidentified charcoal samples from archaeological contexts. For the short-lived samples we use a *General Outlier* parameter to statistically assess poor fit between the radiocarbon determinations and the model, where each sample has a

5% chance of being an outlier (following Bronk Ramsey 2009). For the unidentified charcoal samples, we use a *Charcoal Outlier* parameter to account for the possibility of inbuilt age in these samples, where each sample has 100% probability of being an outlier (following Bronk Ramsey 2009; Dee and Bronk Ramsey 2014). The purpose of running two variant models for colonization was to examine the potential for increased precision and accuracy offered by the *Charcoal Outlier* model, as has been recently suggested by Schmid and colleagues (2018, 2019). All samples have conventional radiocarbon ages (CRAs) >650 BP to maximize the likelihood that they are associated with our target event of colonization. Furthermore, we do not include any samples from monumental architecture contexts; these samples are included in our *ahu Phases*, and logic dictates that they should not be part of the constraining colonization *Phase*. Samples used in our colonization models can be found in Appendix B. OxCal code and results for both models are included below.

4.4.3. Ahu Models

Resolving the tempo of monumentality on Rapa Nui has been fraught with ambiguity given a lack of formal modeling, uncritical use of radiocarbon estimates, and a lack of attention to the information embedded within complex architectural stratigraphy. In addition, much of the research on the chronology of *ahu* construction on Rapa Nui has focused primarily on the earliest radiocarbon dates and often neglected to sufficiently analyze later building episodes. Here, we apply a Bayesian model-based approach to dating monumental structures that integrates radiocarbon dates and relative architectural stratigraphy to examine temporal fluctuations and correlations in monument construction activity. All radiocarbon dates from platform *ahu* contexts can be found in Appendix B.

4.4.3.1. A Relative Construciton Model for Platform *Ahu*

Rapa Nui islanders constructed multiple classes of ritual stone structures that are collectively referred to as *ahu*. Here, we focus our study on the ca. 150 known platform *ahu*, also called 'image-*ahu*' or *ahu moai*, which are the largest and most common form of pre-contact *ahu* (Martinsson-Wallin, 1994). The term image-*ahu* denotes that many of these monuments have one or more *moai* statues, though this is not always the case. Their central architectural feature is a rectangular platform with a dressed stone or closely aligned back wall. These central platforms typically contain combinations of auxiliary features, such as linear alignments of stacked stone projecting laterally from the platform (termed 'wings'), a ramp descending from the front of the platform that is paved with water-worn boulders (*poro*), a pavement/plaza of *poro* stone in front of the ramp, a rectangular embankment enclosing the plaza, and a crematorium (which generally is attached to the back side of the platform). *Ahu* also often contain burial features within different components of the structure. Lastly, their visible attributes and stratigraphic information from archaeological excavations have shown that most platform *ahu* were continually added to over the years with multiple building events (Martinsson-Wallin, 1994; Skjølsvold, 1994; Smith, 1961a). These different architectural features allow for building relative chronologies of *ahu* construction that can be used as informative priors in Bayesian models. Specifically, if we consider the different construction elements as depositional events (Dye, 2016, 2010), then the central platform is logically the initial construction component, as the other components are built off of it and, therefore, wings, ramps, crematoria, etc., must logically post-date platform construction (See Figure 4.2 for a model schematic of a typical platform *ahu*). In most instances the stratigraphic relationships between different architectural elements confirm this generalized sequence (e.g., wing structures that abut the central platform).

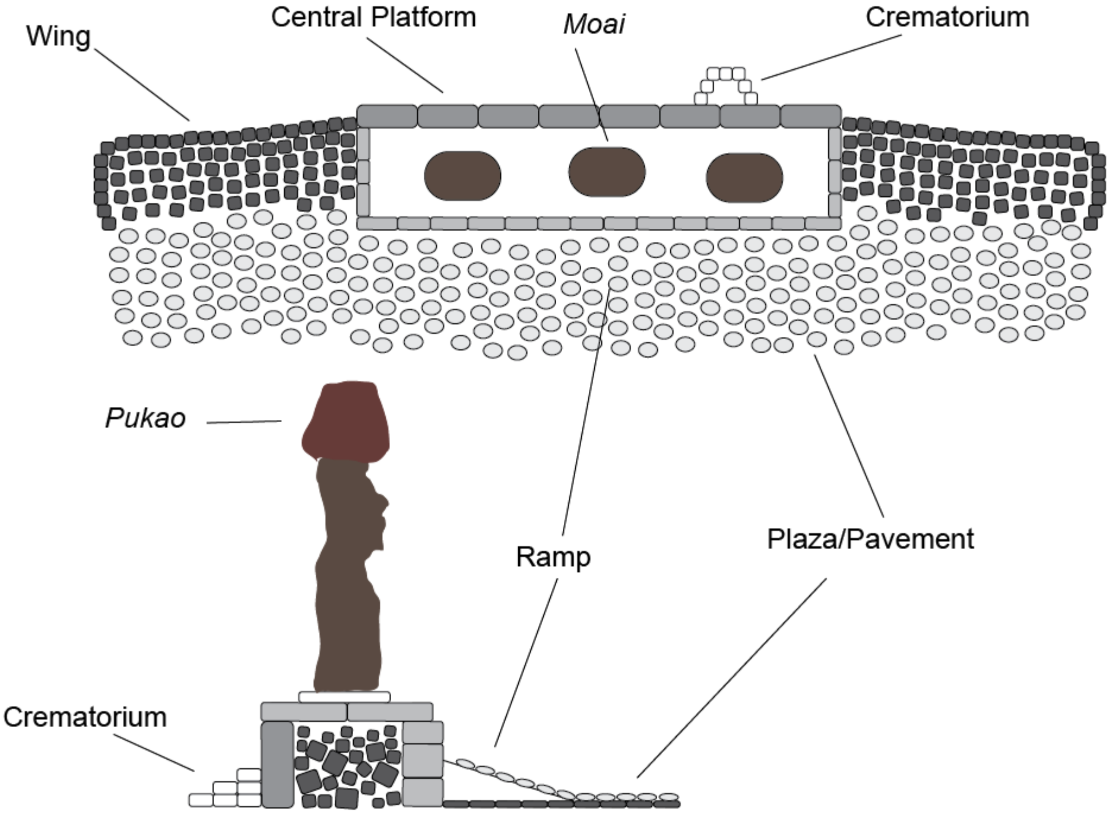

Figure 4.2. Model schematic of a platform *ahu*. Schematic of a typical platform *ahu* showing a plan view (top) and cross-section (bottom). Figure adapted from Martinsson-Wallin (1994) and Skjølsvold (1994).

4.4.3.2. Models for *Ahu* Construction

To build a chronology for events associated with *ahu* construction, we create a series of multi-phase Bayesian models designed to estimate initial platform construction, the timing of later additions, and end of construction for several *ahu*. These models incorporate radiocarbon determinations, relative architectural stratigraphy, and ethnohistoric accounts as informative priors. Using published contextual information from excavations at *ahu*, we group ^{14}C determinations into *Phases* related to the construction of the central *ahu* platform using three classes of events: (1) samples related to events from contexts below the platform are treated as *termini post quos* (TPQs), which we term 'pre-platform construction' phases; (2) samples contextually associated with our target event of platform construction are classified as 'platform construction' phases; and (3) samples from any of the auxiliary features (e.g., ramps, wings) that post-date platform construction are *termini ante quos* (TAQs), which we term 'post-platform' phases. In these models, the determinations from pre-platform, platform, and post-platform events are grouped into unordered *Phases* within an ordered *Sequence*. We also use the *Boundary* start estimate from the colonization model to constrain the estimates for platform construction, as initial *ahu* construction must logically post-date colonization. Lastly, for the end of the *Sequence* we input a uniform calendar date range (of AD 1838-1868 (*Date(U(1838, 1868))* in OxCal) to serve as a cutoff point for the construction estimates . This choice of AD 1838-1868 is based on historic European accounts of the last time a *moai* statue was recorded as still standing upright on an *ahu* platform, which serves as a conservative estimate for the time period after which we assume no platform *ahu* were built (see below for an extended discussion of this rationale). This final parameter simply serves to constrain the right side of the calibrations in the post-platform phase. The general form of these *ahu* models is: Colonization > TPQ (pre-platform) > Target (platform construction) > TAQ (post-platform) > AD 1838-1868.

We constructed multi-phase models for each individual *ahu* with ^{14}C determinations from either (a) TPQ, target, and TAQ; (b) TPQ and target, (c) target and TAQ, or (d) TPQ and TAQ events. Models of types (a), (b), and (c) are constructed as Contiguous *Sequences*, and the start of the target event *Boundary* provides the estimate for initial *ahu* construction, the start *Boundary* for the post-platform phase provides the estimate for later construction events, and the end *Boundary* estimates the end of ahu construction activities. Models of type (d) are constructed as Sequential *Sequences*, and we insert a *Date* command between the end *Boundary* of the pre-platform *Phase* and the start *Boundary* of the post-platform *Phase* to estimate the start of platform construction. We use the *Difference* query to estimate the temporal lag between the colonization *Boundary* and the start of construction for each *ahu*.

Here, we present a series of multi-phase Bayesian models designed to estimate initial platform construction, later additions, and end of construction for several *ahu*. Based on published contextual information from excavations at *ahu*, we group ^{14}C determinations based on their stratigraphic relationship to initial platform construction. We excluded dates with an unclear contextual relationship with the *ahu* and provide the rationale for each exclusion below. ^{14}C samples from contexts stratigraphically pre-dating the construction of the central platform are grouped into *termini post quos* (TPQ) *Phases* (i.e., pre-platform), samples from contexts within the platform itself are grouped into

Target event *Phases* (i.e., platform construction), and samples from contexts stratigraphically post-dating the central platform, such as samples from auxiliary *ahu* components (e.g., ramps, plazas, wings) that must logically post-date the central platform, are grouped into *termini ante quos* (TAQ) *Phases* (i.e., post-platform). Figure 4.2 shows a model schematic of a typical platform *ahu*.

The TPQ *Phases* of these models are constrained by the start *Boundary* estimate from our colonization model given that the construction of *ahu* must logically post-date initial colonization. This colonization estimate is placed within an *After* command specifying that all events must follow colonization. Here, we use the result from our second, more precise colonization model incorporating unidentified charcoal and a *Charcoal Outlier* model. Rather than insert the colonization model code into each *ahu* model, we exported the .prior file for the start colonization *Boundary* estimate (95.4% HPD). Exporting the .prior file ensures that the exact same colonization estimate is used in each *ahu* model, which would otherwise vary slightly given the stochastic nature of OxCal's MCMC. Using the .prior file also has the added benefit of more concise OxCal code for each *ahu* model. This colonization .prior is then inserted within an *After* command at the beginning of each *ahu* model *Sequence*, which specifies that all other parts of the *Sequence* must come after this time (the colonization .prior file can be found at https://github.com/rdinapoli/RN_Ahu_Bayesian).

The end of the TAQ *Phases*, which provide an estimate of the latest possible dates for *ahu* construction activities, are constrained by a uniform calendar date range between AD 1838 and 1868 (*Date(U(1938, 1868))* in OxCal). We chose this date range based on historic European accounts of the last time a *moai* statue was recorded as still standing erect on a platform *ahu*. Specifically, at the time of initial European contact in AD 1722 the Dutch captain Roggeveen (Corney et al., 1967:15) observed that the Rapa Nui islanders "kindle a fire in front of certain remarkably tall stone figures they set up; and, thereafter squatting on their heels with heads bowed down, they bring the palms of their hands together and alternately raise and lower them" which clearly indicates that by AD 1722 image *ahu* were still the focus of ritual activity (Boersema 2015:89-90; Mulrooney et al., 2010:147). Though there are no known European accounts of Rapa Nui islanders constructing platform *ahu* given in this historical account, it is possible, even likely, that these activities continued beyond AD 1722. Furthermore, both the Dutch and later Spanish expedition (in AD 1770) make no mention of fallen *moai* statues. The first European account of toppled *moai* is by Cook in 1774, with a series of European accounts describing both erect and fallen statues continuing up until AD 1838 when Dupetit-Thouars observed four standing *moai* and in AD 1868 Palmer claims there were no longer any erect *moai* on platform *ahu* (see discussion in Edwards et al. 1996). Therefore, we use a conservative estimate of sometime between AD 1838 - 1868 as the time period after which platform *ahu* were likely no longer being built. When put into the end of our *ahu* models the OxCal command *Date(U(1838, 1868))* translates into uniform probability distribution within this time span. Of the different model components, the end of the TAQ *Boundary* is most sensitive to the selected calendar date. As such, we explore the sensitivity of the later model estimates in the construction of our tempo plots, which is presented below.

The general form of these models:

Colonization > TPQ (Pre-Platform) > Target (Platform Construction) > TAQ (Post-Platform) > AD 1838-1868

Because not all *ahu* sites have ^{14}C samples from TPQ, Target, and TAQ contexts, we construct multi-phase models for each individual *ahu* with ^{14}C determinations from either (a) TPQ, target, and TAQ; (b) TPQ and target, (c) target and TAQ, or (d) TPQ and TAQ events. *Ahu* sites lacking one of these combinations of dated contexts are excluded for the analysis. In the case of models of type (a), (b), and (c), we use a Contiguous model where the start of the target event *Boundary* provides the estimate for initial *ahu* construction. In the case of models of type (d), we use a Sequential model and insert a *Date* command between the end *Boundary* of the TPQ Phase and the start *Boundary* of the TAQ Phase to estimate the start of platform construction. We use the *Difference* query to estimate the temporal lag between the colonization *Boundary* and the start of construction for each *ahu*.

Dates from the Gakushuin lab (GaK) from *ahu* Tahai, Hanga Kio‘e, Ko Te Riku, and Huri a Urenga are not included here given known problems with dates from this radiocarbon laboratory; these dates can be found in Ayres (1971), Mulrooney (2013), and Martinsson-Wallin and Crockford (2002). We also excluded a number of human bone dates from *ahu* reported by Commendador and colleagues (2013, 2014). While these samples are known to derive from *ahu* sites, specific and secure contextual information is unavailable (John Dudgeon, personal communication). All ^{14}C samples used in the analysis and OxCal code for each model described below can be found in Appendix B.

4.4.3.3. Estimated Time-Lag between Colonization and *Ahu* Construction

We use the *Difference* query to estimate the temporal lag between the colonization *Boundary* and the start of construction for each *ahu*. For more concise coding we exported the .prior files for colonization start *Boundary* and the start *Boundary* estimates for each *ahu*. All .prior and OxCal files can be found at https://github.com/rdinapoli/RN_Ahu_Bayesian and in Appendix B. Results for using the *Difference* query are shown in Table 4.2.

4.4.3.4. Model-Based Estimates for the Duration of *Ahu* Construction

To explore the duration of *ahu* construction activities, we implement Dye's (2016) 'tempo plot' procedure as a means for examining the temporal patterns of *ahu* construction events. Tempo plots utilize the raw output of OxCal's Markov-Chain-Monte Carlo (MCMC) procedure (using the *MCMC_Sample* query) to summarize the joint posteriors of multiple estimated events and to visualize the Bayes estimate and credible interval of the cumulative temporal distribution of the specified events (Dye, 2016, p. 2). Thus, the tempo plot is a summary of "how many events took place before each date in a specified range of dates" (Dye, 2016, p. 2), where the slope of the curve relates to the rate at which events occur: steeper and flatter shapes of the curve indicate more rapid or slower frequency of events, respectively. In our tempo plot, we treat the timing of initial platform construction and construction of later *ahu* components, such as plazas, ramps, and wings, as a single class of events related to *ahu* construction activities. These events encompass both initial *ahu* construction and further investments made through subsequent additions and modifications to these monuments overtime. In OxCal terms, these are the *Boundaries* for initial platform construction and start and end of TAQ phases. We also use the 'TempoActivityPlot' function of the ArchaeoPhases package (Philippe et al., 2019) to examine the patterns of *ahu* construction activity. The tempo-activity plot is similar to the normal tempo plot, but instead of plotting the cumulative number of events, it graphically displays the first derivative of the tempo plot curve. As such, the tempo activity plot shows the changing rate of construction events. The results of both analyses provide a model-based depiction of the patterns in *ahu* construction activity over time.

The later estimates in the tempo plot may be sensitive to the choice of a calendar date cutoff after which we assume no platform *ahu* were built (e.g., McCoy et al., 2012). To examine the influence of our preferred calendar date range of AD 1838-1868 on the results, we also run the tempo and tempo-activity plots with a cutoff of AD 1771 to examine whether there is a notable change in construction associated with the profound impacts of European contact.

In order to achieve our second objective of estimating the temporal duration of *ahu* construction activities, we implement Dye's (2016) innovative 'tempo plot' technique. Full details of this method can be found in Dye (2016) and are also described in the R package "ArchaeoPhases" (Philippe et al., 2019). The tempo plot works by summarizing the joint posteriors from a series of events in a Bayesian chronological model and plots the cumulative frequency distribution of specified events over time. In essence, the tempo plot provides a graphic that shows 'rhythms' of how many events took place at different times within a range of dates (Dye, 2016:2). Steep portions of the curve suggest rapid accumulation of events, whereas flatter curves indicate a slower pace of events. The plot includes the Bayes estimate and upper and lower bounds of a 95% Bayesian credible interval envelope. The method relies on samples extracted from the raw Markov-Chain-Monte-Carlo (MCMC) procedure produced by OxCal, which is accomplished by calling the *MCMC_Sample* query. Here, we follow Dye (2016) and generate 100,000 MCMC samples extracted at intervals of 25. To do this we constructed a model in OxCal which includes each *Sequence* of our *ahu* models organized into a single unordered *Phase*, with the query *MCMC_Sample("ahu-construction-100k_1838-1868", 25, 100000)* called at the beginning of the OxCal code. The raw MCMC output is written to a .csv file that is then imported into the R package "ArchaeoPhases" to create the tempo plots. For our tempo plots, we treat the timing of initial platform construction and construction of later *ahu* components, such as plazas, ramps, crematoria, wings, etc., as a single class of events related to *ahu* construction activities. These events encompass both initial construction of the *ahu* platform and further investments made through subsequent additions and modifications to these monuments over time. In OxCal model-terms, these events derive from the *Boundary* estimates for initial platform construction, *Boundary* estimates for the start of the TAQ *Phase* (i.e., start of later construction components), and end *Boundary* for the TAQ *Phase* (i.e., latest estimates for construction activity), as the events of interest. We consider each of these *Boundary* estimates as a single class of events relating to *ahu* construction activities. The resulting tempo plot then provides a graphic depiction of the cumulative number of *ahu* construction activity events over time.

We also use the 'TempoActivityPlot' function of the ArchaeoPhases R package to examine the patterns of *ahu* construction activity. The tempo activity plot is similar to the normal tempo plot, but instead of plotting the cumulative number of events, it graphically displays the first derivative of the tempo plot curve. As such, the tempo activity plot shows the changing rate of construction events. This is most useful for our purposes here in examining the effect of different assumptions about when in the post-contact period construction of platform *ahu* likely no longer occurred.

The later estimates in the tempo plot, derived from the end *Boundary* of the TAQ *Phases*, is likely sensitive to our choice of a calendar date cutoff point after which we assume no platform *ahu* were constructed (see similar discussion in McCoy et al., 2012). As a form of sensitivity analysis, we constructed separate tempo plots using AD 1838-1868, our preferred calendar date range, and AD 1771 as cutoff points. Based on European accounts (see discussion above), AD 1838-1868 is a reasonable cutoff point because after this time no *moai* statues were observed standing on platform *ahu*, suggesting that platform construction had ceased. However, given the lack of more direct ethnographic observations and the sporadic nature of 18th and 19th century European visits, it is possible that 1838-1868 is too late of an estimate, and as such may be biasing the later estimates for *ahu* construction too far into post-contact times (see McCoy et al., 2012 for a similar discussion of Hawaiian monumental architecture). Alternatively, based on the Dutch accounts of ritual activities at *ahu* in AD 1722, and neither Dutch nor Spanish reports of fallen statues by AD 1770, it is likely that platform *ahu* were still being used for ritual purposes through that date and were potentially still being constructed (Boersema, 2015, pp. 89–90; Edwards et al., 1996; Mulrooney et al., 2010, p. 147). In 1774, Cook reported the first observation of fallen *moai* statues (Edwards et al. 1996). Therefore, it is possible that platform *ahu* construction had ceased sometime between AD 1771 and AD 1774. Therefore, we also construct tempo plots using a *C_Date* cutoff of AD 1771.

OxCal code for generating the MCMC output for the tempo plots and tempo activity plots, .csv files with the raw MCMC output, and an R script for running the tempo plots can be found in Appendix B and at https://github.com/rdinapoli/RN_Ahu_Bayesian.

4.5. Results of Bayesian Models

4.5.1. Rapa Nui Colonization

The single-phase colonization model using only short-lived samples estimates initial colonization of Rapa Nui in the range *1150-1290 cal. AD* (A_{model}=105.6, $A_{overall}$=101, Figure 4.3). Our second model that incorporates unidentified charcoal samples and a *Charcoal Outlier* parameter suggests a slightly more precise colonization estimate of *1150-1280 cal. AD* (A_{model}=121, $A_{overall}$=120.5, Figure 4.4). Given the negligible difference between these two results, we opted for the more precise estimate with higher agreement indices provided by the outlier model for use in the *ahu* models and tempo plots.

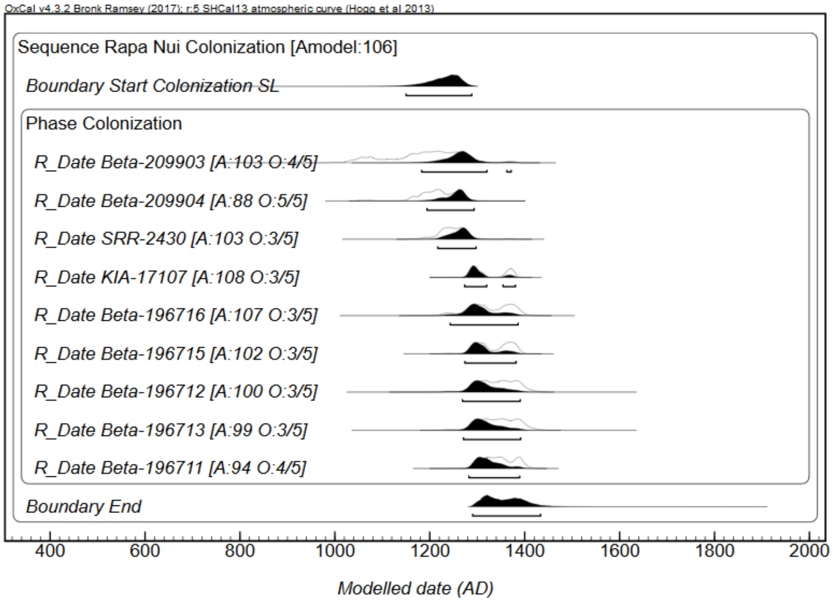

Figure 4.3: Single-phase colonization model using only short-lived samples.

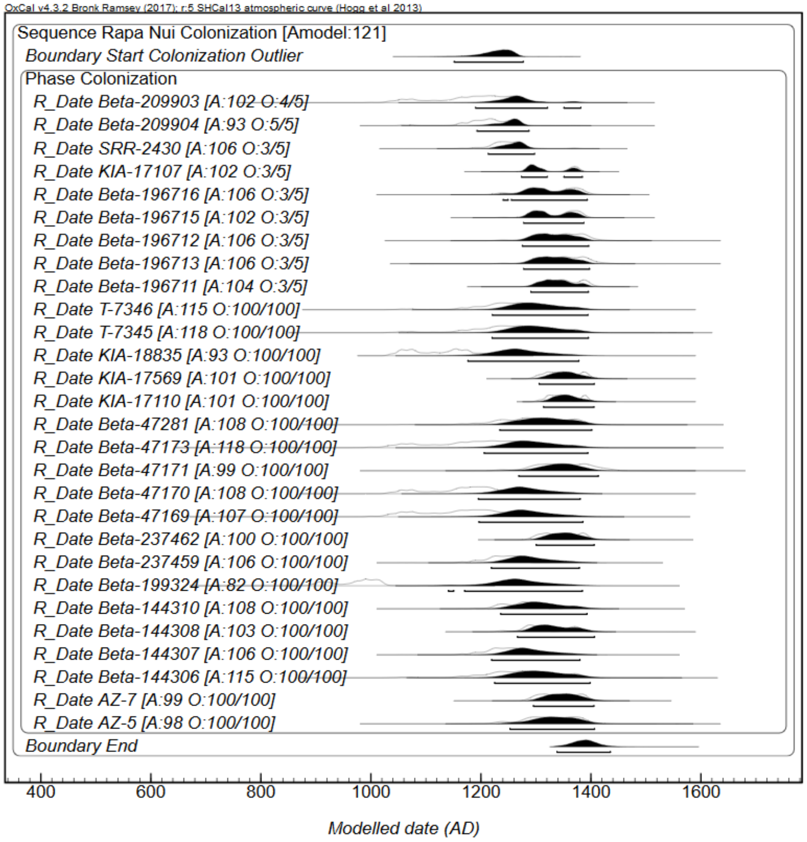

Figure 4.4: Single-phase colonization model using short-lived samples and unidentified charcoal with *Outlier_Model*.

4.5.2. Ahu Ra‘ai

There are five ^{14}C determinations from *ahu* Ra‘ai (Martinsson-Wallin and Wallin, 2000, 1998; Wallin and Martinsson-Wallin, 2008; see also Martinsson-Wallin and Crockford, 2002). Full information for these ^{14}C determinations can be found in Appendix B. Samples Ua-13166 and Ua-13167 derive from combustion features stratigraphically pre-dating the west wing and the central platform and are grouped into a TPQ *Phase*. Sample Ua-13165 derives from a combustion feature within the platform fill and composes the Target *Phase*. Samples Ua-13163 and Ua-13164 derive from the plaza fill and crematorium, respectively, and are grouped into a TAQ *Phase*. All samples are on unidentified wood charcoal. OxCal code is in Appendix B and model results are included below (Figure 4.5).

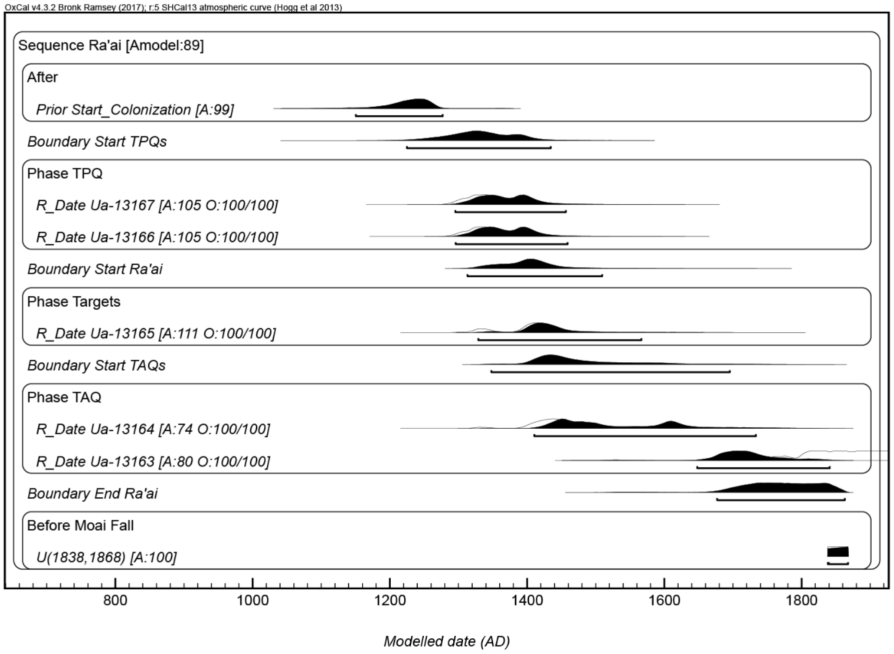

Figure 4.5: Model results for *ahu* Ra‘ai.

4.5.3. Ahu Rongo 1

There are three ^{14}C determinations from Ahu Rongo 1 (Huyge and Cauwe, 2002; see also Martinsson-Wallin and Crockford, 2002). Full information for these ^{14}C determinations can be found in Appendix B. Sample GrA-18380 derives from immediately below a basal stone of the platform wall, and sample GrA-18378 derives from immediately below a basal stone of the wing and should also stratigraphically pre-date the platform wall. These two samples are grouped into a TPQ *Phase*. Sample GrN-26318 derives from the crematorium and composes the TAQ *Phase*. All samples are on unidentified charcoal. We estimate the start of *ahu* Rongo 1 construction by inserting a *Date* command between the end of the TPQ *Phase* and the Start of the TAQ *Phase*. OxCal code is in Appendix B and model results are included below (Figure 4.6).

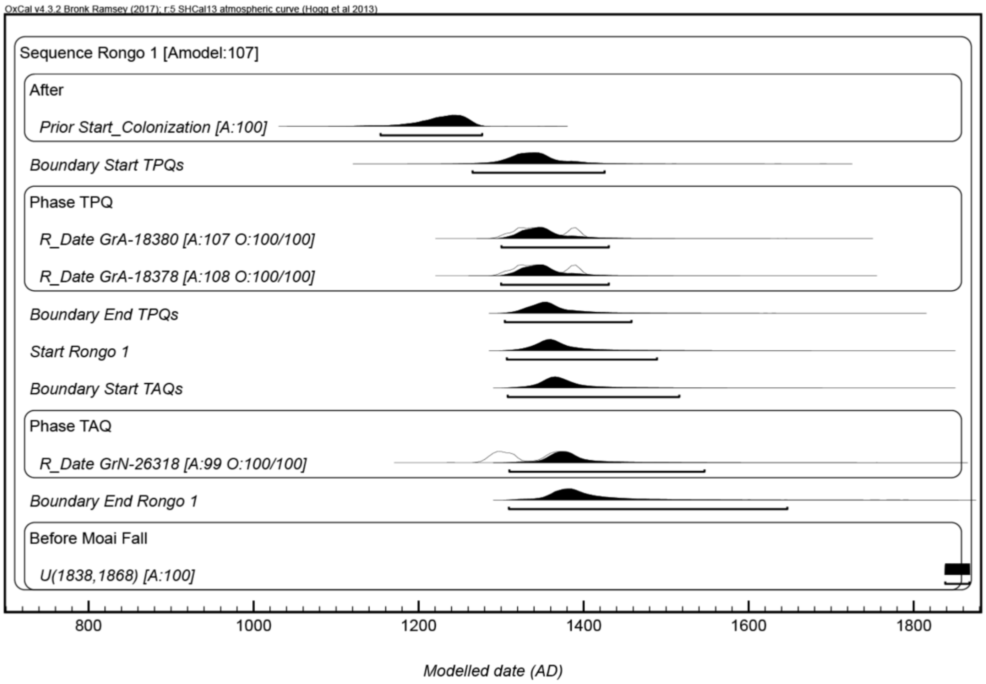

Figure 4.6: Model result for Rongo 1.

4.5.4. Ahu Te Niu

There are 12 ^{14}C determinations from *ahu* Te Niu (Wozniak, 2003). Full information for these ^{14}C determinations can be found in Appendix B. Samples AZ-13 and AZ-28 from excavation unit 26-1-4 were collected from a charcoal lens beneath the rear platform wall (Wozniak, 2003, p. 288 Figure 46). Samples AZ-23, AZ-25, and Beta-95878 derive from excavation unit 26-1-1 and are from a charcoal lens beneath the ramp; this charcoal lens also stratigraphically pre-dates the platform (Wozniak, 2003, p. 292, Figure 48). Sample Beta-106319 derives from excavation unit 26-1-3 and is from a charcoal lens beneath the rear platform wall (Wozniak, 2003, p. 286, Figure 45). Samples AZ-13, AZ-23, AZ-25, AZ-28, Beta-95878, and Beta-106319 are grouped into a TPQ *Phase.* Sample AZ-14 and AZ-22 derive from excavation unit 26-1-2. AZ-14 is from below the ramp pavement and stratigraphically post-dates the platform. AZ-22 derives from atop this ramp pavement and post-dates the ramp and the platform (Wozniak, 2003, pp. 304-307, Figure 50 and 51). Beta-95879 derives from excavation unit 26-4-1 and is from a charcoal lens that stratigraphically post-dates construction of the platform wall (Wozniak, 2003, p. 288, Figure 46). Samples AZ-8 and AZ-20 derive from the crematorium and post-date the platform. Samples AZ-8, AZ-14, AZ-20, AZ-22, and Beta-95879 are grouped into a TAQ *Phase.* To estimate initial construction of Te Niu, we insert a *Date* command between the end of the TPQ *Phase* and the start of the TAQ *Phase.* We were unable to establish sufficient provenience information for sample AZ-24, being described as from excavation unit 26-1-3W ‘behind ahu’ (Wozniak, 2003, p. 304), and thus we excluded it from the analysis. With the exception of two samples on palm nuts and one sample on human bone, all samples from Te Niu are on unidentified charcoal. OxCal code is in Appendix B and model results are included below (Figure 4.7).

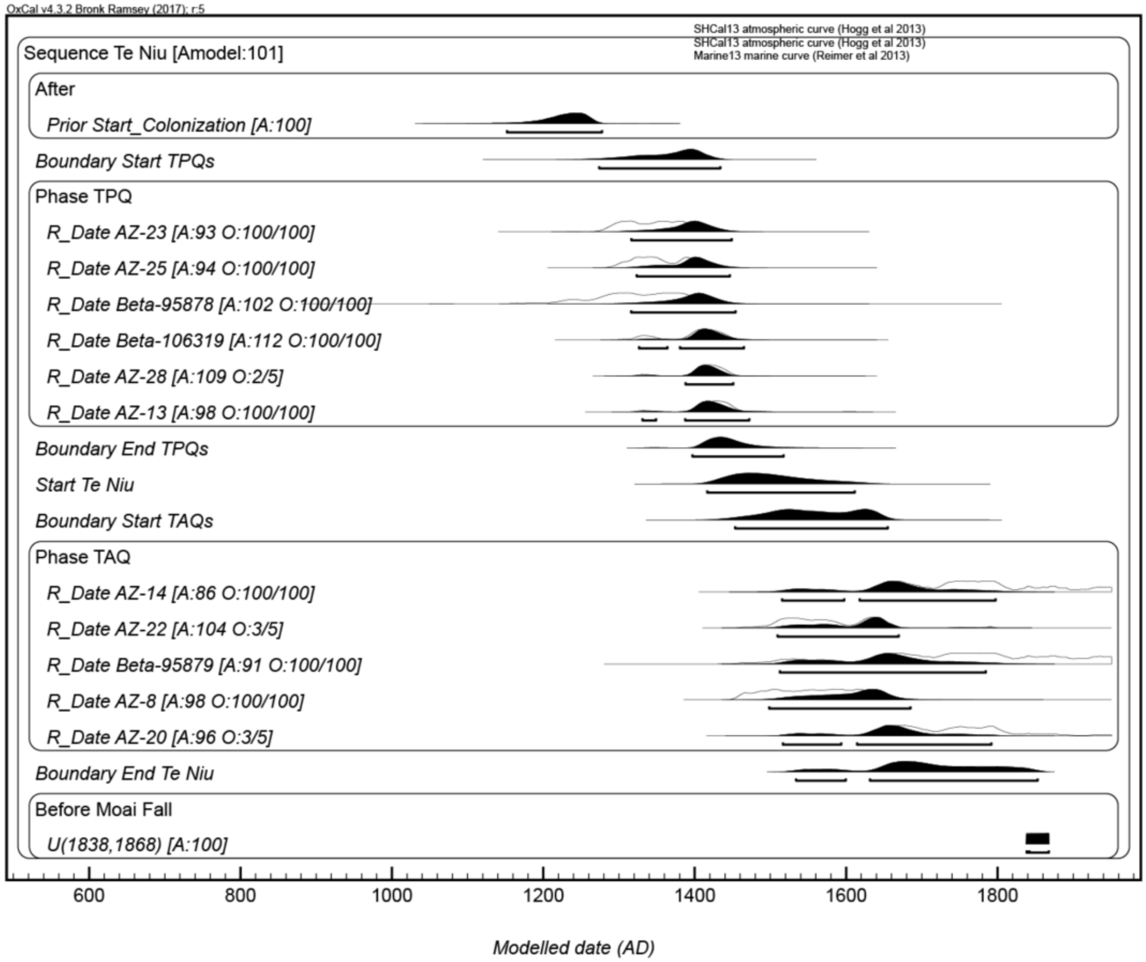

Figure 4.7: Model results for Te Niu.

4.5.5. *Ahu Motu Toremo Hiva*

There are nine ^{14}C determinations for *ahu* Motu Toremo Hiva (Cauwe et al., 2010, 2006). Full information for these determinations can be found in Appendix B. Samples KIA-26464, KIA-26453, and KIA-29812 derive from contexts below the platform foundation stones and are grouped into a TPQ *Phase*. Samples KIA-26452, KIA-26461, and KIA-29813 derive from within the platform and are grouped into a Target *Phase*. Samples KIA-29814 and KIA-26487 are from post-holes within the ramp and thus post-date the central platform, and KIA-26483 derives from a burial feature interpreted by Cauwe et al. (2006, p. 33, 2010, p. 52) as an "inhumation posterior to use of" the *ahu*. These three samples are grouped into a TAQ *Phase*. With the exception of sample KIA-26483 on human bone, all other samples are on unidentified charcoal. Our first attempt to model Ahu Motu Toremo Hiva with the human bone date (KIA-26483) resulted in poor model agreement (A_{model}=39.5, $A_{overall}$=41.9) and indicated a 23% posterior probability this date is an outlier. We re-ran the model with this date removed, which resulted in acceptable agreement indices (A_{model}=95.1, $A_{overall}$=95.8). OxCal code for these models is included below. The first model is our initial attempt with KIA-26483 included, and the second, preferred model "Motu Toremo Hiva v2" is with this sample removed. Results for model version 2 are included below (Figure 4.8).

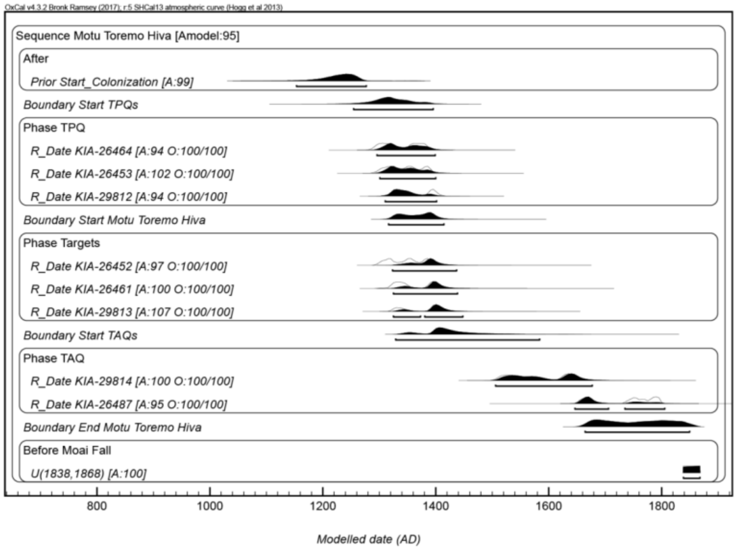

Figure 4.8: Model results for Motu Toremo Hiva.

4.5.6. Ahu Tautira

There are three ^{14}C determinations from *ahu* Tautira (Martinsson-Wallin and Crockford, 2002). Full information for these determinations can be found in Appendix B. Sample UA-13284 derives from under the *ahu* platform and composes the TPQ *Phase*. Sample Ua-13161 derives from a later building event of the platform and thus post-dates the main platform, and sample Ua-13162 derives from the crematorium. We group these two samples into a TAQ *Phase*. To estimate initial construction of *ahu* Tautira, we insert a *Date* command between the end of the TPQ *Phase* and the start of the TAQ *Phase*. All samples are on unidentified charcoal, and the OxCal code is in Appendix B and model results are included below (Figure 4.9).

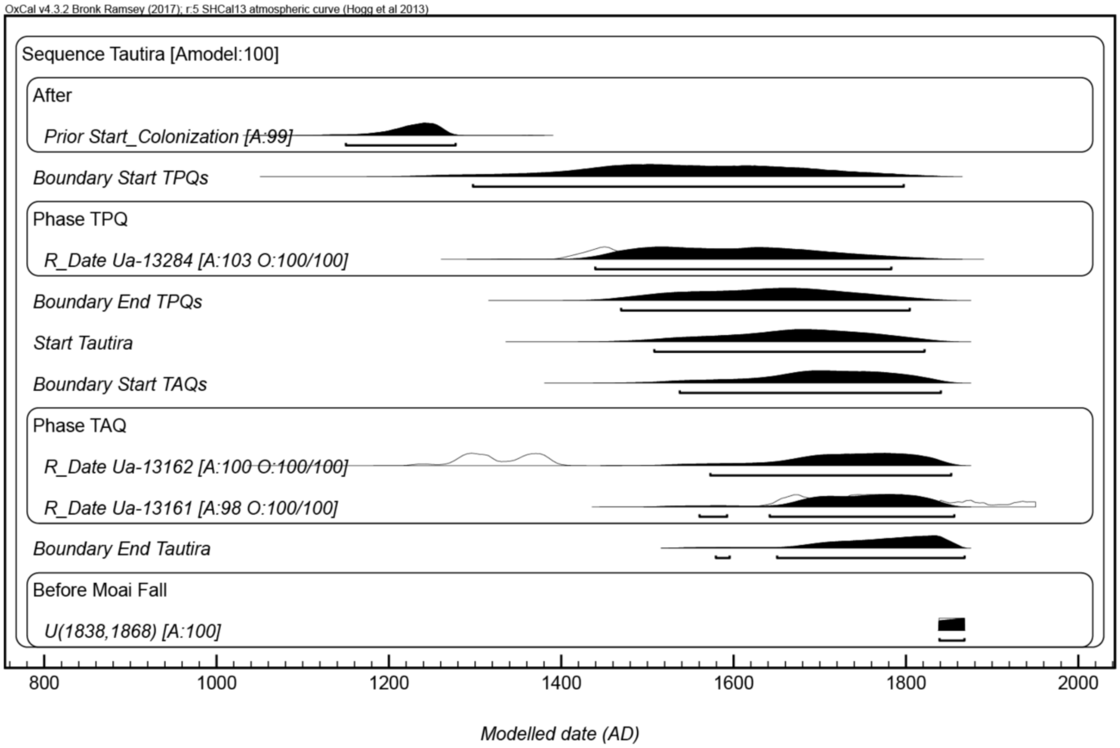

Figure 4.9: Model results for Tautira.

4.5.7. Ahu Vai Teka

There are three ^{14}C determinations from *ahu* Vai Teka (Mulloy and Figueroa, 1978, pp. 118–121). Full information for these samples can be found in Appendix B. Sample I-455 derives from a combustion feature that stratigraphically pre-dates the platform and comprises the TPQ *Phase*. Sample TBN-348-2 derives from within the platform and comprises the Target *Phase.* Sample M-1372 derives from the bottom of a firepit feature in the center of a gardening-enclosure (*manavai*) feature attached to the back of the *ahu*. While the *manavai* does appear the post-date construction of the platform, the firepit feature itself has an unclear association with construction of the *manavai* wall and the *ahu* platform (see Mulloy and Figueroa, 1978, p. 120, Figure 23). Thus M-1372 was excluded from the analysis. All samples are on unidentified charcoal, and OxCal code is in Appendix B and model results are included below (Figure 4.10).

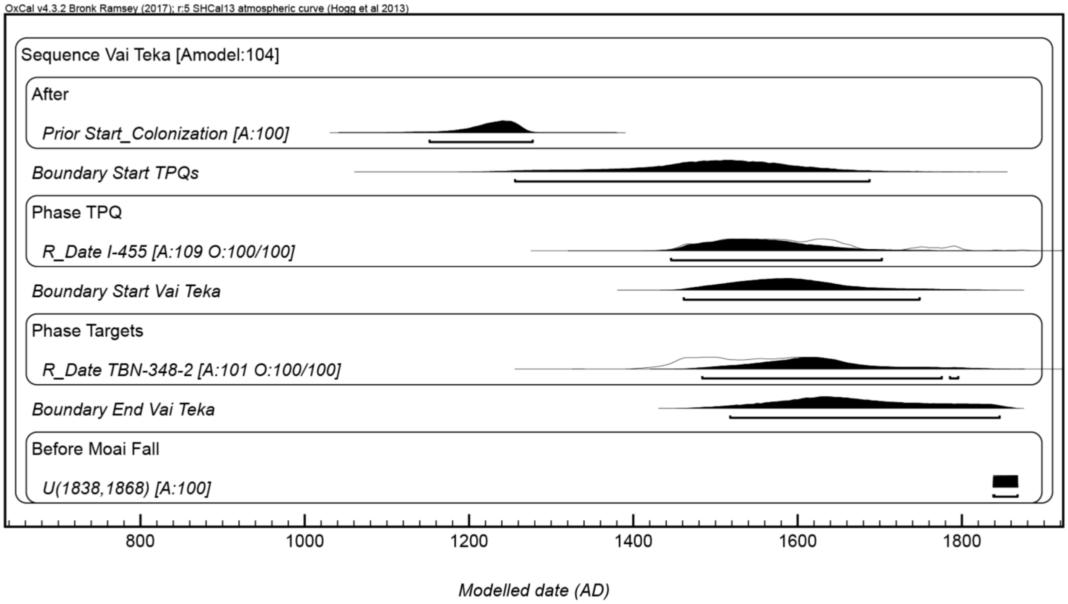

Figure 4.10: Model results for Vai Teka.

4.5.8. Ahu Akivi

There are five ^{14}C determinations from *ahu* Akivi (Mulloy and Figueroa, 1978, pp. 118–121; see also Crane and Griffin, 1965, p. 146). Two samples, M-1371 and M-1374, are from the crematorium and should post-date construction of the main platform; however, both of these radiocarbon determinations are on bulk samples composed of a mixture of human bone and wood charcoal and were thus deemed unsuitable for inclusion in the analysis. Sample TBN-348-1 derives from unidentified charcoal within the ramp pavement but yielded a radiocarbon age of 2216 ± 96 and was subsequently rejected by Mulloy and Figueroa (1978; see also Martinsson-Wallin and Crockford, 2002), so we also exclude it from the analysis. Unidentified charcoal sample I-456 comes from under the southern wing of the *ahu* and stratigraphically pre-dates both the wing and the central platform (Mulloy and Figueroa, 1978, p.119). I-456 composes the TPQ *Phase* for the model. Unidentified charcoal sample M-1370 derives from immediately below the southern wing and antedates the deposition of I-456 and is interpreted by Mulloy and Figueroa (1978, p.119) as being contemporaneous with construction of the wing and likely post-dating the central platform in relative terms. M-1370 composes the TAQ *Phase* for the model. We insert a *Date* command between the end of the TPQ *Phase* and the start of the TAQ Phase to estimate the initial construction of Akivi. Model results are included below (Figure 4.11).

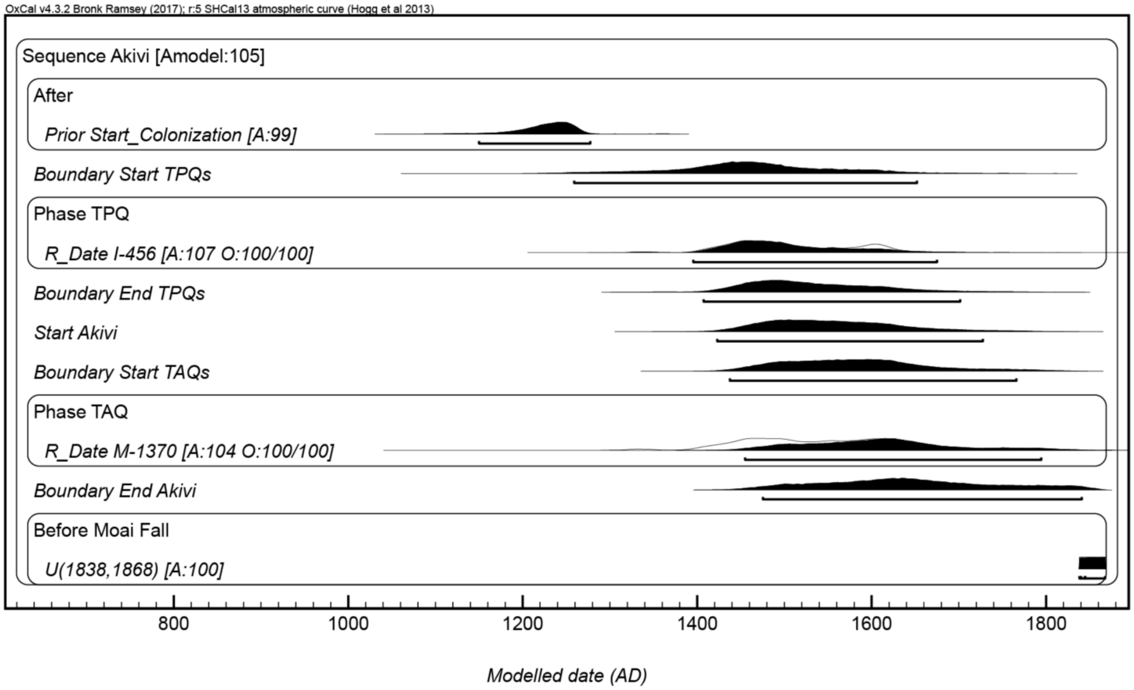

Figure 4.11: Model results for Akivi.

4.5.9. Ahu Ature Huki

There are two ^{14}C determinations from *ahu* Ature Huki (Skjølsvold, 1994, pp. 86–87, 106, Figure 11, 77). T-7979 derives from a charcoal lens stratigraphically pre-dating the platform wall and composes the TPQ *Phase*. Ua-1144 is from below the plaza/ramp pavement, within the ramp fill, and composes the TAQ *Phase*. We insert a *Date* command between the end of the TPQ *Phase* and the start of the TAQ *Phase* the estimate initial construction of Ature Huki. Both samples are on unidentified charcoal. Model results are included below (Figure 4.12).

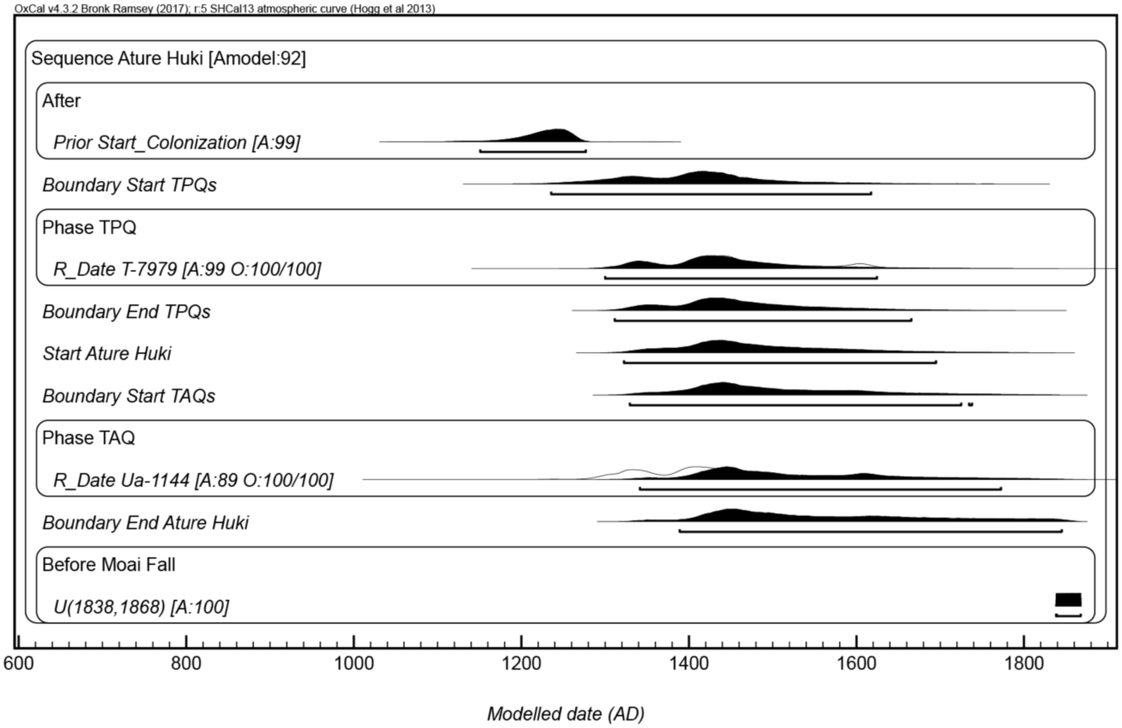

Figure 4.12: Model results for Ature Huki.

4.5.10. Ahu Heki‘i 1

There are four ^{14}C determinations from *ahu* Heki‘i (Martinsson-Wallin, 1998; Wallin and Martinsson-Wallin, 2008). Sample Ua-11700 derives from a stone-lined fire feature under the central portion of the ramp pavement directly adjacent to the central platform. Ua-11700 pre-dates construction of the ramp and based on the published stratigraphy it likely pre-dates the central platform. This sample composes the TPQ *Phase* for the model. Samples Ua-11701, Ua-11702, and Ua-11703 derive from Trench 2 at the southwestern portion of the plaza wall. Samples Ua-11702 and Ua-11703 derive from immediately below the foundation stones of the plaza wall, thus likely dating the later construction phase of the plaza, and comprise the TAQ *Phase* for the model. Sample Ua-11701 is described as originating from a pit feature at the same level as, but not beneath the foundation stones of the plaza wall. Ua-11701 appears anomalously older in relation to Ua-11702 and Ua-11703 and is potentially residual material in the pit fill (Wallin and Martinsson-Wallin 2008, p. 149). Given these ambiguities we exclude Ua-11701 from the model. All samples are on burnt palm nut shells with limited inbuilt age. Model results are included below (Figure 4.13).

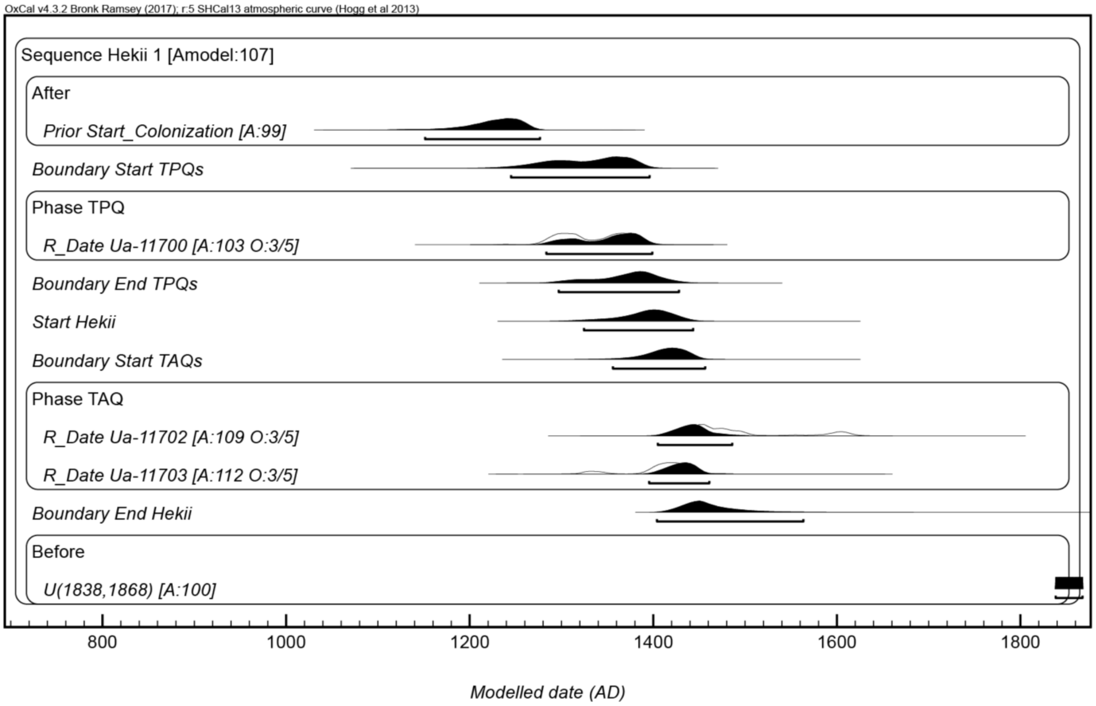

Figure 4.13: Model results for Heki‘i.

4.5.11. Ahu Nau Nau and Nau Nau IV

The largest collection of ^{14}C determinations derives from excavations at Ahu Nau Nau conducted by Skjølsvold (1994). The complexity of the available data warrants an extended discussion here. Different construction episodes were designated “Nau Nau I”, “Nau Nau II”, and “Nau Nau III”, though these all refer to the same complex which we simply refer to as Nau Nau. Skjølsvold’s (1994) Nau Nau IV is a separate, smaller *ahu* structure that is directly adjacent to the east wing of the main Nau Nau complex, and in relative terms it appears to post-date construction of the main complex. Specifically, Nau Nau IV appears to have been built on top of the east wing of, and thus post-dates, the main complex. Our model for Nau Nau includes five *Phases*: a TPQ *Phase* composed of samples that stratigraphically pre-date the main platform, and TAQ *Phase* composed of samples from the plaza that post-date construction of the main platform, a Nau Nau IV target *Phase* that post-dates the TAQ *Phase* for the main Nau Nau complex, and a Nau Nau IV TAQ *Phase* that post-dates the target *Phase* for Nau Nau IV.

Several samples derive from Trench C1 that was excavated within the plaza and come from Skjølsvold (199, pp. 25-26, 106) and redating of the deposits by Wallin et al. (2010). Samples from the bottom brown sand layers of Trench C1 (Ua-4626,Ua-3007, T-6679, T-7341, T-7959, Ua-34186, Ua-34187, Ua-34188, Ua-34189, Ua-34190, Ua-34191) stratigraphically pre-date both the plaza and the central platform and are included within the TPQ *Phase*. Also included in the TPQ *Phase* are sample T-7975 from the bottom of Trench D, T-7343 from the bottom of Trench E, and T-7349 and T-7350 from the bottom of Trench K; these trenches were excavated at the back platform wall and their bottom layers stratigraphically pre-date construction of the platform. Based on documentation provided by Skjølsvold (1994, Figure 12) the basal strata from Trench C1 and Trenches D, E, and K appear to be the same deposit. Several samples from Trench C1 derive either from within the fill of the plaza pavement or stratigraphically post-date the plaza (Ua-617, T-6678, T-7342, Ua-34183, Ua-34184, Ua-34185) and are included with the TAQ *Phase*. Sample T-7347 derives from the plaza floor from Trench B4 and is included in the TAQ *Phase.* Two samples derive from Trench U from the separate structure Nau Nau IV, which based on stratigraphic relationships appears to post-date the main Nau Nau complex (Skjølsvold, 1994, pp. 59, 106-107, Figure 11). These two samples are grouped into two separate *Phases* that post-date the main Nau Nau complex in the *Sequence.* Sample T-7958 derives from the bottom of the Nau Nau IV platform fill and comprises the Nau Nau IV Target *Phase*. Sample T-7976 derives from the pavement of Nau Nau IV and comprises the Nau Nau IV TAQ Phase. ^{14}C samples from Nau Nau are on *Rattus exulans* bone, unidentified charcoal, and palm nut shell. Specific information for each sample can be found in Appendix B.

Several samples from the Nau Nau excavations had to be excluded given uncertainties in contextual relationships and/or calibration procedures. We exclude a series of ^{14}C determinations on abraded coral and algal nodule artifacts from the plaza pavement given the author's own concerns about the unknown, and potentially great time lag between the harvesting of the corals and their deposition at the *ahu* (Beck et al., 2003:100). It also possible that the coral or algal nodules were not live-collected but collected from the beach at Anakena. These data are not included in Appendix B but can be found in Beck et al. (2003) and Mulrooney (2013). Three human bone dates from Jarman et al. (2017), UG-20801, UG-20802, and UG-20803, deriving from the top portions of Trench K from Skjølsvold (1994, pp. 54-56) were also not included. These three samples derive from between 40-140 cmbs and are stratigraphically inverted. Skjølsvold (1994, pp. 54-56) describes this portion of Trench K as heavily disturbed, likely due to its proximity to the nearby crematorium. Because these samples do not derive from within the crematorium feature and are from a shallow and heavily mixed deposit, we are unable to confidently assess how they relate to platform construction and thus do not include them. Sample T-7348 is from Trench B6, which, being several meters outside of the main portion of the *ahu*, has an unclear relationship with the structure and is excluded (see Skjølsvold, 1994, Figure 11) . Sample Ua-1740 from the bottom layer of Trench C1 is on aquatic bird bone with an uncertain marine reservoir correction and is excluded. Sample T-7344 is from the upper portion of Trench E and has an uncertain stratigraphic relationship with construction of the platform; it appears equally likely to pre- or post-date the platform and had to be excluded (see Skjølsvold 1994, Figure 43).

Our first attempt to model Nau Nau had poor agreement indices (A_{model}=42.9, $A_{overall}$=33.8) and two dates were flagged as having a high posterior probability of being outliers, Ua-3007 (45%) and Ua-34187 (15%). We subsequently re-ran the model (Nau Nau v2) with these determinations removed, which resulted in acceptable agreement indices (A_{model}=100.2, $A_{overall}$=98.1). OxCal code for both models is included in Appendix B. Model results for model version 2 is included below (Figure 4.14).

4.5.12. Ahu Not Modeled

Several *ahu* with associated radiocarbon dates were not subjected to Bayesian modeling as they did not meet the criteria presented above.

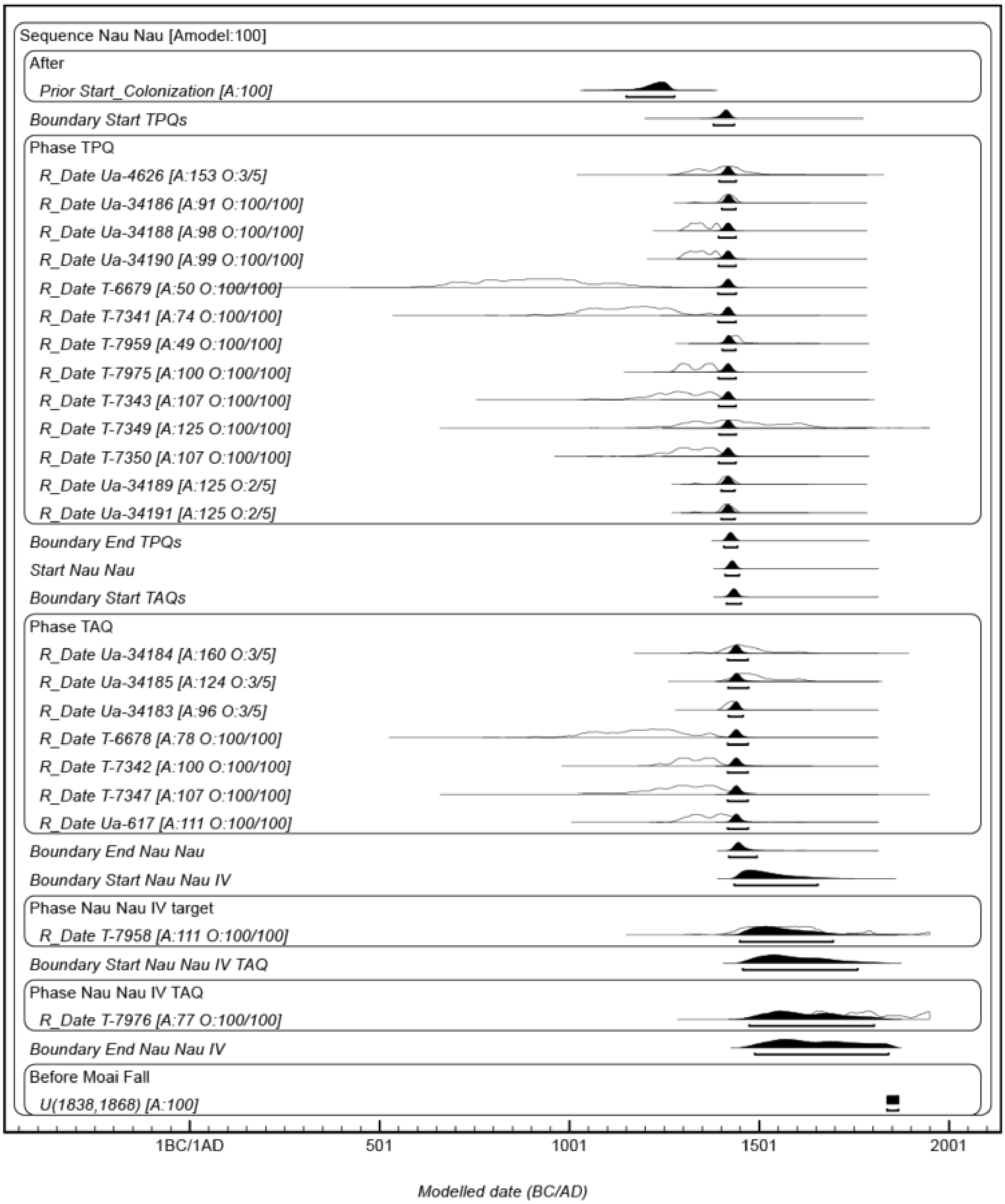

Figure 4.14: Model results for Nau Nau and Nau Nau IV.

4.5.12.1. Te Peu

There are four ^{14}C determinations from Ahu Te Peu (Jarman et al., 2017; Martinsson-Wallin and Crockford, 2002; Smith, 1961b). Samples Beta-155725 and Beta-155726 are modern and are thus excluded from the analysis. Sample M-732 has a radiocarbon age of 1640 ± 250 and is rejected by Smith (1961b) and Martinsson-Wallin and Crockford (2002) as anomalous. Human bone sample RN-026 derives from a burial feature from within the *ahu* and thus post-dates initial construction (Jarman et al., 2017). However, given the lack of TPQ or target date samples, we do not model Te Peu. We note here that the initial construction of Te Peu likely pre-dates the burial feature date presented by by Jarman et al. (2017).

4.5.12.2. Viri o Tuki

There are four ^{14}C determinations from *ahu* Viri o Tuki (Huyge and Cauwe, 2005). Three samples on carbonized nutshell, Beta-155732, Beta-155733, and GrA-25878, have insufficient provenience information. They are simply described as being from "the immediate vicinity of the annex structure" or "found in close relationship with the annex structure (both on the inside and outside)" (Huyge and Cauwe, 2005, p. 8). Thus, these three samples are excluded from the analysis as we cannot establish their relative relationship with platform construction. GrA-25872 is from a hearth feature in a layer stratigraphically post-dating the *ahu*, but, given the lack of other usable samples from TPQ or Target events, we also exclude it from the analysis. However, we note here that construction of *ahu* Viri o Tuki was some time before AD 1450-1627, the 95.4% calibrated range of GrA-25872.

4.5.12.3. Vinapu 1 and 2

There are three ^{14}C determinations from *ahu* Vinapu 1 (Tahira) (Mulloy, 1961, pp. 97–100; Smith, 1961b, p. 394). Sample K-523 derives from a charcoal lens within the ramp fill and Sample M-711 is from the crematorium, and both likely post-date construction of the central platform. Sample M-709 is derived from a fire feature underneath a fallen *moai* statue and loose boulders atop the surface of the ramp (Mulloy, 1961, p. 97). This sample provides a TAQ for the ramp and a TPQ for the time the *moai* fell. However, given that there are no available TPQ or target dates for the construction of the platform, and all three samples derive from contexts which likely post-date construction of the platform by an uncertain amount of time, we do not model Vinapu 1.

There are four ^{14}C determinations from *ahu* Vinapu 2 (Martinsson Wallin, 2004; Martinsson-Wallin, 1994; Mulloy, 1961, p. 118; Smith, 1961b, p. 394). Sample T-5175 is from a bulk sample of a mixture of charcoal and ash and is thus excluded from the analysis. Samples M-710, Ua-19463, and Ua-19464 derive from underneath the earthen embankment that surrounds the wings and plaza of the *ahu* (see Martinsson-Wallin, 2004, Figure 1). While these three samples are TPQs for the embankment feature, which itself should post-date the *ahu* platform, these samples are equally likely to pre- or post-date construction of the platform. Given these uncertain relative relationships we exclude them from the analysis and do not model Vinapu 2.

4.5.12.4. Ahu No. 31-286

There is a single ^{14}C determination (Ua-11704) from Ahu No. 31-286, which is adjacent to *ahu* Heki‘i (Martinsson-Wallin, 1998). The sample derives from Trench 4 which was directly adjacent to the platform wall, and was recovered from underneath the foundation stones. While this sample provides a reliable TPQ for the *ahu*, given that there are no samples from either target or TAQ contexts, we do not include it in our analyses.

4.5.12.5. Structure 1 at Orongo

There is a single ^{14}C determination (T-193) from the possible *ahu* Structure 1 at the ceremonial complex of Orongo (Ferdon, 1961; Smith, 1961b). This sample derives from a stone-lined fire pit feature adjacent to the southwest edge of the later construction phase of Structure 1b (Ferdon, 1961, pp. 226-229, Figure 62). Because of the unclear association between this pit feature and construction of the main platform, and the lack of other samples from this structure, we exclude it from our analyses.

4.5.13. Summary of Results for Initial Ahu Construction

Based on the available data, I was able to create Bayesian models for 11 *ahu*. Results for the time lag following colonization until the estimated timing of initial *ahu* construction are presented in Table 4.2. Figure 4.15 shows the modeled distributions for these estimates.

Table 4.2: Initial *ahu* construction. Estimates for initial platform construction for 11 *ahu* sites found across Rapa Nui and the estimated time lag between initial human colonization and construction of each *ahu.* All models have agreement indices >60.

Ahu name	**Initial platform construction estimate (95.4% HPD)**	**Years after colonization (95.4% HPD)**	**A_{model}**	**$A_{overall}$**
Akivi	*1420-1730 cal. AD*	180-515	104.8	104.3
Ature Huki	*1320-1695 cal. AD*	80-480	92.2	94.2
Heki‘i	*1320-1445 cal. AD*	70-260	106.8	109.3
Motu Toremo Hiva	*1315-1415 cal. AD*	60-230	95.1	95.8
Nau Nau	*1410-1450 cal. AD*	145-285	100.2	98.1
Nau Nau IV	*1435-1655 cal. AD*	180-445	100.2	98.1
Ra‘ai	*1310-1510 cal. AD*	65-310	89.2	89.1
Rongo 1	*1305-1490 cal. AD*	55-285	106.5	105.5
Tautira	*1505-1825 cal. AD*	260-610	99.7	100.2
Te Niu	*1415-1615 cal. AD*	165-405	100.8	93.6
Vai Teka	*1460-1750 cal. AD*	220-535	103.8	103.9

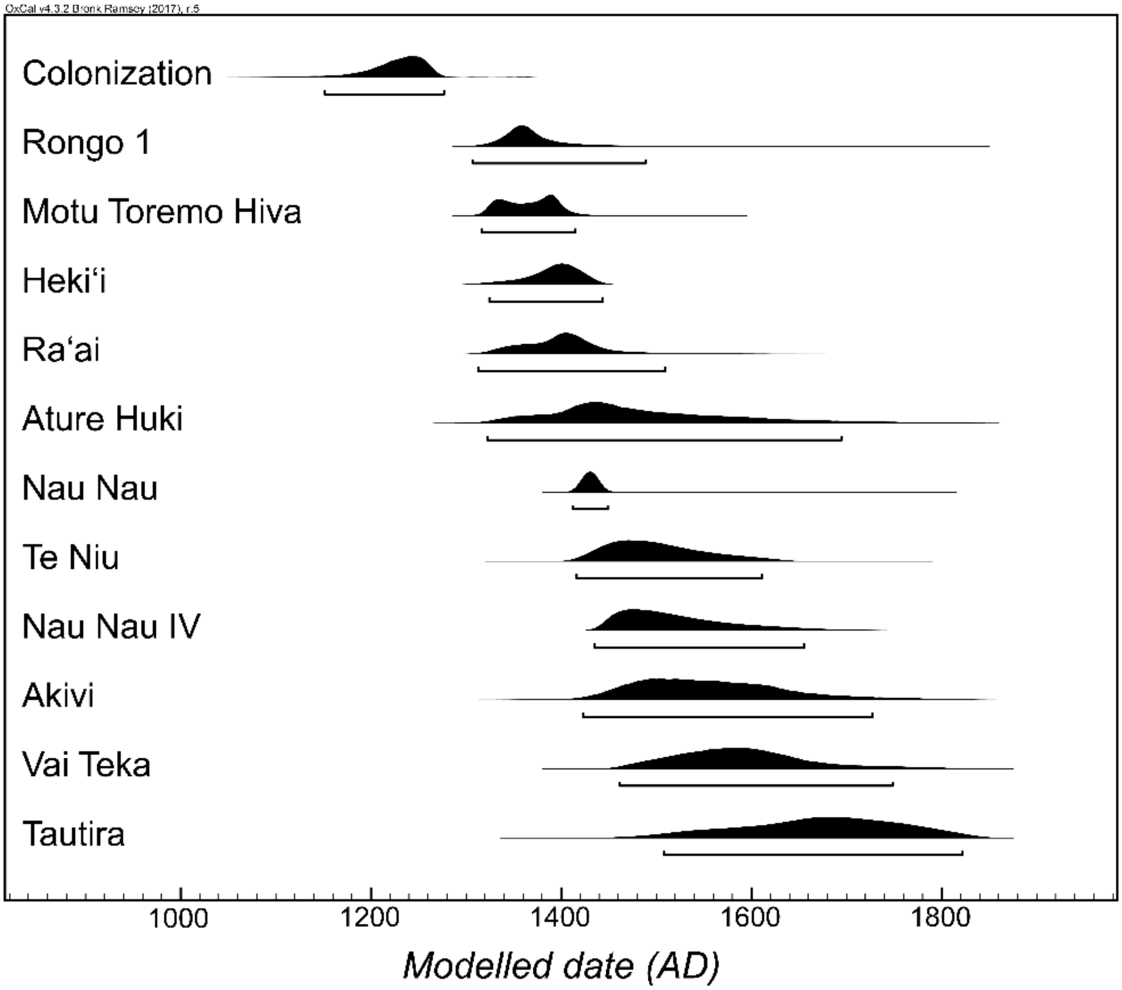

Figure 4.15: Rapa Nui colonization and ahu construction estimates. Bayesian estimates for colonization and initial platform construction for 11 *ahu*.

Samples within the models for *ahu* Rongo 1, Motu Toremo Hiva, Ra‘ai, Ature Huki, Akivi, Vai Teka, and Tautira are comprised of unidentified charcoal, and as such these estimates may be affected by inbuilt age. Models for Ahu Heki‘i, Nau Nau, and Te Niu contain both short-lived and unidentified charcoal samples in their TPQ (pre-platform) and TAQ (post-platform) *Phases* and thus their results are more accurate estimates for the timing of platform construction.

4.5.14. Tempo of Ahu Construction Activities

Tempo and tempo-activity plot results are shown in Figures 4.16 and 4.17. The 11 *ahu* in our study have multiple construction elements, and these plots include estimated boundaries for initial platform construction, boundaries for the start of later construction episodes (TAQ *Phases*), and boundary end estimates for non-platform components. Results of the sensitivity analysis examining the effect of different calendar date cutoffs for the likely end of *ahu* construction can be found below. For our sample of 11 *ahu*, the shape of the tempo plots using an AD 1838-1868 cutoff point indicate a fairly rapid period of *ahu* construction from ca. AD 1350-1450, followed by a steady tempo of *ahu* construction that continues beyond European contact in AD 1722. The results indicate that *ahu* construction activities continue into post-contact times, with a flattening of the upper bound of 95% credible interval at ca. AD 1750. The shape of tempo activity plot in Figure 4.17 suggests that the rate of activity begins to slowly decline beginning around AD 1550 through the 18th century.

Using an AD 1771 cutoff produces results that are essentially identical for time periods before AD 1700, but suggests a possible cessation of construction activities around the time of initial European contact in AD 1722 (based on the flattening of the upper bound of the 95% credible interval envelope, Figure 4.19). The greatest difference between the results using the different cutoff dates is shown in the tempo-activity plots in the latter part of the 18th century (Figures 4.20 & 4.21). Using an AD 1838-1868 cutoff suggests possible construction activities continuing just prior to this date, whereas the AD 1771 cutoff appears to artificially truncate the activity. Based on the available historical evidence and the results presented here, we suggest that ca. AD 1838-1868 is a more reasonable and conservative cutoff point. However, both iterations of the tempo plots suggest that *ahu* construction activities likely continued at least until European contact in AD 1722.

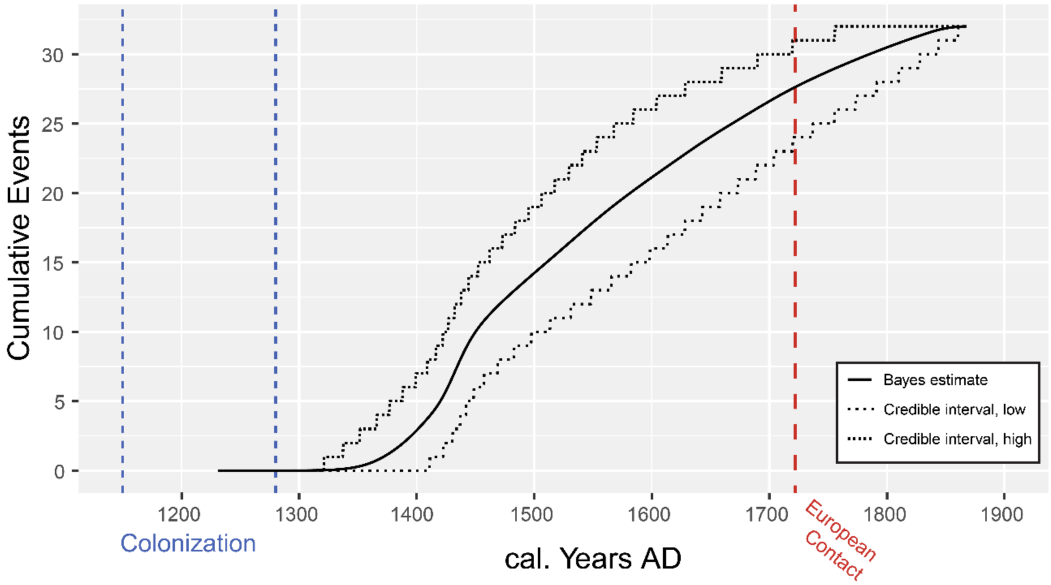

Figure 4.16: Tempo of *ahu* construction events. Tempo plot for the cumulative number of *ahu* construction events, including initial construction and later building activities. Dashed black lines are the upper and lower bounds of the 95% Bayesian credible intervals.

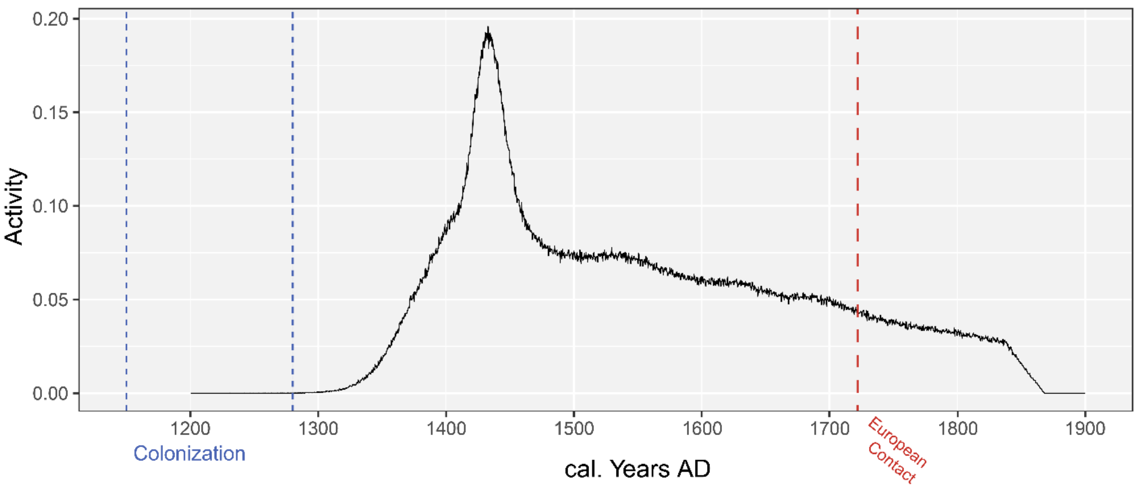

Figure 4.17: Rate of change in ahu construction events. Tempo-activity plot showing the first derivative of the tempo plot Bayesian estimate, or rate of change over time in *ahu* construction events.

4.5.14.1. Results of Tempo Plot Sensitivity Analyses

The tempo plot and tempo activity plot results using an AD 1838-1868 and AD 1771 cutoff are included below (Figures 4.18 and 4.19). An AD 1838-1868 cutoff suggests that *ahu* construction activities rapidly increase between ca. AD 1350-1450, followed by a more gradual tempo of *ahu* construction events that continue into early post-contact times. The upper bound of the 95% credible interval envelope flattens out ca. AD 1750, suggesting that, based on our sample of 11 *ahu*, construction activities continued to around this time, though it is possible that they continued into the early AD 1800s. Using an AD 1771 cutoff produces results that are essentially identical for time periods before AD 1700, but suggests a possible cessation of construction activities around the time of initial European contact in AD 1722 (based on the flattening of the upper bound of the 95% credible interval envelope). We also note that using an AD 1771 cutoff yields models with lower agreement indices. The greatest difference between the results using the different cutoff dates is shown in the tempo activity plots in the latter part of the 18th century (Figures 4.20 and 4.21). Using an AD 1838-1868 cutoff suggests possible construction activities continuing just prior to this date, whereas the AD 1771 cutoff appears to artificially truncate the activity. Based on the available historical evidence and the results presented here, we suggest that ca. 1838-1868 is a more reasonable and conservative cutoff point. However, both iterations of the tempo plots suggest that *ahu* construction activities likely continued until European contact in AD 1722. Thus, both tempo plots are consistent in contradicting the previous assumption of a pre-Contact cessation in *ahu* construction related to societal collapse.

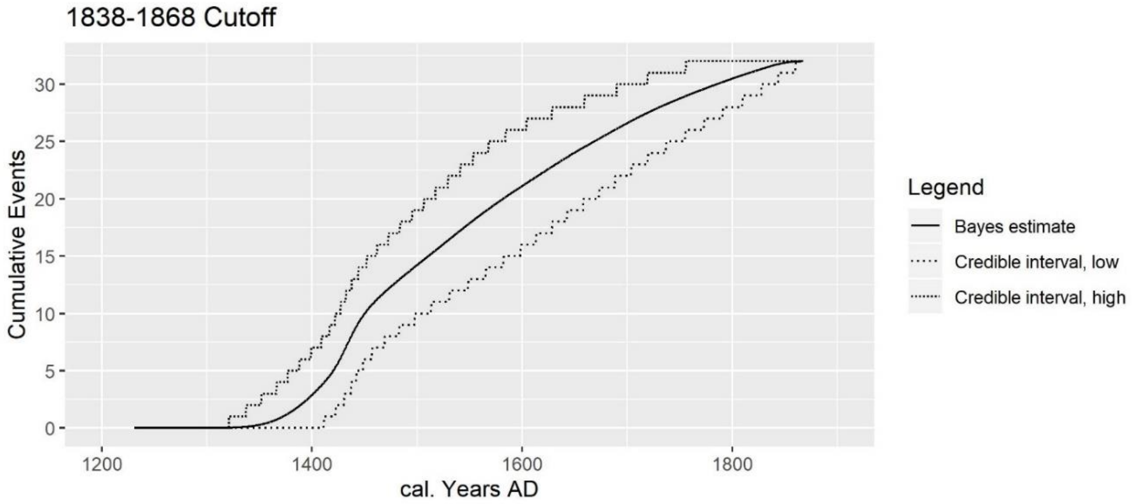

Figure 4.18: Tempo plot results using an AD 1838-1868 cutoff.

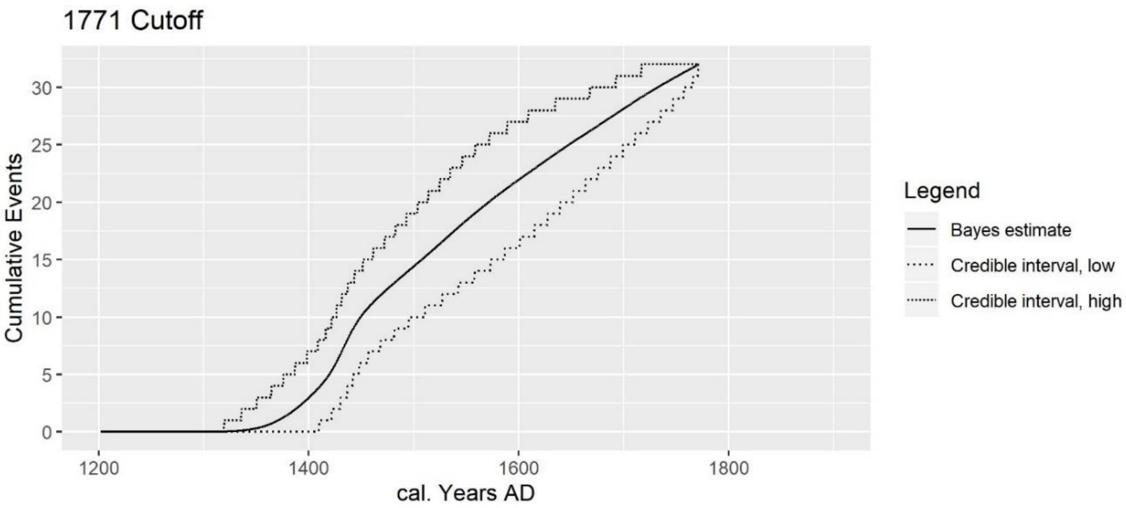

Figure 4.19: Tempo plot results using an AD 1771 cutoff.

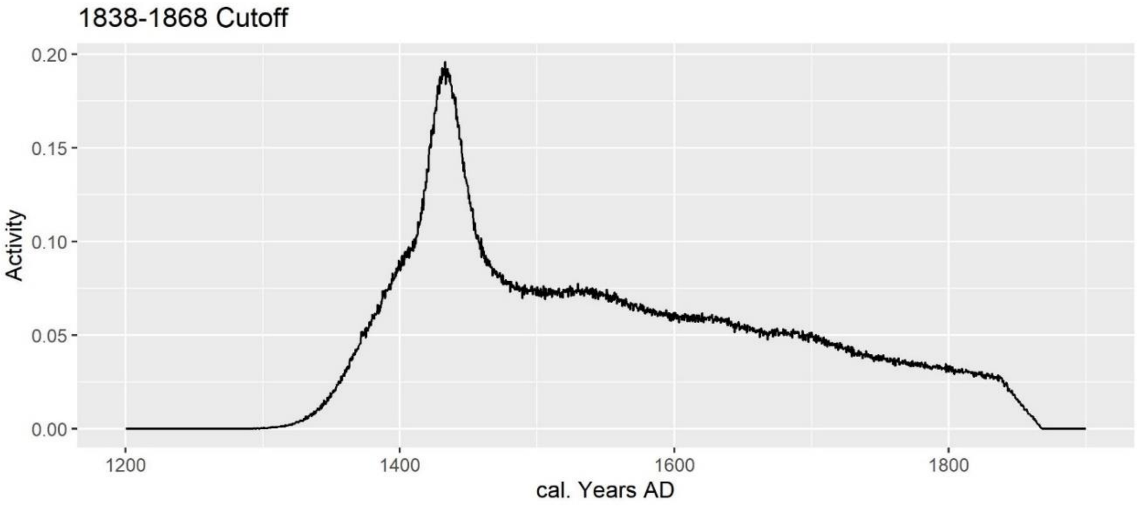

Figure 4.20: Tempo activity plot using an AD 1848 cutoff.

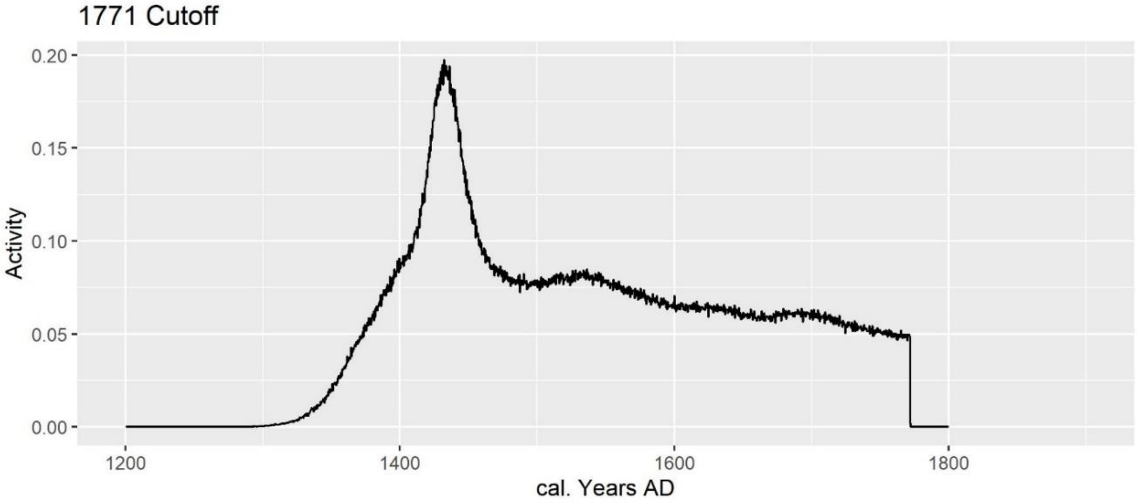

Figure 4.21: Tempo activity plot using as AD 1771 cutoff.

4.6. Discussion

Our Bayesian colonization estimate of *1150-1280 cal. AD* is in broad agreement with previous estimates based on short-lived samples (Hunt and Lipo, 2006; Lipo and Hunt, 2016; Wilmshurst et al., 2011). However, our estimate is both broader and potentially earlier than the estimate of 1200-1253 cal. AD presented in Wilmshurst et al. (2011) and Schmid et al.'s (2018) Bayesian estimate of *1245-1280 cal. AD* (*68.2% HPD*). The difference between our results and those recently published by Schmid et al. (2018) is potentially explained by their use of several younger ^{14}C samples that are unrelated to colonization, some samples not derived from archaeological contexts (e.g., those samples from Mann et al. (2008)), and their presentation of 68.2% HPD rather than 95.4% estimates. Given the available radiocarbon data, our results provide currently the most accurate, if somewhat less precise, colonization estimate for the island and add to a growing corpus of analyses suggesting initial Polynesian colonization of Rapa Nui between the late 12th and early 13th centuries AD.

Our earliest estimate comes from *ahu* Rongo 1, which has an initial construction estimate of *1305-1490 cal. AD*, estimated at some 55-285 years after colonization. The latest initial construction estimate is from *ahu* Tautira, estimated at *1505-1825 cal. AD*, some 260-610 years after colonization. Each of these estimates, however, are derived from unidentified charcoal samples with potential inbuilt age, and as such should be treated as TPQs for initial construction. The most secure estimates come from *ahu* Nau Nau (*1410-1450 cal. AD,* 145-285 years after colonization), Heki'i (*1320-1445 cal. AD,* 70-260 years after colonization), and Te Niu (*1415-1615 cal. AD*, 165-405 years after colonization). Hence, given the models and available data from 11 *ahu*, what we can confidently state is that initial platform *ahu* construction began sometime between the early-14th and mid-15th centuries AD. These model-based estimates for initial *ahu* construction are later than previous *ad hoc* interpretations of ^{14}C samples (Martinsson-Wallin et al., 2013b; P. Wallin et al., 2010, p. 43; Wallin and Martinsson-Wallin, 2008, p. 154), which suggested initial construction potentially as early as 1100-1250 AD . These results have implications for monumentality in the wider region, as they call for a reassessment of previous claims that megalithic construction began on Rapa Nui prior to elsewhere in East Polynesia (Martinsson-Wallin et al., 2013b). Specifically, our revised estimates for initial *ahu* construction may be penecontemporaneous with temple (*marae*) construction in central East Polynesia.

While our results are based on 11 of ca. 150 known platform *ahu* on Rapa Nui, this represents the largest possible sample of features with reliable chronological data and thus our results provide the most complete island-wide synthesis currently possible. It is possible, however, that initial *ahu* construction began earlier at locations not covered by our sample. In addition, the tempo-activity plot in Figure 4.17 suggests a relatively slow decrease in the rate of *ahu* construction events from ca. AD 1550 through the 18th century, though we stress that this result should serve as a hypothesis in need of further testing as additional radiocarbon dates from *ahu* contexts become available. In particular, our analysis lacks samples from Rapa Nui's south coast, which contains some of the highest densities of large platform *ahu* on the island (Martinsson-Wallin, 1994). *Ahu* on Rapa Nui's south coast have been intensively studied by Stevenson (1986), whose work yielded a large corpus of obsidian hydration dates. Given uncertainties with obsidian hydration dating on Rapa Nui and elsewhere (see section 4.4.1), these dates could not be included in our Bayesian models. While Stevenson's (1986) original obsidian hydration chronology for south coast *ahu* is consistent with the results of our Bayesian models, Stevenson's (1997) later efforts that include a revised hydration rate are incompatible with both our estimate for initial colonization of Rapa Nui and the timing of *ahu* construction. This inconsistency is due to the lack of a secure clock mechanism for obsidian hydration dating (Anovitz et al., 1999), and for this reason we exclude these dates.

The most significant results from our Bayesian analyses are the tempo plots for the duration of *ahu* construction activities (Figures 4.16 and 4.17), which provide important falsifying evidence that directly challenges core components of Rapa Nui's collapse narrative. Previous chronologies for platform *ahu* have hypothesized that their construction ceased in the 17th century (e.g., Martinsson-Wallin et al., 2013b; Stevenson, 1997; Wallin and Martinsson-Wallin, 2008). The claim of a pre-contact end to platform *ahu* construction stems from assumptions about a transition in Rapa Nui culture history from an "Ahu Moai" phase, during which platform *ahu* were constructed and *moai* statues erected upon them, to a period of cultural and demographic collapse termed the "Huri Moai" phase that saw the toppling of *moai* and destruction of platform *ahu* (Kirch, 2017, 1984b; Martinsson-Wallin et al., 2013b). The occurrence and chronology of the Huri Moai phase are largely based upon Englert's (1948) conjecture of AD 1680 as the timing for the outbreak of a war described in oral traditions collected in the late 19th and early 20th centuries; however, archaeological evidence in support of this event is either lacking or has been debunked (Lipo and Hunt, 2009; Mulrooney et al., 2009). The results of our Bayesian chronology add to these previous studies questioning the empirical sufficiency of the 'Huri Moai' phase or a cultural collapse in late pre-contact Rapa Nui. Our results also question recent claims by Rull (2016) and colleagues (Rull et al., 2018) that a major drought ca. AD 1600 caused an end to *moai*/*ahu* construction The results of our tempo plots indicate a rapid period of *ahu* construction between ca. AD 1350-1450 with a steady period of construction events that continue into the early historic era. In this regard, given that many of the ^{14}C dates from our sample of 11 *ahu* are from unidentified charcoal only strengthen this result, as their potential for inbuilt age may indicate that these activities occurred even more recently.

These results suggest that the activities of the so-called "Ahu Moai" phase that included statue platform construction and use likely continued up to and beyond European contact. This conclusion is bolstered by the fact that in AD 1722 the Dutch captain Jacob Roggeveen observed rituals being performed by islanders in front of statue platforms, and in 1770 the Spanish also observed that statue platforms were still being used for ritual activity (Corney et al., 1967). For example, Roggeveen (Corney et al., 1967, p. 15) states “what the form of worship of these people comprises we were not able to gather any full knowledge of, owing to the shortness of our stay among them; we noticed only that they kindle fire in front of certain remarkably tall stone figures they set up; and, thereafter squatting on their heels with heads bowed down, they bring the palms of their hands together and alternately raise and lower them.” As others have argued (Boersema, 2015; Mulrooney et al., 2010), this direct observation suggests that platform *ahu* were still the focus of ritual activity at the point of, and following, European contact. This conclusion suggests that the observations made by the Dutch in AD 1722, and likely the Spanish in AD 1770, were relatively accurate depictions of Rapa Nui communities and their traditions. These findings are significant as they highlight the resilience of Rapa Nui communities following the devastating demographic impacts following European arrival (e.g., Fischer, 2005; Hunt and Lipo, 2011; Peiser, 2005; Rainbird, 2002). Indeed, the steady continuous nature of construction of *ahu* features in the history of Rapa Nui strongly supports an emerging model in which this group-level activity served as a vital component of communities necessary for long term sustainability on this tiny and remote island (DiNapoli et al., 2019, 2018; Hunt and Lipo, 2018, 2011).

In 1979, Carl Sagan popularized the aphorism “extraordinary claims require extraordinary evidence.” This aphorism has become “a fundamental principle of scientific skepticism” (Voss et al., 2014, p. 893). Dramatic claims about societal collapse events require methods that are capable of linking expectations about collapse to the archaeological record. Our approach, and that of Dye (2016, 2012, 2010) offers one means of addressing this need. Here, we have provided a template for model-based approaches that address questions related to the tempo of collapse in other regions. In particular, our results highlight the utility of the tempo plot technique for quantifying the timing and rate of change in archaeological events within a Bayesian framework. To date, there have been few applications of the method beyond Dye's (2016) original formulation, which include Banks et al.'s (2019) study of the tempo of change in Upper Paleolithic lithic typologies and Marsh et al.'s (2017) examination of the expansion of the Inca Empire. Our results demonstrate that the tempo plot technique has wide applicability for quantifying the timing and rate of change of archaeological processes, in particular declines or cessation of activities associated with purported 'collapse' events and provides a viable alternative to the more common approach of using summed probability distributions of radiocarbon dates. Tempo plots can also provide a useful extension of more common Bayesian approaches and offer ways to better characterize and quantify similar case studies around the world, such as the rate of decline at various Maya political centers (e.g., Ebert et al., 2017, 2016; Hoggarth et al., 2016) and other areas (e.g., Bar-Oz et al., 2019; Carter et al., 2019; O'Shea et al., 2019).

Rapa Nui remains one of the most popular accounts of a society that self-destructed and is persistently used as a paragon of societal collapse. In particular, there are numerous recent non-archaeological studies that treat this collapse event as fact, and which attempt to use Rapa Nui to validate and calibrate general-purpose economic and demographic models (e.g., Akhavan and Yorke, 2019; Anderies, 2000; Basener and Ross, 2004; Basener and Basener, 2019; Bologna and Flores, 2008; Brander and Taylor, 1998; Brandt and Merico, 2015; Cazalis et al., 2018; D'Alessandro, 2007; Dalton et al., 2005;

Dalton and Coats, 2000; de la Croix and Dottori, 2008; Dockstader et al., 2019; Erickson and Gowdy, 2000; Pezzey and Anderies, 2003; Reuveny, 2012; Reuveny and Decker, 2000; Roman et al., 2017; Takács et al., 2019; Uehara et al., 2010). The results of our Bayesian models, along with recent dates from the Rano Raraku statue quarry (Sherwood et al., 2019; Simpson et al., 2018a), indicate there was not a pre-contact ‘collapse’ in *ahu* or *moai* construction, but that monument activity continued into the post-contact era. These findings add to the growing corpus of independent lines of evidence contradicting the traditional ‘collapse’ narrative for Rapa Nui (Hunt and Lipo, 2011; Lipo et al., 2016; Mulrooney, 2013b; Mulrooney et al., 2010; Simpson and Dussubieux, 2018a), and thus question the results of a broad range of interdisciplinary research on societal collapse that assume the occurrence of this event with certainty.

CHAPTER V

REVISTING WARFARE, MONUMENT DESTRUCTION, AND THE ‘HURI MOAI’ PERIOD

5.1. Introduction

Warfare is considered by many anthropologists to have played a central role in human history, from early human evolution, emergence of complex societies, to our recent history (e.g., Bowles, 2009; Carneiro, 1970; Choi and Bowles, 2007; Glowacki et al., 2017; Gómez et al., 2016; Keeley, 1996; Turchin, 2007; Turchin et al., 2013; Zefferman and Mathew, 2015). Consequently, identifying the occurrence of warfare in past societies and its importance for societal change is a significant, but often difficult, issue for archaeologists to address. The most common lines of archaeological evidence used to infer warfare are systematic patterns of skeletal trauma, defensive/fortified features, and weapons (e.g., Dolfini et al., 2018; Keeley et al., 2007; Martin and Harrod, 2015; Walker, 2001). In many regions of the ancient world this archaeological evidence overwhelmingly supports claims that warfare and violence were important drivers of social transformation (e.g., Arkush and Tung, 2013; Lambert, 2002; Maschner and Reedy-Maschner, 1998; Milner, 1999). However, critical reevaluations of archaeological and ethnohistorical evidence have shown that some cases are more complicated than once thought (e.g., Andrushko and Torres, 2011; Arkush and Stanish, 2005; Kohler et al., 2014) or have suggested wholesale reinterpretations of warfare narratives (e.g., Fry and Söderberg, 2013; Jiménez, 2018; Smith-Guzmán and Cooke, 2018). Clearly, violence and warfare were prevalent in the past. However, because warfare is not an inevitable outcome of human social interaction (e.g., Glowacki et al., 2017), we must critically evaluate the evidence for war from the available archaeological and ethnohistorical evidence. Here, we offer a critical evaluation of one popular, and controversial, case study where warfare has long been assumed a key driver of wholesale societal change and population collapse — Rapa Nui (Easter Island, Chile; Figure 5.1).

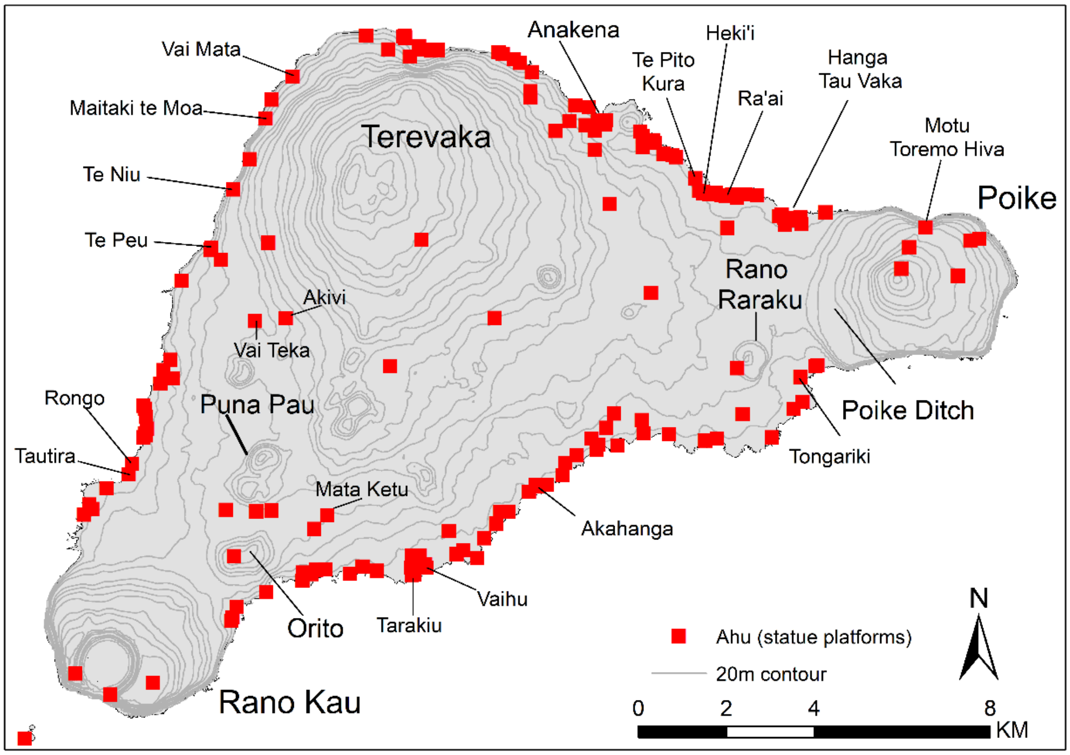

Figure 5.1: Rapa Nui with locations mentioned in the text.

In AD 1722, Europeans first encountered the remote island of Rapa Nui. As they reached the shore, they witnessed a puzzling sight: a mostly treeless and marginal environment with a human population they estimated to be only a few thousand who had constructed an impressive array of megalithic platforms (*ahu*) and multi-ton stone statues (*moai*) (Figure 5.2). These observations of contact-era Rapa Nui have engendered fascination and intense debate ever since. In a historic context, the paradox of the islanders' cultural achievements relative to the isolated and resource-poor landscape became popularly known as 'the mystery of Easter Island.' Early European explorers placed blame for the island's condition on its indigenous population (e.g., Forster 1774, quoted in Jakubowska, 2014). This account holds that naïve actions of ancestral populations ultimately led to the assumed devastated state of the island and its inhabitants at the point of contact. While Heyerdahl and Ferdon (1961) framed this action as the consequence of conflict between Polynesians and South Americans, starting with Mulloy (1974), more recent versions hold that precontact populations were once much larger and lived under a set of more prosperous environmental conditions. These narratives propose that, due to hypothesized Malthusian growth, the island's population subsequently collapsed with a self-imposed ecological catastrophe (e.g., Bahn and Flenley, 1992; Diamond, 2007, 2005, 1995; Flenley and Bahn, 2003; Kirch, 1984b). In these accounts, as the precontact environment fell into disarray, *moai* and *ahu* construction ceased, and intense, violent conflict broke out between the island's clan groups, who battled with obsidian spears (*mata'a*), sought refuge in fortified caves (*ana kionga*), destroyed chiefly houses (*hare paenga*) and *ahu*, and toppled each other's *moai* statues in a prolonged period of internecine warfare termed the "Huri Moai" phase (Kirch, 1984b; Lee, 1986; Smith, 1961a; Van Tilburg, 1986).

Figure 5.2: Aerial images of Ahu Vaihu and Ahu Akahanga with fallen *moai* (top and middle), and recently reconstructed Ahu Tongariki.

Despite the popularity of the story, over about the last 15 years substantial empirical evidence has accumulated that raises doubt on many aspects of the collapse narrative, and instead points to Rapa Nui as a model case study for the resilience of populations faced with a risky and uncertain environment. Important revisions to this narrative include the causes and consequences of deforestation (e.g., Hunt, 2007, 2006; Hunt and Lipo, 2009; Hunter-Anderson, 1998; Orliac and Orliac, 2008), demonstration of a continuity in land-use (e.g., Mulrooney, 2013b; Stevenson et al., 2015) and monument construction over time (DiNapoli et al., 2020), documentation of the lack of evidence for elite control over lithic resources (Simpson et al., 2018a; Simpson and Dussubieux, 2018b), and critical reexaminations of ethnohistorical accounts (e.g., Boersema, 2018, 2015; Lipo and Hunt, 2009; Mulrooney et al., 2010, 2009; Pollard et al., 2010).

Many, however, continue to present the collapse narrative in one form or another as fact (e.g., Bahn and Flenley, 2017; Brandt and Merico, 2015; Kirch, 2017; Kolb, 2020; Reuveny, 2012; Roman et al., 2018, 2017; Scheffer, 2016). Though some recent claims (e.g., Nunn et al., 2007; Rull, 2020b, 2016; Rull et al., 2013) hold that its cause was climatic in origin rather than anthropogenic, the notion that the island suffered from an ecological and cultural catastrophe before European contact remains popular. Central to these claims is the notion that prior to the arrival of Europeans, islanders engaged in extensive and violent warfare as the result of competition over diminished resources and social upheaval. The idea that warfare was both common and intense on late precontact Rapa Nui stubbornly persists in even some of the most recent literature (e.g., Bahn and Flenley, 2017; Kirch, 2017; Kolb, 2020, 2012; Wallin and Martinsson-Wallin, 2011; Younger, 2008). In his review of warfare in Polynesia, Younger (2008, p. 929), for example, classifies Rapa Nui as a place where intergroup violence was "chronic: warfare essentially continuous." In his recent treatise on monumental architecture, Kolb (2020, pp. 207–208) argues that,

> [s]ometime after 1500 (and maybe as late as 1770), profound sociopolitical and religious changes in Rapa Nuian [*sic*] society resulted in the cessation of statue carving and significant modification or destruction of most *ahu* platforms. *Moai* statues were intentionally toppled over…The reason behind such a drastic change is under debate, the most likely reason being the rise of internecine warfare ties to a generalized degradation of the environment, population pressure, and/or rising social tensions.

Likewise, in his latest overview of Polynesian prehistory, Kirch (2017, p. 236) insists that "intertribal raiding and warfare became pervasive, during what has been called the Huri Moai Period, from about A.D. 1500 to 1722" based on claims that "the rise of endemic warfare is clear from the late precontact archaeological record," and that the use of lethal spear-like weapons is evident from "considerable ethnohistoric information."

It is not our goal here to revisit the collapse debate in its entirely (see, for example, Hunt and Lipo, 2018, 2011, 2007; Larsen and Simpson, 2014; Lipo et al., 2018; Mulrooney et al., 2010; Rainbird, 2002; Tainter, 2006). Rather, we focus our attention on the claims about widespread warfare and monument destruction, particularly in light of new evidence to the contrary. We critically review the main arguments that have been used to support the notion that warfare was prevalent in precontact Rapa Nui during the so-called 'Huri Moai' phase. We examine archaeological and ethnohistoric evidence typically claimed for warfare, including oral traditions, historic accounts, lethal skeletal trauma, weapons, fortifications, and the chronologies of *ahu* construction and *moai* toppling. Our findings reveal that there is little empirical justification for warfare, nor as a criterion denoting a culture historical phase, leading us to conclude that Rapa Nui's culture history needs fundamental revision. This conclusion raises caution about other claims: if warfare is not part of the famous example of Rapa Nui, as was long accepted, perhaps other cases are in need of careful and systematic reexamination.

5.2. Rapa Nui Culture History and the 'Huri Moai' Phase

Following the traditional practice of culture historical periodization (Dunnell, 1971; Lyman et al., 1997), early researchers divided Rapa Nui's archaeological sequence into a number of discrete phases. The concept of 'phase' in an archaeological context is generally used to denote a distinctive configuration of features that existed for a period of time over some finite space. The interpretation of phase, however, often goes beyond this definition. For example, Willey and Phillips (1958, p. 49; also Rouse, 1955 for a similar view) suggested that "the equivalent of phase ... ought to be 'society.'" While early workers tended to be more cautious about the culture/phase equivalence (e.g., Abbott, 1972; Brain, 1978; Phillips and Willey, 1953) since they realized that such equivalencies were accidental rather than structural, phases are often confused as being cultural entities rather than simply measurement tools.

On Rapa Nui, the use of phases was initially driven by the need for culture historians (particularly Carlyle Smith) to create a chronology for the island's history. Using an *ad hoc* set of features that describe *ahu* construction, culture historians associated with Heyerdahl's 1950s expedition (Heyerdahl and Ferdon, 1961; Smith, 1961a), separated "early" (the beginning of *ahu*/*moai* construction) features of the archaeological record from "late" (i.e., post-*ahu*/*moai* construction) forms and added a "middle" phase that effectively captured most of the pre-European contact occupation of the island. Smith (1961a) designated the early phase as "Ahu Moroki," referring to the initial building of *ahu* characterized by the construction of a dressed-stone seawall. Following Englert (1948), Smith (1961a) termed the middle period "Ahu Moai," referring to when *moai* statues and other architectural elements were added to *ahu*. For the late phase, Smith (1961a, p. 184) introduced the term "Huri Moai," or literally the "statue-overthrowing-time," which he linked to a hypothesized battle of AD 1680 (discussed below). Over time, these basic phases have remained, though their meanings have changed to reflect new interests. For example, Mulloy (1974) later tied this chronology to changes in the island's ecology. Ayres (1974) then relabeled the basic chronology into phases of "settlement and developmental," "expansion," "decadent," and "protohistoric" – terminology that is consistent with cultural neo-evolutionary (orthogenetic) concepts popular at the time for the New Archaeology (see Dunnell, 1980). Following Ayres, Kirch (1984b, see also 2000, 2017) adjusts the phases to be "initial settlement" and "Ahu Moai" separated from a late precontact "decadent/Huri Moai" phase.

In this way, Rapa Nui's phases have become associated with notions of cultural 'stages' rather than simply denoting chronological arrangement of cultural patterns, an interpretation that far exceeds their original purpose (Van Tilburg, 1996). Rather than simply measurement tools for parsing chronology, phases have become integral to the traditional archaeological narratives of the island, in particular as stages of progressive or orthogenetic development followed by cultural regression/collapse. Like elsewhere around the world, phases have come to be treated as real cultural phenomena that are the subject matter for explanation rather than the tools that culture historians originally intended (Lipo, 2001).

Fundamentally, the logic that is embedded in the chronological framework of Rapa Nui's phases consists of three known facts. First, Polynesian voyagers colonized the island from somewhere in central East Polynesia, now thought to have occurred around the 12th-13th centuries AD (DiNapoli et al., 2020; Hunt and Lipo, 2006; Schmid et al., 2018; Wilmshurst et al., 2011). Second, Rapanui people initially began to invest in *moai* that were placed atop massive stone *ahu* structures at some point after settlement, and this activity continued until some point when people stopped making *ahu* with *moai*. Third, Europeans arrived in 1722. It is upon these fundamental aspects of the chronology that layers of interpretation have been added to account for the proposed 'phases.' Specifically, the cessation of *ahu* and *moai* construction has become associated with the consequence of increased intensity of monument building assumed to result in resources being exhausted until the society began "a downward spiral of cultural regression" until it "crashed devastatingly" (Kirch, 1984b, p. 264). Thus, the phase of *moai* and *ahu* building (Ahu Moai period) resulted in ecological catastrophe, followed by cessation of *moai* construction, then leading to a period of warfare, "starvation, a population crash, and a descent into cannibalism" (Diamond, 1995, p. 62). It is imagined that during this late precontact time the island no longer saw the construction of *ahu* and *moai*, but instead saw internecine warfare, social disintegration, and population loss (e.g., Englert, 1970). This period of chaos is thought to have ended at some undefined time following the arrival of the Dutch in 1722 and subsequent European contacts (the "proto-historic" phase). Lee (1986) and Van Tilburg (1986) continued with this tradition, firmly embedding it in the literature. Stevenson (1997) narrowed the “decadent” phase to a shorter period of “warfare and fragmentation” that immediately precedes European contact. Other authors (e.g., Bahn and Flenley, 2017; Kolb, 2020, 2012) have adopted this general chronological framework (Figure 5.3).

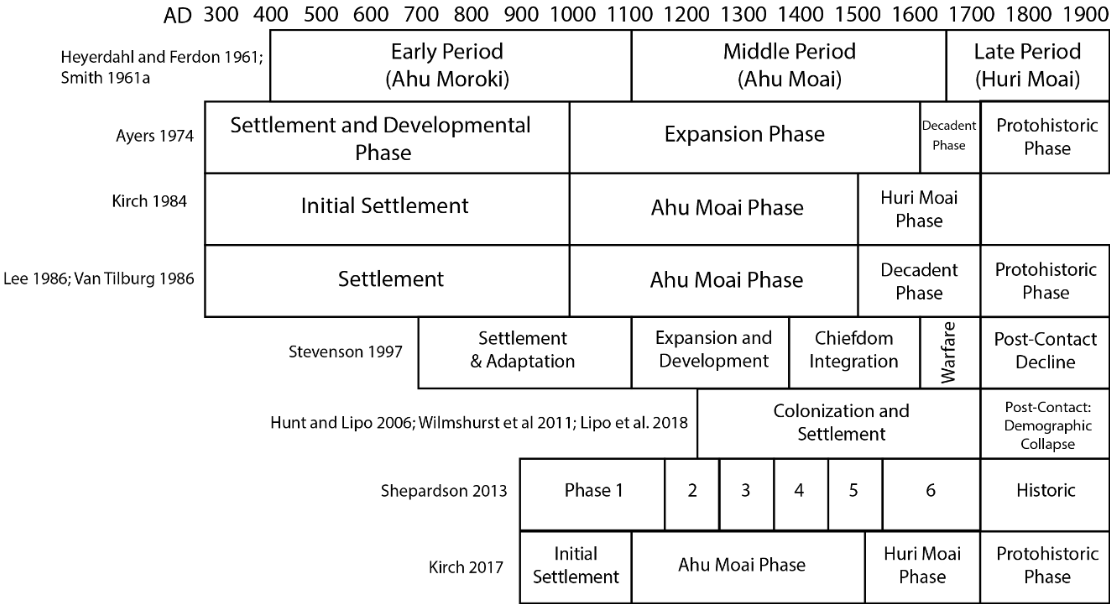

Figure 5.3: Cultural historical phases used for Rapa Nui. Figure adapted from Lee (1986) and Shepardson (2013, p. 211).

A temporal scheme for Rapa Nui that includes a late-precontact “decadent” or “Huri Moai” phase is commonplace, including in Diamond’s popular narratives (2007, 2005, 1995), Kirch’s (2017) most recent review of Pacific archaeology, and in recent syntheses of monumental architecture in the Pacific (e.g., Kolb, 2020, 2012; Martinsson-Wallin, 2014). The idea that late pre-European contact groups engaged in warfare in competition over diminished resources holds appeal to those who believe that our own history is likely to follow the same pattern (essentially, a microcosm of Earth’s current problems of overharvesting resources, taxing the environment, overpopulation, etc.).

Consequently, the “Huri Moai” phase has resulted in a bit of a cottage industry of non-archaeologists who have attempted to model the island as if these events were a certainty and a parable for what could happen to the earth as a whole (e.g., Basener and Ross, 2004; Bologna and Flores, 2008; Brander and Taylor, 1998; Brandt and Merico, 2015; Cazalis et al., 2018; Dalton and Coats, 2000; de la Croix and Dottori, 2008; Erickson and Gowdy, 2000; Reuveny, 2012; Reuveny and Decker, 2000; Roman et al., 2017; Uehara et al., 2010).

An important part of the rationalization and timing of the “Huri Moai” phase comes from the assumption that at ca. AD 1680—some 42 years before the arrival of the Dutch—the island experienced tremendous upheaval (e.g., Bahn and Flenley, 1992, p. 180; Flenley and Bahn, 2003, p. 170; Stevenson and Haoa, 2008; Vargas et al., 2006, p. 233). This date initially was proposed by Englert (1948) who assigned a precontact date for a battle described in oral traditions between two groups known as the Hanau Eepe and the Hanau Momoko (Thomson, 1891, pp. 528–532). The names of these groups are often translated into English as “Long Ears” and “Short Ears” (respectively), though “fat or heavy-set people” and “thin, slender people” (respectively) is likely a more accurate translation (Mulloy, 1993; Mulrooney et al., 2009, p. 94). This battle was thought to have taken place at the base of Poike where a long linear depression exists, the so-called ‘‘Poike Ditch’’ (Figure 5.1; see Reanier and Ryan, 2003; Smith, 1961a, 1961b). Frequently mentioned in late 19th and early 20th century ethnohistoric accounts (e.g., Métraux, 1940; Routledge, 1919; Thomson, 1891), Englert treated the battle as a historic event, and one that took place prior to Roggeveen’s arrival in AD 1722. Believing the battle occurred during the latter end of prehistory, Englert reasoned that the event took place a ‘‘few decades before Roggeveen’’ and, as a result, he ‘‘fixed the date at AD 1680’’ (Englert, 1970, p. 91).

While based in speculation, the date became a fixture in the literature and for years researchers have continued to use the period around AD 1680 as a time that distinguishes a “Huri Moai” or “Decadent” phase from previous points in time during which platform *ahu* were constructed and the iconic *moai* were carved and transported (e.g., Ayres, 1974; Bahn, 1993; Flenley, 1998, 1996, 1979; Horrocks and Wozniak, 2008; Lee, 1992; Martinsson-Wallin, 2014, 2004, 2000; Martinsson-Wallin et al., 2013b; McCoy, 1976; Nunn, 2000, 1998, 1997; Nunn et al., 2007; Nunn and Britton, 2001; Stevenson, 1997, 1984; Stevenson and Haoa, 2008; Stevenson and Haoa-Cardinali, 1998; Van Tilburg, 1994; Wallin and Martinsson-Wallin, 2011). Some contemporary researchers, however, are skeptical about the veracity of an AD 1680 event, as the date itself and associations lack empirical sufficiency (e.g., Boersema, 2015; Lipo and Hunt, 2009; Mulrooney et al., 2009). Yet, many continue to assume that late prehistory was a period of dramatic transformative change marked by some combination of environmental and sociopolitical shifts (e.g., Bahn and Flenley, 2017; Kirch, 2017; Kolb, 2020, 2012; Puleston et al., 2017; Rull, 2020b, 2018, 2016; Rull et al., 2018, 2013; Shaw, 2000a, 2000b; Vargas et al., 2006).

Common in collapse narrative accounts is the idea that the key impact of environmental change was social strife that escalated into systematic inter-group violence. Previous traditions such as *ahu* and *moai* construction ceased to be a central part of the society. Following the conjectured battle of AD 1680, social relations on the island declined into a prolonged period of internecine warfare where it is speculated that the island’s clan groups fought and killed each other with spears, built fortified caves, committed cannibalism, destroyed houses and *ahu*, and toppled each other’s *moai*. The reasoning for this narrative comes from a variety of sources. Aside from gross speculation, the most common lines of evidence cited are the abundance of obsidian implements, called *mata‘a*, which are assumed to be spearpoints, misinterpretations of calibrated radiocarbon dates, the fact that all *moai* at *ahu* were eventually no longer standing, cave features modified with stones from elite houses, and oral traditions collected in the late 19th and early 20th centuries. Below, we critically evaluate each of these lines of evidence.

5.3. Revisiting the Empirical Evidence for Warfare

While there is a commonality of injury and mortality of individuals, it is important to distinguish two classes of violent interaction: 1) interpersonal violence; and 2) warfare. Interpersonal violence is defined as that perpetrated between a small number of individuals, who may be of a similar group affiliation, and includes personal fights, homicides, assassinations, domestic violence, and revenge killings (e.g., Arkush and Tung, 2013; Fry and Söderberg, 2013; Younger, 2011, 2009). Warfare, in contrast, is defined as organized violence, often lethal, at the scale of groups that conflict over differences in affiliation rather than individual attributes or actions (e.g., Arkush and Tung, 2013; Baustian et al., 2012; Milner, 1999; Thorpe, 2003; Younger, 2009; Zefferman and Mathew, 2015). Warfare is definitively group-to-group violence between entities at the scale of alliances, political communities, or other groups that share identity (Tefft and Reinhardt, 1974, p. 154). While this class of interaction includes lethal violence between individuals, the mechanisms leading to group-level conflict are distinct from those in which a single individual might attack another (Younger, 2011). Interpersonal violence might lead to warfare, but the latter occurs as a function of coordinated and cooperative effort between sets of individuals. Here, we focus our definition of warfare as it relates to the assumptions related to the "Huri Moai" narrative on Rapa Nui: cases in which the outcome was large-scale loss of life as a result of violence.

Discerning the occurrence of warfare from the archaeological record is fraught with ambiguities. Simple observations of isolated instances of violence are insufficient evidence to claim warfare, as they often are more appropriately explained as interpersonal violence. Given the definition of warfare, identifying it archaeologically requires looking for evidence associated with activity at the group, rather than single individual, scale. For this reason, the direct archaeological evidence for warfare comes from two sources: 1) skeletal evidence; and 2) material culture.

5.3.1. Skeletal Evidence

Systematic and widespread physical evidence on skeletal material related to perimortem injuries that likely caused death is one class of information used to identify warfare (e.g., Baustian et al., 2012). For example, cranial fractures, facial fractures, bone-embedded projectile points, and defensive wounds such as cut-marks on phalanges, radii, and ulnae might be used to indicate warfare (e.g., Kelly, 2013, p. 161; Martin and Harrod, 2015). Of course, the presence of these attributes would have to be sufficiently numerous to distinguish the incidence of warfare from occasional interpersonal violence (Baustian et al., 2012, p. 104). One should note that skeletal evidence often cannot be used as the sole evidence of warfare alone: if violence was systematic in ways consistent with our definition of warfare, we would also expect to find evidence in other artifact classes (e.g., defensive features, specialized weapons, etc.).

5.3.1.1 Skeletal Trauma

Skeletal trauma on human remains is perhaps the clearest archaeological evidence for violence and warfare in past populations (Arkush and Tung, 2013; Martin and Harrod, 2015; Walker, 2001). Healed or unhealed skeletal fractures are strongly indicative of sublethal or lethal violence, with unhealed cranial injuries providing the clearest evidence for violent death. It is important, however, to distinguish between skeletal trauma resulting from smaller-scale interpersonal violence and the high percentage of lethal trauma expected from widespread warfare. Such evidence for war is abundant, for example, in the archaeological records of North and South America (e.g., Arkush and Tung, 2013; Lambert, 2002; Milner, 1999; Tung, 2007) and Europe (e.g., Boldsen et al., 2015; Dolfini et al., 2018; Guilaine and Zammit, 2008; Thorpe, 2003).

Given the claims for widespread warfare expressed by some archaeologists and the mentions of warfare in Rapa Nui oral histories, one would expect there to be abundant evidence for lethal skeletal trauma. In a series of studies, Owsley and colleagues (Gill and Owsley, 1993; Owsley et al., 2016, 1994) analyzed a large sample of human remains collected and excavated from caves, *ahu*, and *avanga* (burial features) on Rapa Nui. Though not all samples or deposits are well-dated, the available radiocarbon dates on teeth from these burials indicate that most date to ca. post-AD 1650, though some are considerably earlier (Commendador et al., 2014, 2013; Owsley et al., 2016, p. 225). In addition, the overall lack of European artifacts from the burials suggests that most are precontact (Owsley et al., 2016, p. 225). Therefore, the available skeletal evidence likely dates to the time periods when warfare is thought to have been most intense by many scholars. To date, a total of 4,169 craniofacial bones, comprising an estimated 476 cranial vaults, have been examined for signs of trauma. Of these, 3.1% of the individual bones show signs of traumatic injuries, and of the 476 cranial vaults, 112 (23.53%) show some evidence of trauma, but only 11, or 2.31%, exhibited lethal injuries (Owsley et al., 2016, p. 239). Males exhibited double the amount of cranial fractures as women (Owsley et al., 2016, p. 237), and notably nearly all post-cranial fractures are healed. Overall, the vast majority of injuries are relatively minor, and healed, blunt force traumas, rounded or ovoid in shape, to the frontal and parietal cranial bones. Trauma resulting from sharp-edged weapons (e.g., *mataʻa*) are rare, and there are only two observed cases of healed fractures with obsidian embedded in bone (Owsley et al., 2016, p. 236).

Although the Rapa Nui skeletal sample does exhibit incidences of cranial trauma, remarkably few of these resulted in fatalities. From a bioarchaeological perspective, there is little support for the idea that lethal violence or war was ever widespread (Gill and Stefan, 2016). Nor is there evidence from the skeletal data that *mataʻa* or other lithic implements were commonly used as weapons. While Bahn and Flenley (2017, pp. 191–192) may be correct in their claims that *mataʻa* injuries were common, as suggested by some early European accounts (see Lee et al., 2004; Richards, 2008; Ruiz-Tagle, 2007), these were likely minor as they appear to have left little skeletal evidence. One would expect that if serious or lethal wounds from *mataʻa* were common, then we should see more than the few cases of sharp-edged trauma observed in the relatively large Rapa Nui skeletal sample. The common blunt force fractures to the skull are small and usually healed, which Owsley et al. (2016, pp. 245–249) suggest “are consistent with injuries that would be caused by throwing rocks, a practice extensively documented in Rapa Nui ethnohistories” and that “a near absence of facial bone fractures suggest that most confrontations did not involve hand-to-hand combat”, and instead “that most injuries resulted from frequent personal confrontations, family disputes, or occasional small-scale conflict where the intention was to harm, but not necessarily to kill.” Thus, the available skeletal evidence documents a case in which there were contests between Rapanui individuals but that these rarely resulted in death.

5.3.1.2 Cannibalism

Claims of precontact warfare on Rapa Nui have also highlighted the extent to which violence and famines among the islanders escalated to the point of cannibalism (Diamond, 2005, 1995; Kirch, 2000, p. 274; Skjølsvold, 1994, p. 112; Van Tilburg, 1994, p. 109110; cf. McLaughlin, 2005). In Diamond’s (2005, 1995) account, for example, ecological catastrophe included the loss of resources necessary to support the island’s population, a condition that lead to intense competition over the meager remaining resources, the emergence of skirmishes of greater and greater violence, followed by constant warfare, and finally rampant cannibalism and chaos. In one notable passage, Diamond (2005, p. 109) dramatically writes,

> In place of their former sources of wild meat, islanders turned to the largest hitherto unused source available to them: humans, whose bones became common not only in proper burials but also (cracked to extract the marrow) in late Easter

> Island garbage heaps. Oral traditions of the islanders are obsessed with cannibalism; the most inflammatory taunt that could be snarled at an enemy was "The flesh of your mother sticks between my teeth."

Kirch (2000, p. 274) has similarly claimed that the island's midden deposits "have a sickeningly high frequency of charred and fractured human bones".

While such stories present a horrific late precontact history for the island, there is simply no unambiguous archaeological evidence to support these claims (Hunt and Lipo, 2007; McLaughlin, 2005; Mulrooney et al., 2010). Owsley et al. (2016, p. 246) point out that the large assemblage of human remains demonstrates "a lack of convincing physical evidence for the practice of cannibalism, such as a cache or assembly of burned bones or bones with chops and cuts characteristic of dismembering and defleshing." In addition, Mulrooney et al. (2010, p. 145) note that occurrence of small amounts of human bone, burnt or otherwise, is not to be unexpected in archaeological contexts given cultural practices of cremation and using human bone for manufacturing artifacts, such as fishhooks and needles. Thus, we are left with only hearsay, likely embellished European accounts, and mentions in oral traditions collected in the late 19th and early 20th centuries argued in support of cannibalism (e.g., Bahn, 1997; Fischer, 2005, pp. 55, 79, 1992; Flenley and Bahn, 2003, p. 156; McLaughlin, 2005).

5.3.2 Material Culture

Given that the human skeletal data for Rapa Nui lacks clear indications of warfare, we now turn to material archaeological evidence which might signify group-level aggression. There are several aspects of material culture observed in the archaeological record that are expected if warfare was prevalent in the past. For example, one obvious line of evidence for warfare is defensive structures: constructed features that required group cooperation and investment that afforded defense to the group members within. Examples of defensive structures include modified hilltops, walls/palisades, moats, and ditches. These can take the form of locations to which populations retreat when threatened or locations in which the entire group lives (e.g., a fortified village, such as a Māori *pā*) (e.g., Best, 1927; McCoy and Ladefoged, 2019). Other expressions of culture related to warfare include weapons, iconography, and systematic monument destruction.

5.3.2.1 Fortifications

One of the hallmarks of inter-group aggression and warfare in the archaeological record is fortified, defensive features (Keeley et al., 2007; Parkinson and Duffy, 2007). As Kirch (1984b, p. 207) has noted, "archaeological evidence for prehistoric warfare in Polynesia consists of occasional weapons (slingstones, spear points, etc) found on the surface or in excavations, and of fortifications. Of these two classes of evidence, the second is far and away the most important, providing critical data on the age, development, and degree of armed conflict." If warfare was widespread on Rapa Nui, then we should expect patterns in the archaeological record similar to elsewhere in the Pacific where warfare is evident (DiNapoli et al., 2018; Field, 2008; Field and Lape, 2010). We would expect Rapa Nui examples to include features such as ditch-embankment complexes or modified hilltops in the most defensible places (e.g., the high elevation areas at Rano Kau, Terevaka, Rano Raraku, Poike, Maunga Orito, etc.) (Figure 5.1). Such features are common, and indeed focal, aspects of the settlement pattern elsewhere in the Pacific, such as Fiji (e.g., Field, 2004; Smith and Cochrane, 2011), Rapa Iti (Kennett and McClure, 2012), Sāmoa (Best, 1993; Cochrane and Mills, 2018), Tonga (e.g., Clark et al., 2018; Parton et al., 2018), and New Zealand (e.g., Best, 1927; McCoy and Ladefoged, 2019; Walter et al., 2006). Critically, however, *there is not a single recorded instance of such a feature on Rapa Nui*, nor are there historical accounts of anything resembling a defensive feature of this nature (e.g., no palisaded areas). Arguments that the 'Poike ditch,' a series of elongated depressions on the interior base of the Poike peninsula, represents a defensive feature (Figure 5.1; Smith, 1961c, 1961b) have found little support (Lipo and Hunt, 2009; Mulrooney et al., 2009; Reanier and Ryan, 2003) and its form is likely geologic in origin. Katherine Routledge (1919, p. 281), for example, concluded that "there is a marked depression running across the eastern volcano from the mainland, but after much consideration we came to the conclusion that it was a natural phenomenon due to geological faulting."

Some argue that the island's many caves may have served a defensive purpose, or as refugia in times of war (Bahn and Flenley, 2017; Kirch, 2017; Stevenson and Haoa, 2008, p. 174). Indeed, there are several instances of caves exhibiting modified entrances that, in some cases, act to obscure or conceal the entrance. Some of these modifications include the use of *paenga* stones, which are rectangular, dressed basalt slabs including one or more cylindrical holes. *Paenga* stones usually occur as the foundations of domestic features called *hare paenga*, assumed to be elite houses. The occurrence of *paenga* stones within these modified caves is often associated with the destruction of elite dwellings during times of war and their reuse in so-called 'fortified' caves. Kirch (2017, p. 237), for example, has recently claimed that, "the rise of endemic warfare is clear from the late precontact archaeological record. The finely worked basalt foundation slabs of elite houses were pulled apart and used to fortify subterranean lava tubes and caves." This observation, however, neglects to include the common reuse of *paenga* stones in a range of archaeological features, including *umu* (ovens), *manavai* (gardens), *tupa* (observatories), and even *ahu*. Figure 5.4 shows the reuse of a *paenga* stone within the seawall of Ahu Te Peu, a large image-*ahu* (*ahu* with *moai*) on Rapa Nui's west coast. This is not an isolated instance, *paenga* stones are often incorporated into earlier building phases of *ahu* (Smith, 1961a, p. 214). The reuse of *paenga* stones in the construction of image-*ahu* is significant because it shows that stones from *hare paenga* were being reused in this fashion prior to when *moai* were supposedly toppled (i.e., the Huri Moai phase). The assumption that this indicates "destruction of elite dwellings" is unnecessary and simply represents a widespread pattern of stone reuse (Figure 5.4).

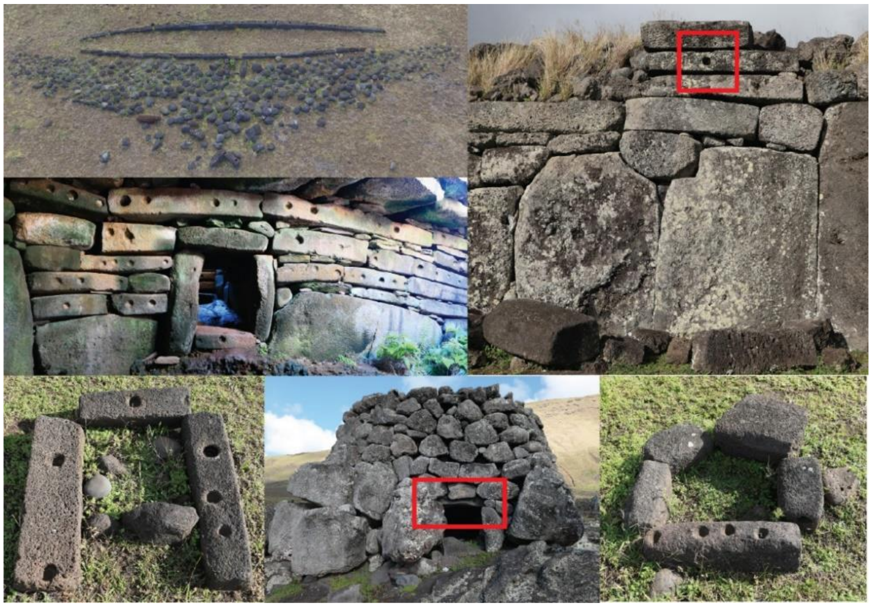

Figure 5.4: Reuse of paenga stones in a range of archaeological features. Clockwise from top-left: intact *hare paenga*; Ahu Te Peu with *paenga* built into seawall; *umu* (oven), *tupa* (observatory), and *umu* with *paenga;* modified cave with *paenga* near Ahu Vai Mata.

Furthermore, it is incorrect to call these features ‘fortified,’ for while they often have modified entrances, they lack nearly all the common characteristics of fortifications found in the Pacific (e.g., Field, 2008; Field and Lape, 2010) and indeed elsewhere in the world (Keeley et al., 2007). More accurate descriptors would be simply ‘hiding places’ or ‘refugia,’ and Stevenson et al. (2019) have recently argued that the caves served as the locations of ritual activity. One possible function as ‘hiding places’ is offered by McCoy (1976, p. 36) who suggests they may have simply been modified for protection from the elements:

> Partially sealed entrances are a rather common modification contributing to dark interiors [of the caves]. They are a marker of probable seasonal habitations occupied during the colder, wetter period of the of the year...Stone walls were constructed below the drip line the entire breadth of the cave mouth except for a low, narrow crawlway used for entry. The wall acted as a buffer against the penetrating cold air and blowing rain.

McCoy (1976, pp. 36–37), however, also suggested a refuge function for some modified caves. Importantly, if these caves were refugia, then they would not be effective for hiding from people intimately familiar with the island’s geography (Hunt and Lipo, 2011, p. 99). Similar to elsewhere in Polynesia, Rapanui people likely had an intimate knowledge of their landscape, including caves, so even if cave entrances were obstructed by rock walls, their locations would still be known to others. Modified caves, however, would have been very effective hiding places from outsiders, such as Europeans or Peruvian slave raiders who repeatedly captured Rapanui people throughout the 19th century (Fischer, 2005; Hunt and Lipo, 2011, p. 99). The chronology of the use of these modified caves is not well understood, but recent dating programs suggest their use is largely post-contact (Mulrooney et al., 2010; Stevenson et al., 2019), which is also supported by the presence of European artifacts in these caves (Lipo and Hunt, 2009, p. 313).

5.3.2.2. Weapons

One of the most common artifacts found on Rapa Nui are flaked obsidian tools with wide blades and narrow stems called *mata'a* (Figure 5.5). The common assumption has been that these implements are weapons, specifically 'spearheads' (e.g., Bahn and Flenley, 2017; Diamond, 2005; Kirch, 2017). If warfare and lethal conflict were widespread, one would expect strong engineering constraints on effective weaponry. This selective pressure would lead toward a dominance of pointed, thin shafts well-suited for lethal penetration of internal organs. While similar to stemmed obsidian tools found elsewhere in the Pacific, *mata'a* are unlike the darts, arrows, or spearheads found elsewhere in the world. In a geometric morphometric analysis of 423 *mata'a*, Lipo et al. (2016) demonstrated that, on the whole, the distal end of *mata'a* bear little resemblance to a pointed spearhead and in fact have few unifying characteristics other than a stemmed base and a sharp edge. Additionally, historical collections of *mata'a* demonstrate that they were not often hafted onto anything resembling a spear-shaft but instead on short handles (Figure 5.5). In other words, *mata'a* lack the formal characteristics expected for a systematic lethal weapon.

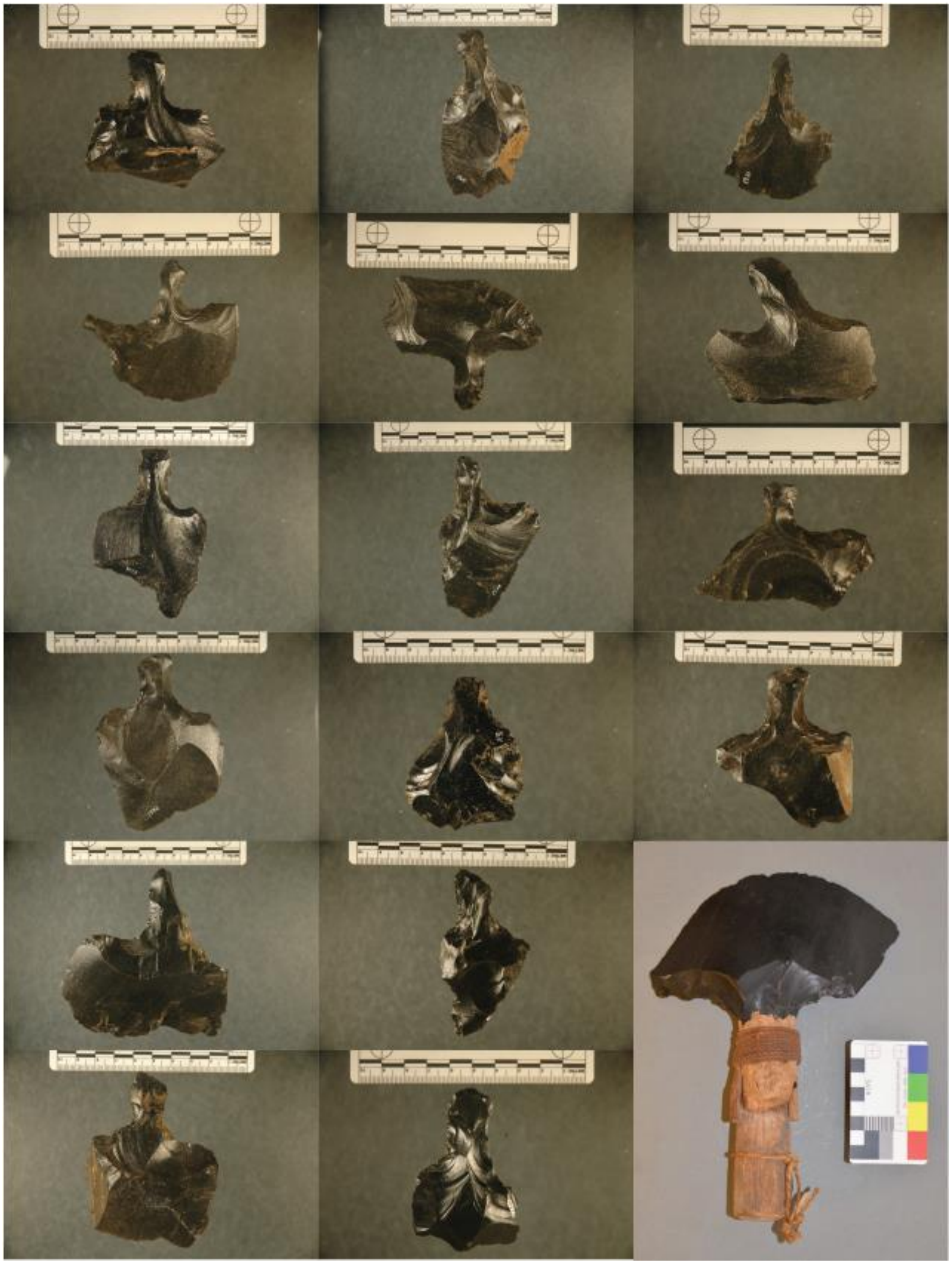

Figure 5.5: Examples of *mata'a* from archaeological contexts. Bottom right is a hafted example from ethnographic collections (courtesy of the British Museum). Photos by C.P. Lipo and T.L. Hunt.

In recent use-wear analyses of 12 *mataʻa,* Torrence and colleagues (2018) reach similar conclusions and point to evidence that *mataʻa* were used for a variety of tasks and were likely idiosyncratic in use. Four of the 12 *mataʻa* they analyzed may have been used for cutting of "soft, elastic material," such as fish, meat, flesh, or skin, which they argue may reflect *mataʻa* use in occasional interpersonal violence, though these patterns may also be consistent with butchering animal foods (e.g., rats, chickens) or "scarification or tattooing in ritual practices or medical practices, as speculated by Lipo et al. (2016:184)" (Torrence et al., 2018, p. 11). The remaining eight *mataʻa* analyzed by Torrence et al. (2018) either did not show clear use-wear patterns or exhibited use-wear consistent with the processing of plant materials or shell, as previous analyses of *mataʻa* form and use attributes have found (e.g., Ayres et al., 2000b; Church and Ellis, 1996; Church and Rigney, 1994), clearly indicating the empirical evidence for *mataʻa* is simply not consistent with their centrality in warfare as has been often claimed.

Kirch (2017, p. 304 emphasis added) has recently argued that while "[i]t has been claimed that the *mataʻa* were not weapons at all but agricultural implements ...*considerable ethnohistoric information refutes this*." Such a statement appears to rely on comments made by early European visitors who commonly assumed that the hafted obsidian tools they observed could have been weapons (e.g., Cook 1774, cited in Ruiz-Tagle, 2007, p. 168). Strikingly, there are no historically documented cases of violence carried out with *mataʻa*, whether against Europeans or among Rapanui people. In AD 1722, Bouman, a captain on Roggeveen's Dutch visit to Rapa Nui, observed that "[t]he people had, to judge by appearances, no weapons" and "[t]hey don't even know what one can do with a knife until we showed them. They cut bananas with a sharp small black stone around the stem” (von Saher, 1994, pp. 99–100). The human skeletal evidence and use-wear analyses of *mata‘a* discussed above support these findings and suggest that they were likely multipurpose cutting/scraping tools. Furthermore, obsidian hydration dating, although problematic in any absolute sense (Anovitz et al., 1999), suggests a dissociation between peak *mata‘a* use and periods when intense warfare is speculated (Stevenson and Williams, 2018).

Aside from *mata‘a*, the other potential weapons used by Rapanui are wooden clubs (*paoa*) and rocks. Early European accounts document the presence of *paoa*, though there are few direct observations of them being used for lethal violence (e.g., Richards, 2008, p. 54), and even fewer cases of skeletal trauma that can be attributed to them (Owsley et al., 2016). Indeed, observations by La Perouse in AD 1790 suggest that these objects were not weapons, but rather status symbols (Boersema, 2015, p. 74). The weapon most commonly reported by historic visitors to the island, and the one attributed to most of the cases of skeletal trauma, are rocks.

5.3.2.3. The Chronology of *Ahu* Construction and *Moai* Toppling

Today, none of Rapa Nui’s *moai* stand upright on the *ahu* (monumental platforms) except for those restored in the 20th century (Figure 5.2). A particularly important event in the Huri Moai narrative of Rapa Nui’s precontact collapse is the destruction of image-*ahu*, where, as the island’s clans descended into warfare, they would knock down the statues of enemy clans (Bahn and Flenley, 2017; Kirch, 2017, 1984b). However, other possibilities have been proposed. Edwards et al. (1996), for example, argue that image-*ahu* would have been particularly susceptible to earthquakes, which are documented historically and could easily cause *moai* to fall, and, though the evidence for precontact earthquakes is slight, they present evidence for differential fall patterns consistent with seismic activity. For example, in their study of 24 of the largest image-*ahu* having a total of 111 *moai*, Edwards et al. (1996, p. 13) found that, “in all cases, the fall of the statues was caused by a loss of leverage of the basal structure, and 80% of the statues fell inland. This occurred because the most vulnerable point of the building is the fragile and unstable front slab wall...that would tend to burst open with minimum effort, letting the rubble filling spill out and thus destabilizing the megalithic stone statues.” Furthermore, they found that roughly 80% of *moai* fell in a west-northwest direction, consistent with toppling from an earthquake.

Cauwe (2016, 2014) has recently suggested that *moai* were intentionally toppled but during non-violent ritual activity. This interpretation is based on the observations that most *moai* on image-*ahu* fell inland in a prone position, that a relatively small portion of them are broken, and that there is little evidence for the destruction of *ahu* platforms, which he argues would be inconsistent with aggressive destruction. Volcanic tuff, a relatively weak material of which the majority of *moai* are made, would be expected to break more frequently if they were violently toppled (Cauwe, 2014).

An additional explanation could be that *moai* fell simply due to lack of attention and maintenance following the population loss and cultural changes that occurred after European contact (Hunt and Lipo, 2011, p. 153).

Precisely what caused the *moai* to fall remains unclear. What is clear, however, is that these events are almost certainly post-contact (Figure 5.6; Edwards et al., 1996; Fischer, 2005, p. 80; Pollard et al., 2010). The first two European visits by the Dutch in

AD 1722 and Spanish in AD 1770, for example, make no mention of fallen *moai*, and in fact the Dutch documented the only observed case of rituals being performed at image-*ahu*, suggesting *ahu* and *moai* were still the focus of religious activity by 1770 (Boersema, 2015, pp. 89–90; Mulrooney et al., 2010; Pollard et al., 2010, p. 565). Four years after the Spanish visit of 1770, Cook noted that some statues had fallen (Ruiz-Tagle, 2007). Over the ensuing decades the number of reported *moai* still standing declines, and by 1868, Palmer notes that all the statues had fallen (Palmer, 1870). This historical record indicates that widespread 'statue toppling' cannot be part of any precontact period.

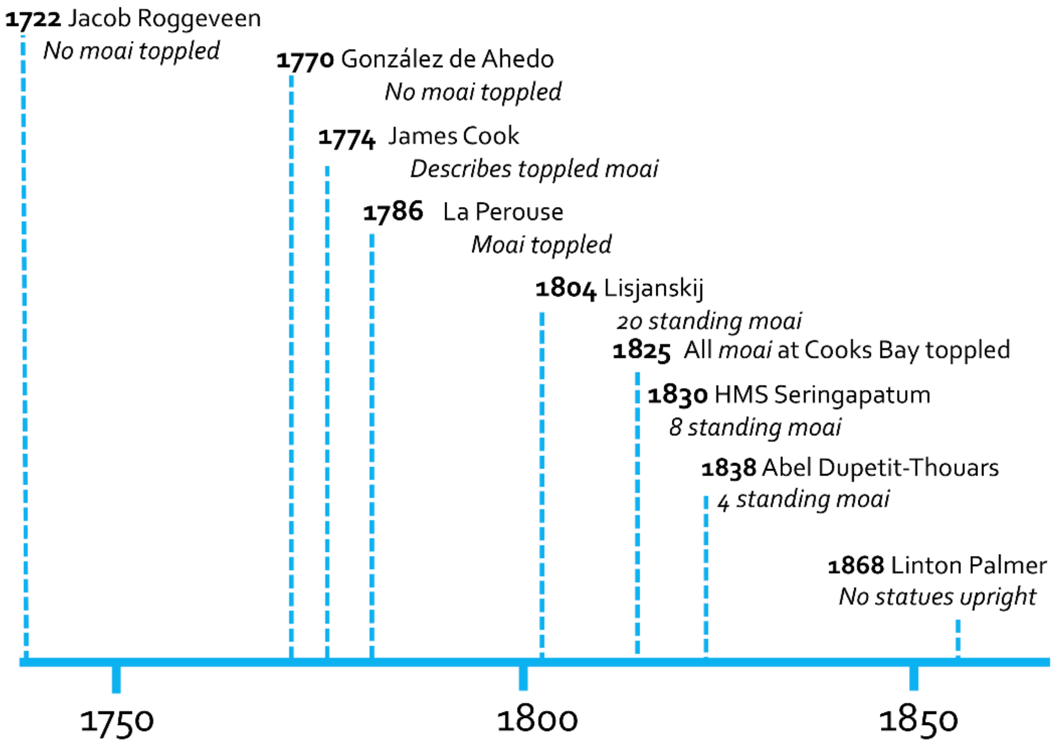

Figure 5.6: Timeline of European reports regarding the status of *moai* suggesting that statues fell post-contact.

As with the chronology for statues falling, the chronology of statue platform (*ahu*) construction also continues into the post-contact period. Recent Bayesian chronological modeling provides little support for the notion that platform *ahu* construction ceased ca. AD 1600, which is a central component of the Huri Moai narrative in Rapa Nui's culture historical scheme (DiNapoli et al., 2020). Instead, the results of this chronological modeling clearly show that platform *ahu* construction continues at least until European contact in AD 1722, and likely even further into the historic era (DiNapoli et al., 2020). Figure 6.7 shows the cumulative number of dated platform *ahu* construction events along with the hypothesized timing of the onset of the Huri Moai period and European contact. What these results show is that at least 10 *ahu* construction events, or ~30% of the total sample of dated contexts, occur within this time frame. These results provide important falsifying evidence to previous claims that platform *ahu* construction ceased during a 'destruction phase' (Martinsson-Wallin, 1994, p. 142; Martinsson-Wallin et al., 2013b, p. 417, Figure 7) or "[d]egeneration of ceremonial sites" in the shift from the Ahu Moai to Huri Moai periods (Wallin and Martinsson-Wallin, 2008, p. 154). The fact that statue platforms were being built and modified throughout the supposed Huri Moai phase also suggests that the *moai* statues erected upon them were also being carved and transported during this timeframe as well. Similar results have also been recently reported for the statue quarry at Rano Rararku, where Sherwood et al.'s (2019) radiocarbon dating program indicates that activities at the *moai* quarry also likely continue into historic times. Together, these European accounts and archaeological evidence provide no support for claims of precontact monument destruction that define the Huri Moai phase.

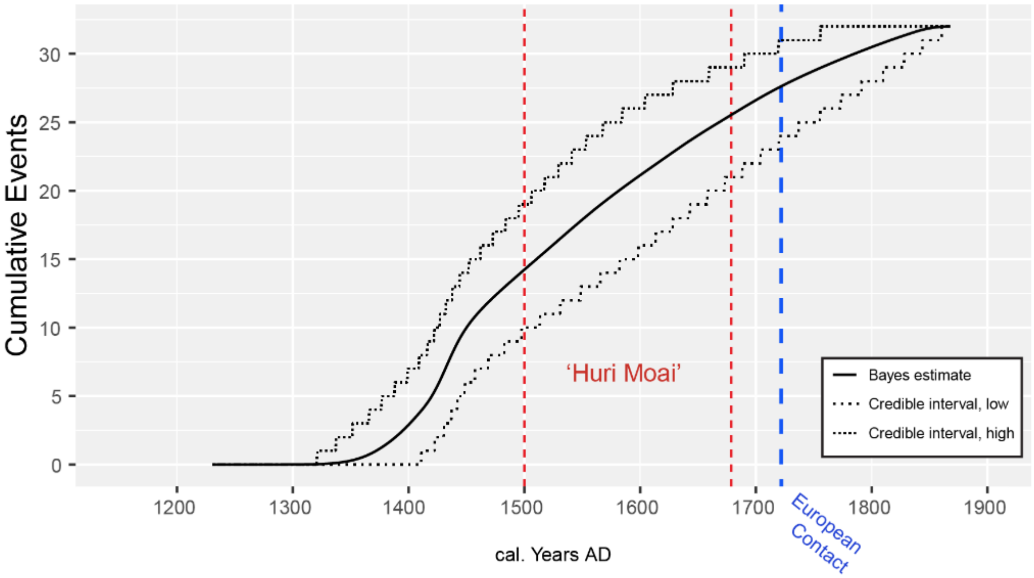

Figure 6.7: The chronology of statue platform construction. Red lines indicate the time range that has been previously proposed for the onset of the Huri Moai phase. Figure adapted from DiNapoli et al. (2020).

5.4. ETHNOHISTORIC ORIGINS

Given the absence of *physical* evidence of warfare, what is the origin of assumptions that the island must have been the site of tremendous violence and fighting?

5.4.1. Historical Accounts

The accounts of the first European visitors provide valuable information on Rapa Nui culture at a time when the Huri Moai phase is believed to be well underway. As detailed above, the defining feature of this phase—the 'toppling' of the *moai*—did not occur until well after European arrival. Early European accounts, from the first visit in 1722 through the arrival of Eyraud in 1864, include very few mentions of warfare or a violent society. In fact, most historical accounts comment on the peaceful and nonviolent nature of Rapanui—at least until they began to fight against the ravages of European whalers and slave raiders. The available documents from the Dutch, Spanish, English, and French visits in the 18th century consistently express views that the Rapanui were non-violent and appeared to possess few weapons (Boersema, 2018, p. 161, 2015, p. 73). Don Francisco Antonio de Agüera y Infanzon (1770, cited in Ruiz-Tagle, 2007, p. 63) noted that,

> I made a bow and arrow, duly strung, by way of experiment, and on handing it to one of those with the scars he instantly stuck it on his head as an ornament, and then hung it round his neck with much joy, being totally ignorant of its use and effect. They did the same with a knife and with a cutlass, which they took hold of indifferently by the point or by the hilt.

As has been noted elsewhere (e.g., Fischer, 2005), most violent acts documented in historical accounts are against Rapanui by Europeans.

With the increasingly frequent visits of Europeans, who often used their firearms against Rapanui for 'thievery' and other perceived infractions, accounts of violent acts by the islanders also increase in frequency. However, these are chiefly against Europeans. After the most heinous act of violence against the Rapanui—the Peruvian slave raids (Maude, 1981)—the first Catholic missionary, Eyraud, arrived in 1864. In his nine month stay on the island, the longest by any European at that time, he does mention that the Rapanui had 'spears' though he offers no accounts of people using them against others:

> I have noticed that the Kanacs are very careful not to spill blood...Even though they have had knives since the arrival of Peruvians, they never use them in their feuds. If they want to send someone into the next world, they find it simpler to use stones...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 (Lee et al., 2004, pp. 24–25).

A key point is that by AD 1864, nearly 150 years since contact, there are essentially no documented cases of intergroup violence among the Rapanui, whether with *mata‘a* or other weapons, in the historical record.

Beginning in AD 1869 with the writings of the Catholic missionary Roussel, however, we see an abrupt change to accounts of a society at war, and Roussel seems to have had a particular impact on our understanding of the history of the island. Roussel highlights the degree of interpersonal violence among the islanders, stating, “the natives hid their deceitful, violent and sometimes ferocious characters. I cannot count the times that I have seen a man attacking the face or the head of his wife with a knife to kill her or mortally injure her” (Lee et al., 2004, p. 50). However, Roussel’s descriptions of war are vague as they do not detail any specific event, and after recounting how these activities took place he notes that, “So that is how things stood when the missionary arrived,” suggesting he did not witness these events first-hand (Lee et al., 2004, p. 44). His descriptions of weapons also lack indications of a first-hand account. The precise reasons for this dramatic shift in the narrative are unclear, though it is possible that Roussel imagined, or fabricated, the past prevalence of war to legitimize his conversion of the Rapanui (Schávelzon and Igareta, 2017, p. 315). Indeed, Roussel later adds that, “Thanks to the Religion, exercising his influence over the natives, he [Roussel] was able to put an end to these raiding parties.” (Lee et al., 2004, p. 44).

Roussel’s influence on the island was substantial for Europeans and Rapanui alike. With his previous experience in Mangareva and as a fluent speaker of Pa‘umotu (the language of the Tuamotu Islands)—largely intelligible to Rapanui speakers—Roussel was treated as an authority on Polynesian traditions even to islanders (Fischer, 2005). The fact that his writings of Rapa Nui history, filled with secondhand accounts, are at stark contrast with previous observers suggests he took liberties when reporting about the island's past, embellishing them to suit his goal as a missionary. While based simply on his assumed authority on the topics, including violence, his accounts likely influenced the islanders' own traditions. Thus, the accounts of the 'savagery' and warfare among the Rapanui became legendary.

Later in 1872, Pierre Loti, who spent four days on Rapa Nui and popularized aspects of the Huri Moai narrative with his writings and drawings of war and *moai* toppling (Figure 6.8; Schavelzon, 2014), noted that,

> There was a terrible time, in the past, that is still spoken of with awe by the old people of today. There were too many islanders on Rapa Nui and many of them starved to death on this island that nobody was able to leave. As a result, great wars erupted among the tribes, with wholesale massacres and cannibalism...*when Vancouver landed on the island*...he was still able to see traces of armed camps on all the mountains and remains of fortification barriers on the slopes of all the craters (Lee et al., 2004, p. 93 emphasis added).

In addition to his writings not being first-hand observations of intergroup violence and laden with his preconceptions of the Rapanui as 'savages' (Schavelzon, 2014), we are unaware of any writings by Vancouver about Rapa Nui. Vancouver did, however, visit Rapa Iti in the Austral Islands, well-known for its fortified settlements (Anderson, 2012a), so it is likely that Loti's assumptions about Rapa Nui were the result of a confusion between the two islands. Nevertheless, the speculative accounts of Roussel and Loti were then treated as historical facts continuously reiterated by later European visitors (e.g., Métraux, 1940; Routledge, 1919; Thomson, 1891), and accepted by modern day archaeologists.

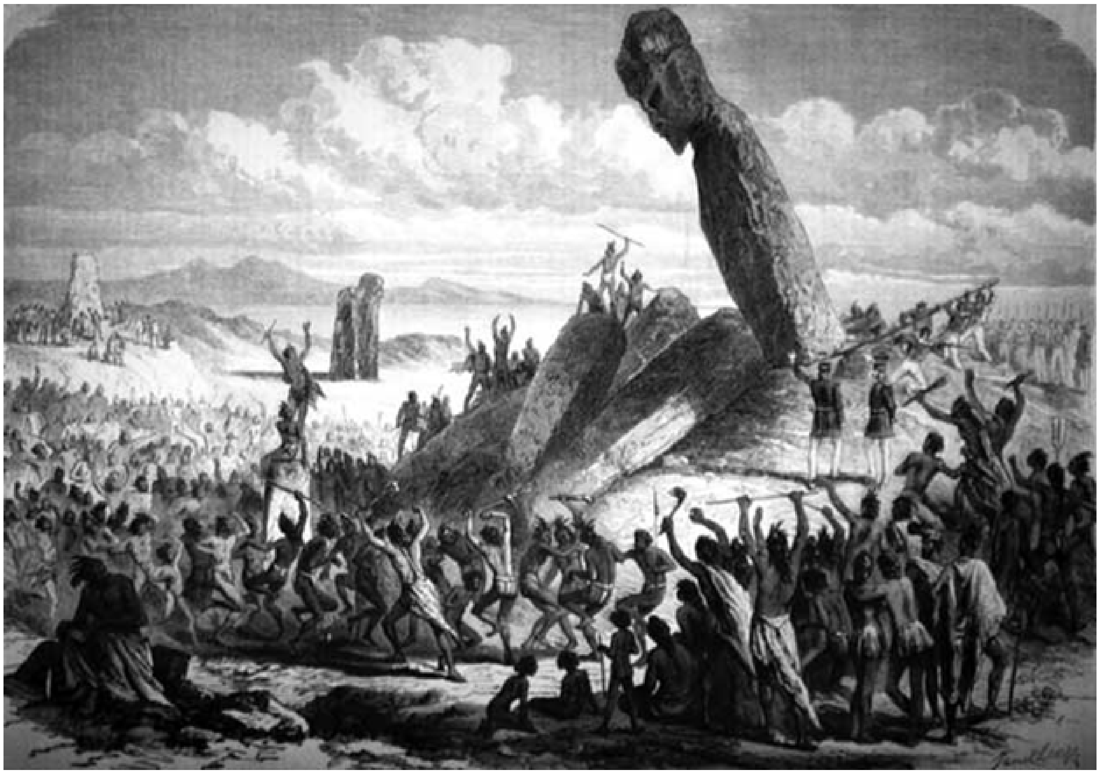

Figure 6.8: Engraving of speculative sketch made by Loti in 1872 depicting moai toppling. From Schavelzon (2014, p. 2).

5.4.2. Oral Histories

Oral histories and traditions provide an invaluable source of information regarding a vast range of issues of interest to archaeologists. The first detailed ethnographic research on Rapa Nui began in the late 19th and early 20th centuries (e.g., Englert, 1948; Métraux, 1940; Routledge, 1919; Thomson, 1891), nearly 200 years after initial European contact, and these works have been very influential in structuring archaeologists' views on precontact Rapanui culture, ranging from issues of subsistence to social organization. According to these first ethnographers, mentions and comments of warfare in the past (i.e., prior to the missionaries), which sometimes also include accounts of cannibalism and *moai* toppling, were commonly reported by their informants (e.g., Métraux, 1940, pp. 74, 87, 149; Thomson, 1891, p. 476). Aside from brief comments about the past importance of warfare, these works overlap in their telling of two main large battles or wars, the first being a fight between Tuʻu and Hotu iti, and the second being the famous battle of the Hanau Eepe and Hanau Momoko.

These traditions of warfare, however, are at odds with the archaeological record and historical accounts detailed in previous sections. While it is not our intent to imply that these oral traditions are 'false,' we must be cautious in assuming they are unembellished historical facts occurring during a precontact 'Huri Moai' or 'decadent' phase. The stark contrast between these oral histories—collected in the late 19th and early 20th century—with the precontact archaeological evidence and early (18th-19th century) historical accounts implies either that these events were very late (e.g., late 19th century) or they are legends of only recent antiquity.

Métraux (1940), who conducted the most detailed ethnographic work, notes that "no mention of a real war is made in the story" of the battle between Tuʻu and Hotu iti (1940, p. 85), and regarding the battle between the Hanau Eepe and Hanau Momoko he argues it is likely not a pre-contact event but suggests ''very likely the fight between the Long-ears and Short-ears is a fairly recent theme''(1940, p. 74). A critical point is that these two wars are not mentioned by Roussel (1869, in Lee et al. 2004), who, given his descriptions of widespread warfare and violence, and the fact that he spent multiple years on the island, almost certainly would have noted these events, again suggesting they are recent. Peiser (2005, p. 530) has noted that, "the natives' recollections of warfare and violent conflict most likely belong to the hostilities in the wake of European attacks on the island" (see also Holton, 2004). Gill and Stefan (2016, p. 298) interpret the stark contrast between the bioarchaeological evidence for violence and the late 19th/early 20th century ethnographies as possibly indicating, “these events occurred temporally late, and were within the recent “folk memory” of the native informants.” Similarly, Mulrooney et al. (2009, p. 94) argue that these ethnographies, “must be examined with caution due to the context in which they were recorded. The severe [post-contact] population decline would have resulted in the loss of traditional knowledge, and those stories that were collected may have been shaped more by the contemporary social context than the precontact period they were supposedly describing” (see also Stevenson et al., 2002, pp. 213–214). Accounts of cannibalism in oral traditions are also not supported by direct ethnographic observation or archaeological evidence, and the speculative claims of Europeans and missionaries are better interpreted in light of the misconceptions, prejudice, and ulterior motives of these individuals (Fischer, 1992).

5.5. Discussion

On Rapa Nui, where warfare has long been assumed a critical factor in societal change preceding European contact, we find few, if any, of the common archaeological correlates of it, such as large-scale skeletal trauma, fortifications, or systematic production of lethal weapons. The fact that Rapa Nui lacks anything resembling the fortifications common elsewhere in the Pacific is significant, as these would certainly be expected if large-scale intergroup fighting was common (e.g., DiNapoli et al., 2018; Field, 2008; Field and Lape, 2010). The reuse of house stones in modified caves is better interpreted as simply stone reuse than ‘destruction of elite houses,’ and the use of these caves may simply reflect habitation or ritual activity that likely dates largely to the post-contact era (Stevenson et al., 2019). Based on European accounts, the Rapanui wielded wooden clubs and stones as weapons, the latter of which they often used against European aggressors. The common claim that *mata'a* were weapons of war is not supported by archaeological or historical evidence. While it is clear from the human skeletal data that there was a relatively high degree of interpersonal aggression, this fighting was largely non-lethal and casts considerable doubt on the claim that killing and warfare were widespread.

The available historical data from the initial ca. 150 years of European visits is consistent with this archaeological evidence. The abrupt shift in the historical narrative, beginning with Roussel and Loti, following the slave raids, deportations, and epidemics of the 19th century that reduced the population to only a few hundred people, is best treated cautiously given the ulterior motives, prejudice, or confusion of these visitors. *Moai* falling and cessation of *ahu* construction, the defining characteristics of the supposedly pre-contact Huri Moai phase, was a post-contact phenomenon, and causes other than intentional toppling are possible.

This overall lack of archaeological or historical evidence for warfare indicates that the Huri Moai or Decadent Phase is simply not a component of Rapa Nui's past, and that the island's pre-contact and early post-contact culture history is in need of substantial revision. A solution, and one that fits the available archaeological and historical evidence, is that the activities that characterize the "Ahu Moai phase" (i.e., *ahu* and *moai* investments) continued into early historic times. This notion is supported historically given that the Dutch observed ritual activity at *ahu* and that *moai* falling was largely a post-contact phenomenon. Archaeologically, chronological studies of land-use over time provide no indication of major changes in settlement patterns away from *ahu* (e.g., Mulrooney, 2013b; Mulrooney et al., 2009; Stevenson, 1986; Stevenson et al., 2015; Vargas et al., 2006). Furthermore, the available secure radiocarbon dates and settlement pattern studies suggest that *ahu* begin to be constructed shortly following colonization in the 12th-13th centuries and remain the focal points of most settlements throughout precontact times (e.g., DiNapoli et al., 2020; Hunt and Lipo, 2018; McCoy, 1976; Morrison, 2012; Vargas et al., 2006). Empirical chronological evidence for an end to *moai* carving and transport in precontact times is also equivocal or altogether lacking, again likely dating to the historic era (Graves and Ladefoged, 1995, pp. 166–167; Graves and Sweeney, 1993, p. 120). The limited reliable radiocarbon dates from the statue quarry at Rano Raraku do not support the idea of an abandonment of *moai* production (Sherwood et al., 2019; Simpson et al., 2018a, p. 27). In short, sometime soon after initial colonization we see the establishment of a dispersed, coastal settlement system organized around ritual architecture that continued into the historic era, and all available archaeological evidence points to relatively non-violent intergroup interaction on Rapa Nui. In this way, previous ‘phase’ schemes for Rapa Nui that have been forwarded since Heyerdahl’s 1950s expedition lack utility. Decoupling the cessation of *ahu* and *moai* construction and use from a precontact ‘collapse’ now forces us to look closer at the details of the history of colonization, trends in monument investment by communities across the island over time, and the series of effects that European arrival brought to the island after AD 1722.

While violence and warfare were indeed key factors in the emergence and transformation of many human societies (e.g., Dolfini et al., 2018; Guilaine and Zammit, 2008; Keeley, 1996; Turchin, 2007; Turchin et al., 2013), claims about the past importance of war often need to be critically evaluated, as empirical data are not always consistent with historical assumptions (e.g., Fry and Söderberg, 2013; McCoy and Ladefoged, 2019; Smith-Guzmán and Cooke, 2018). The evidence outlined here for Rapa Nui indicates that a substantial revision of the island's culture history is needed. This not only opens up new avenues for exploring the fascinating history of this tiny and remote island, but also has implications for studies beyond archaeology. In particular, recent research that has treated the "Huri Moai" phase and supposed collapse of Rapa Nui society as the model for what could happen in our current globalized society are in need of critical reexamination as well (e.g., Basener and Ross, 2004; Basener and Basener, 2019; Bologna and Flores, 2008; Brander and Taylor, 1998; Brandt and Merico, 2015; Cazalis et al., 2018; Dalton and Coats, 2000; de la Croix and Dottori, 2008; Erickson and Gowdy, 2000; Reuveny, 2012; Reuveny and Decker, 2000; Roman et al., 2018, 2017; Uehara et al., 2010). In retrospect, contemporary scholars who further the arguments made by individuals like Roussel simply perpetuate mid-19th century traditions of imposing myths on the island and its people to suit external preconceptions. Far from being the prime example of over-use of resources, internecine warfare, and 'cultural regression,' Rapa Nui is better thought of as a model case study for human resilience in a marginal environment, the devastating impacts of European contact, and as a cautionary tale of uncritically accepting historical assumptions.

CHAPTER VI

COSTLY SIGNALING AND MONUMENT CONSTRUCTION ON RAPA NUI

6.1. Introduction

Monumental architecture remains a most conspicuous aspect of the archaeological record. There is a high degree of cross cultural variation in features classified as ‘monuments’ or ‘monumental architecture’, with these features differentially occurring as mounded earthworks in eastern North America and Amazonia (e.g., Bernardini, 2004; Pluckhahn et al., 2016; Watling et al., 2017), stone-work temples, such as the *marae* of East Polynesia (e.g., Cochrane, 2015; Kahn and Kirch, 2014), to the massive pyramids of Mesoamerica and Egypt (e.g., Marcus and Flannery, 2004). What all these monumental structures have in common is that their “scale and elaboration exceed the requirements of any practical functions that a building is intended to perform” (Trigger, 1990, p. 119). This scale and elaboration imply that relatively large numbers of individuals were needed to construct them, suggesting a degree of coordination, cooperation, or managerial presence. Hence, common proximate explanations for the occurrence of monument construction posit that they function within emergent social complexity, such as increased political hierarchy/religious authority, inter-group or inter-elite competition, and intra-community cooperation (e.g., Bradley, 2012; DeMarrais et al., 1996; Kirch, 1990a; Kolb, 2020; Moore, 1996; Osborne, 2014; Scarre, 2011; Trigger, 1990). While these are reasonable proximate explanations, there have been only limited attempts to build more general and ultimate explanations for why these forms of human cooperation and competition are so often expressed as large architectural features. Given the pervasiveness of monument construction in the archaeological record, and that it remains a central focus of archaeological research, this lack of a general model for monument construction represents a significant limitation to our understanding of many past human societies. Indeed, the independent occurrence of these group-level construction behaviors in many different times and places in human history suggests a common process in their emergence (Neiman, 1997; Roscoe, 2009; Trigger, 1990).

From an evolutionary ecological perspective, what explains the widespread occurrence and temporal persistence of a behavior such as monument construction, which appears to entail costs much greater than the potential benefits (DiNapoli and Morrison, 2017, p. 7; Graves and Ladefoged, 1995; Hunt and Lipo, 2001; Neiman, 1997; Norenzayan et al., 2016, p. 47)? One possibility is *costly signaling theory* (CST), which proposes that many energetically 'wasteful' traits are mutually adaptive in social contexts by transmitting otherwise unobservable information about the signaler, like reproductive fitness, trustworthiness, or competitive ability, to a receiver (Gintis et al., 2001; Grafen, 1990; Johnstone, 1997; Zahavi and Zahavi, 1999). Although theoretical approaches and archaeological manifestations of monuments are highly variable (Buccellati et al., 2019; Hildebrand, 2013; Levenson, 2019; Osborne, 2014), most researchers have converged on the idea that they are inherently communicative phenomena (e.g., Kolb, 2020), whether the information conveyed is control of energy (e.g., Abrams, 1994, 1989; Abrams and Bolland, 1999; McCurdy and Abrams, 2019; Trigger, 1990), religious or political power (e.g., Artursson et al., 2016; Earle and Spriggs, 2015; Inomata, 2006; Kirch, 1990a; Kolb et al., 1994; Moore, 1996; Neiman, 1997; Smith, 2011), community membership (e.g., Bernardini, 2004; Dungan and Peeples, 2018; Fogelin, 2003; Thomas, 1990), territorial control (e.g., Howey and Clark, 2017; Renfrew, 1976), or some combination of these factors. In other words, monuments were designed to more effectively communicate some underlying quality of individuals or groups. Considering these common features of monuments—*high energetic costs and communicative function*—CST holds great potential to better inform their evolutionary and ecological origins.

Here, I test the predictions of CST for monumental architecture against the archaeological record of Rapa Nui (Easter Island, Chile, Figure 6.1), famous for its elaborate ritual architecture. Following initial Polynesian colonization of this small, isolated, and ecologically marginal island between *1150-1280 cal. AD*, around the mid-14th to 15th centuries, an intensified period of statue (*moai*) and statue platform (*ahu*) construction began that continued through European arrival in AD 1722 (Chapter 5; DiNapoli et al., 2020). In this short time span, Rapa Nui islanders carved nearly 1000 megalithic *moai*, hundreds of which were transported over volcanic terrain and erected on more than 150 *ahu*. *Ahu* sites formed the focal points for domestic, social, and especially religious activity, and several researchers hypothesize that these monuments served as territorial displays of community cooperation and competition over the island’s limited resources (e.g., DiNapoli and Morrison, 2017; Hunt and Lipo, 2018, 2011; Kirch, 2017, 1984b; McCoy, 1976; Rainbird, 2002; Stevenson, 2002; Van Tilburg, 1994). Given Rapa Nui’s small size, isolation, and plethora of religious megaliths, it offers a potential ‘model-system’ to better understand the evolutionary and ecological dynamics of monument construction (DiNapoli et al., 2018).

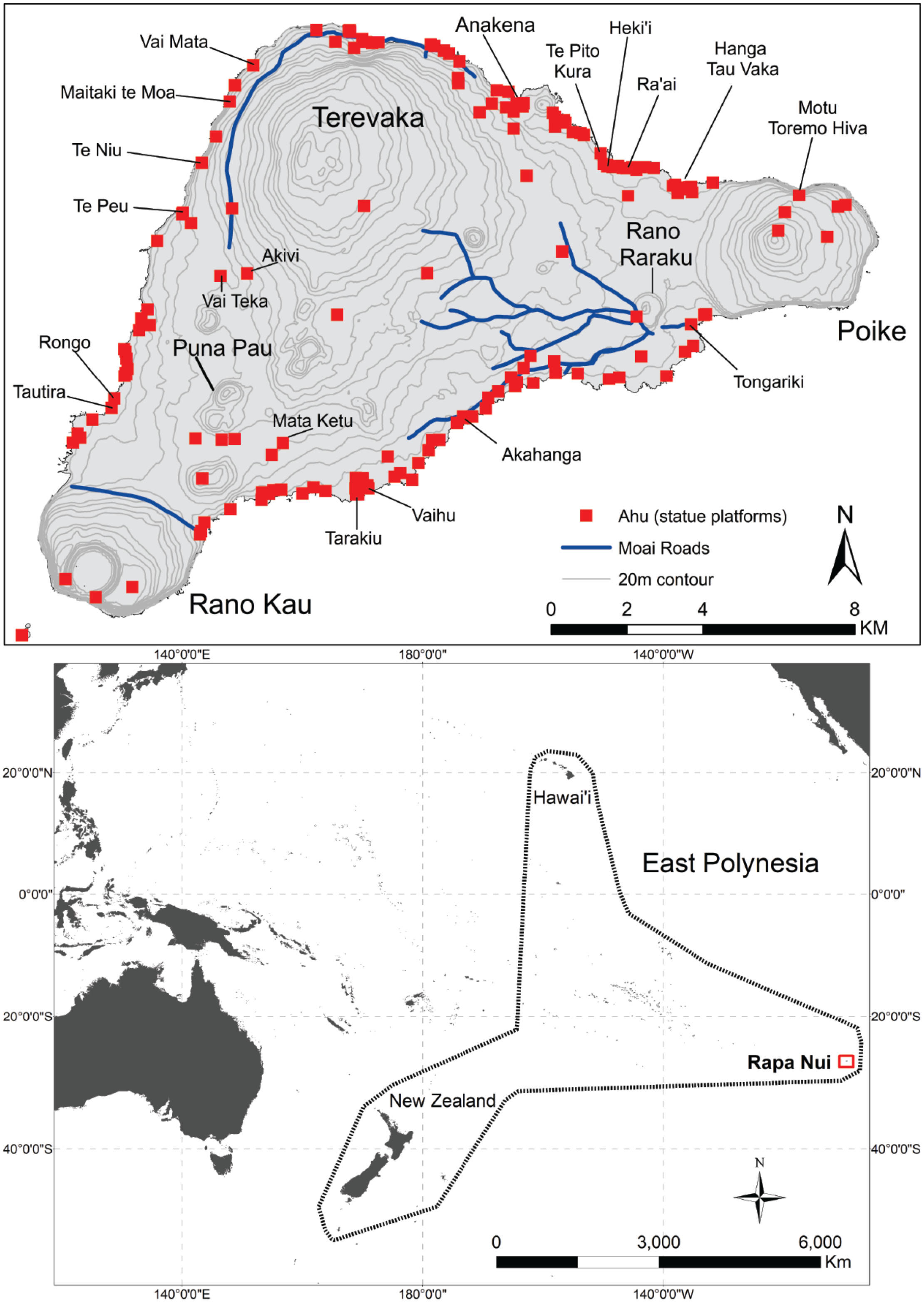

Figure 6.1: Rapa Nui (Easter Island) and locations mentioned throughout the text.

The central hypothesis of this chapter is that, in addition to their well-known religious roles, monument construction became widespread within Rapa Nui society as highly visible and conspicuous displays of communities' cooperative and competitive ability to control and defend their limited resources, resulting in reduced violent interaction between groups and greater community longevity. I provide tests of this hypothesis through quantitative modeling of: 1) the energetic costs of building monuments; 2) the visibility of monuments on the landscape; 3) the relationship between the costs of monumental signals, their visibility, and contested subsistence resources; and 4) spatio-temporal patterns of monument construction. The analytical approach and results presented here provide a series of model-based explanations for previously unresolved questions in Rapa Nui culture history as well as case study for researchers in other regions to test CST-based hypotheses for the dynamics of monument construction.

6.2. Monumental Architecture and Costly Signaling Theory

Costly signaling theory (CST) seeks to explain many puzzlingly 'wasteful' traits observed in animals and humans, ranging from ornamentation in birds to human big game hunting (Hawkes and Bliege Bird, 2002; Zahavi, 1975; Zahavi and Zahavi, 1999). CST posits that these traits evolved as forms of communication designed to influence the response of receivers by providing an honest indicator of some underlying quality of the signaler (Johnstone, 1997; Maynard Smith and Harper, 2003). Signaling can benefit both signaler and receiver by allowing them to assess each other's otherwise unobservable qualities in less costly ways, such as threat displays versus physical/violent conflicts (Maynard Smith and Harper, 1995; Roscoe, 2009). However, because low-quality individuals would benefit from ‘cheating’ by faking high-quality signals, which would undermine the stability of this strategy, the signal must provide an honest indication of the underlying quality. One way that this honesty can be ensured is for the signal to be so costly that it is either impossible or detrimental for low-quality individuals to fake (i.e., a *costly signal*) (Bliege Bird and Smith, 2005; Grafen, 1990; Smith and Bliege Bird, 2005; cf. Számadó, 2011).

Ethnographic applications of CST have clarified many human behaviors that were previously difficult to explain with other human behavioral ecology (HBE) models, such as energetically inefficient foraging and displays of public generosity, but which were well accounted for by CST as social displays of underlying qualities as potential mates, alliance partners, or competitors (e.g., Bliege Bird and Power, 2015; Bliege Bird and Smith, 2005; Boone, 2000, 1998; Hawkes and Bliege Bird, 2002; Smith, 2004; Smith et al., 2003). A significant focus of ethnographic approaches to CST is the study of religious ritual displays as signals of in-group devotion and commitment (e.g., Bulbulia and Sosis, 2011; Henrich, 2009; Irons, 2001; Norenzayan et al., 2016; Power, 2017; Sosis, 2003; Sosis and Alcorta, 2003; Sterelny, 2019). A key finding of these studies is that religious costly signals can solve conflict of interest and collective action problems inherent to human societies by maintaining in-group cooperation and cohesion while serving as signals of competitive ability to out-groups (e.g., Atran and Henrich, 2010; Norenzayan and Shariff, 2008; Watson-Jones and Legare, 2016). These ethnographic studies highlight the potential of CST to explain a wide range of social behaviors under a coherent evolutionary ecological framework and help clarify issues of both intra-group cooperation and inter-group competition.

CST is increasingly being applied in archaeology to explain a wide range of topics (see Conolly, 2017; Quinn, 2019 for recent reviews). Archaeological approaches include explanations for the appearance of Paleolithic art (e.g., Gittins and Pettitt, 2017; Kuhn, 2014), the building of elaborate defensive structures (e.g., Čučković, 2017; O'Driscoll, 2017), processes underlying why individuals seek and exchange prestige goods (e.g., Neff, 2014; Pierce, 2017; Plourde, 2008; Quinn, 2015), elaborate mortuary practices (e.g., Silvestri et al., 2017; Watson and Phelps, 2016), big-game hunting (e.g., Grimstead, 2010; McGuire and Hildebrandt, 2005), and monumental architecture (e.g., Neiman, 1997). Compared to the ethnographic studies discussed above, archaeological applications of CST are still developing, with some sparking contentious debate (e.g., Broughton and Bayham, 2003; Codding and Jones, 2007; McGuire et al., 2007), owing to the persistent challenge of sufficiently linking the theoretical predictions of HBE models like CST with empirical archaeological data (Bird and O'Connell, 2006; Codding and Bird, 2015; Quinn, 2019).

Monumental architecture provides a promising research subject given its inherent construction costs, visibility, hypothesized communicative function, and links to religious signaling research (Atran and Henrich, 2010, p. 26; Bliege Bird and Smith, 2005, p. 232; Conolly, 2017; Norenzayan et al., 2016, p. 47; Quinn, 2019). Quinn (2019, p. 286) for example, highlights the fact that monumental architectural features potentially contain information about both the behavioral (e.g., the construction patterns/processes) and material (e.g., archaeological record) aspects of the signal. Moreover, some have argued that monuments are a common component of human societies in that they are a potentially potent signal given human sensory biases to associate 'bigness' with a sense of awe/power (Joye and Dewitte, 2016; Joye and Verpooten, 2013; Verpooten and Joye, 2014). This hypothesis of a direct relationship between monuments and signaling power is supported by theory on sensory biases in signal evolution (Guilford and Dawkins, 1993; Johnstone, 1997, p. 161; Soler et al., 2014), which predict that signal form should be connected to the underlying quality being displayed (Maynard Smith and Harper, 1995).

There have been several recent applications of CST to better understand the dynamics of monument construction (Aranyosi, 1999; Church, 2012; De Souza et al., 2016; Glatz and Plourde, 2011; Kantner and Vaughn, 2012; Neiman, 1997; Roscoe, 2009; Safi, 2015; Wandsnider, 2015, 2013; Wright, 2017), which have reached a number of common conclusions, such as that monument construction served as a highly visible index of competitive or cooperative ability, was most intense during increased competition and resource stress, in politically contested spaces, and in some cases resulted in a lack of violent interaction between groups. Wandsnider (2015, p. 81) suggests that, "[s]uch signals should…be important when stressful conditions prevail, creating opportunities for signalers, both individuals and groups, to display both their prosocial orientation and their effectiveness." The common thread in these studies is that the process of constructing these features, their persistence and visibility on the landscape, as well as community-level activities that took place at them, served as an honest costly signal of the underlying quality of individual- and group-level cooperative and competitive ability.

While some have approached monument construction in terms of individual-level signaling among elite political rivals (e.g., Glatz and Plourde, 2011; Neiman, 1997), recent studies have framed monumental signaling at the group- or multi-level scales (e.g., DiNapoli et al., 2018; Hunt and Lipo, 2018, 2011; Roscoe, 2009; Wandsnider, 2015). Framing monument construction at the group-level makes sense given that the size and elaboration of most monuments required a degree of labor that no one individual is likely capable of achieving. Instead, monumental architectural features in the archaeological record represent the accumulation of the aggregate efforts of several individuals working together, often over very long time spans, to achieve a common goal. The costs of constructing and maintaining a monument are thus incurred by individuals and groups, and the benefits are potentially reaped by both individuals and the community. Monument construction thus potentially represents a kind of multi-level costly signaling, what Roscoe (2009, p. 72) argues is best understood as a kind of "ritualized fighting," where these individual construction efforts are signaled to the in-group, and the construction activity itself and the completed construction product provide a material index of the group's capacity for coordinated collective-action that is signaled to other communities (Wandsnider, 2015, p. 91). Roscoe (2009, p. 97) argues that these kinds of 'conspicuous constructions' displayed group's potential to mobilize committed individuals and resources for the collective good whereby the scale of monuments, "signaled the size and commitment of its sponsoring group, the number of kin and allies willing to support its projects, the individual commitments and abilities of all these individuals, and their capacity to suppress their individual interests in order to work together and organize large-scale action."

In addition to reduced violent conflict within and between groups, there are several other hypothesized benefits and implications to this community-level signaling.

One important benefit is that through collective signaling of community defensive abilities, some groups are able to secure preferential access and exclusion of non-community members from territory and critical resources. In addition, by virtue of being very difficult or impossible to fake, individual contributions to monument construction potentially solve free-rider problems inherent to sustained collective action within groups, resulting in greater intra-community cooperation (Gintis et al., 2001; Roscoe, 2009, p. 102; Smith and Bliege Bird, 2005). A final key implication of a multi-level signaling dynamic is the potential selection for 'modular' organization in decentralized, smaller-scale societies (Roscoe, 2009). This modular organization takes the form of nested subgroups optimally sized for reproduction, subsistence, and defense, where signaling within the group serves to maintain cooperation and mitigate conflicts of interest in reproductive and subsistence activities to maintain effective defense and broadcast collective action to rival communities (Roscoe, 2009). As discussed above, one key way that this kind of modular social signaling dynamic can be maintained is through religious and ritual activities that signal in-group devotion, while simultaneously broadcasting formidability and the potential for collective defense to outgroups. These groups thus substitute

> symbolic fighting on a ceremonial plaza for actual fighting on a battlefield. Rather than take up arms and resort to dangerous or lethal combat, they instead took up material distributions, exhibitions of singing and dancing, and *monumental architecture* and resorted to symbolic combat, to displays that reliably communicated who would win a fight to the death without anyone having to engage in an actual fight to the death. By honestly *displaying*—rather than actively *deploying*—their military capacity, every individual, every subgroup, and every group in the system was able reliably to determine who would win a physical fight over conflict of interest without any individual or unit having to risk the actual mortal combat that would jeopardize their individual interests in survival and their collective interests in cooperative action (Roscoe, 2009, p. 90 emphasis added).

These previous studies have been critical for furthering our understanding of why some forms of cooperation and competition manifest as monumental architecture and provide key insights into other puzzling phenomena in the past, such as the organization of some small-scale societies and the lack of violent interaction in certain times and places. However, more studies are needed to assess the general explanatory power of CST for monuments more broadly (Conolly, 2017; Roscoe, 2009). The goal of this chapter is to investigate whether CST helps explain the culture history and patterns of monument construction on the Polynesian island of Rapa Nui (Easter Island, Chile). Below, I briefly introduce the case study of Rapa Nui and then derive several predictions from CST which are then tested using quantitative models and archaeological and environmental data from the island.

6.3. Rapa Nui as a Model System

Rapa Nui is a small (164 km^2), relatively low-elevation (~500 masl), volcanic island (0.78-0.11 mya) at the southeastern extremity of Polynesia, lying >3000 km from South America and >2000 km from the nearest Polynesian island (Vezzoli and Acocella, 2009). Its climate is cool, windy, and subtropical, and the island receives relatively low annual rainfall and frequent droughts (Cañellas-Boltà et al., 2013; Genz and Hunt, 2003; Mann et al., 2008; Morrison, 2012; Puleston et al., 2017; Rull, 2020b). Compared to other Polynesian islands, its soils are leeched and nutrient depleted, which, when combined with climatic factors, renders Rapa Nui unsuitable for growing many tropical

Polynesian crops (Ladefoged et al., 2010; Louwagie et al., 2006; Vitousek et al., 2014). Rapa Nui lacks lagoons and large coral reefs, has a relatively homogeneous rocky shore marine habitat, and while there is a low diversity of marine taxa, overall biomass is arguably similar to elsewhere in the Pacific (Friedlander et al., 2013, pp. 526–527; Hubbard and Garcia, 2003). The island also lacks obvious sources of surface freshwater, with no permanent streams and few lakes, owing to the porous nature of the underlying substrate (Herrera and Custodio, 2008). These environmental conditions placed significant constraints on the island's communities.

Rapa Nui was settled between *1150-1280 cal. AD* as part of the rapid population expansion into East Polynesia (DiNapoli et al., 2020; see also Hunt and Lipo, 2006; Sear et al., 2020; Wilmshurst et al., 2011). The community structure is aptly described as 'hyperlocal' (Hunt and Lipo, 2011, p. 126), with a series of small, dispersed communities thought to represent familial clans or simpler 'open chiefdoms' (e.g., Kirch, 1984b; McCoy, 1976; Métraux, 1940; Morrison, 2012; Stevenson, 1986). Though inland settlements existed, settlements were primarily situated along the coast as dispersed redundant sets of habitation, domestic, and cultivation features ca. 100-200 m inland from *ahu* (e.g., McCoy, 1976; Morrison, 2012; Stevenson, 2002, 1997, 1984, p. 47; Stevenson and Haoa, 2008; Vargas et al., 2006). *Ahu* formed the focal points for these communities and served as gathering locations for ceremonies and resource sharing (Hunt and Lipo, 2018; Martinsson-Wallin, 1994). While these communities must have interacted at larger-scales to some degree in procuring certain raw materials such as obsidian, basalt, red scoria, and *moai* tuff (e.g., Hixon et al., 2018; P. C. McCoy, 2014; Seager Thomas, 2014; Simpson et al., 2018a, 2018b; Simpson and Dussubieux, 2018b;

Stevenson et al., 2013), bioarchaeological, genetic, and cultural transmission analyses reflect surprisingly low degrees of intercommunity interaction for such a small island (e.g., Commendador et al., 2013; Dudgeon, 2008; Gill et al., 1983; Gill and Owsley, 1993; Lipo et al., 2015, 2010; Polet and Bocherens, 2016; Stefan, 1999). As discussed in detail in Chapter 5, mounting evidence indicates that most inter-community interaction that did occur was largely non-violent, with little evidence for lethal warfare or pre-contact monument destruction. Together, the existing evidence indicates relatively small-scale, decentralized social organization in pre-contact Rapa Nui.

Subsistence strategies on Rapa Nui were constrained by the island's marginal environment, which inhibited opportunities for irrigated cultivation, agroforestry, or intensive reef foraging common elsewhere in Polynesia (Allen, 2017; Kirch, 1994; Lambrides and Weisler, 2016; Quintus et al., 2019). Multiple lines of evidence indicate a mixed horticultural and marine foraging subsistence system (e.g., Commendador et al., 2019, 2013; Horrocks et al., 2017; Horrocks and Wozniak, 2008; Jarman et al., 2017; Polet and Bocherens, 2016). Drought-resistant sweet potato (*Ipomoea batatas*), which was grown in the island's abundant rain-fed rock-mulch gardens (e.g., Bork et al., 2004; Ladefoged et al., 2013; Stevenson et al., 2006, 1999; Wozniak, 2018, 1999), was the staple food source along with several other introduced cultigens (Tromp and Dudgeon, 2015). Soil surveys and productivity modeling indicate that potential cultivation yields were relatively marginal, spatially homogeneous, and temporally variable, resulting in a dispersed, risky, and unpredictable agricultural resource base (e.g., Ladefoged et al., 2010; Louwagie et al., 2006; Morrison, 2012; Puleston et al., 2017; Stevenson et al., 2015). Ethnographic accounts suggest little marine resource consumption (e.g., Métraux, 1940), but zooarchaeological and stable isotope studies indicate otherwise (Ayres, 1979; Ayres et al., 2000a; Jarman et al., 2017; Steadman et al., 1994; cf. Commendador et al., 2019, 2013). Freshwater was a limited critical resource, which was obtained from small (<1 m diameter) rainwater basins (*taheta*), temporary ponds, groundwater in small lava tubes, and coastal seeps (Brosnan et al., 2019; DiNapoli et al., 2019; Dudgeon and Tromp, 2014; Hixon et al., 2019). Ethnohistoric sources suggest that the island's two crater lakes were rarely used, likely due to their inaccessibility (Hixon et al., 2019; cf. Rull, 2020b). Of these water sources, ethnohistoric accounts indicate that coastal seeps were the most important water source, whereby the Rapanui would trap seeping groundwater at the coastline by constructing 'wells' (*puna*) or drank directly from the sea in locations of abundant groundwater discharge (Brosnan et al., 2019; Hixon et al., 2019). Recent spatial modeling shows that *ahu* locations are strongly associated with the locations of the island's freshwater sources (DiNapoli et al., 2019).

Given the island's small size and marginal environment, Rapa Nui is remarkable in terms of both the quantity and size of its monumental architecture. Within as little as 55 years following initial Polynesian settlement of the island, Rapanui people began constructing the island's megalithic platforms (*ahu*) and anthropomorphic stone statues (*moai*), which by the time of Dutch arrival in AD 1722 were a dominant component of Rapa Nui's coastal landscape (Figure 6.2; DiNapoli et al., 2020). Ethnohistoric and archaeological evidence confirm that *ahu* were religious sites, that the *moai* erected upon them represented ancestor deities, and that these monuments served as the focal points for pre-contact community life (Beardsley, 1996; Hunt and Lipo, 2018; Kirch, 1984b; Martinsson-Wallin, 1994; McCoy, 1976; Métraux, 1940; Morrison, 2012; Routledge, 1919; Stevenson, 2002, 1986; Thomson, 1891). The over 300 *ahu* of Rapa Nui are commonly classified into four or more types: image- or platform-*ahu*, which are defined by a rectangular, dressed-stone platform and typically contain one or more *moai*; semipyramidal *ahu* characterized by heaps of basalt boulders forming a half-pyramid shape; rectangular *ahu* with upturned ends called *po'e po'e*, and a grouping of irregular *ahu* (Martinsson-Wallin, 1994). Of these, semipyramidal, *po'e po'e*, and irregular types are thought to be post-contact features[4], whereas platform *ahu* were constructed throughout Rapa Nui's pre-contact sequence (DiNapoli et al., 2020). The discussion and analysis here are focused on the factors influencing the construction of Rapa Nui's platform *ahu*.

Figure 6.2: Partially restored Ahu Nau Nau at Anakena beach showing platform, *moai*, and *pukao*.

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[4] Though it is often assumed that these features occur later in Rapa Nui culture history, additional radiocarbon dates and chronological models would be useful for testing this hypothesis.

Rapa Nui communities constructed ca. 150 platform *ahu*, many of them several meters tall and >50 m long, and which are composed of a combination of dressed slabs and stacked cobbles and boulders of basalt (Figure 6.3). These features consist of a central rectangular platform composed of dressed and/or closely aligned basalt slabs, lateral projections of stacked cobbles and boulders called 'wings,' a ramp that descends forward from the platform, pavements of water worn boulders (*poro*), and often crematoria, burials, embankments, *moai*, and *pukao*. While there is a common set of architectural components, there is considerable stylistic variation in individual *ahu* as well as aggregate, community-scale variation in patterns of *ahu* construction (e.g, Martinsson-Wallin, 1994; Martinsson-Wallin and Wallin, 2014; Stevenson, 2002). For example, certain locations are characterized by a single large platform (e.g., Vaihu, Te Pito Kura) and some exhibit multiple *ahu* adjacent to one another (e.g., Te Peu, Hanga Tau Vaka, Anakena), whereas others show evidence of multiple platforms being combined into a single large structure (e.g., Akahanga, Figure 6.4). These patterns have also been demonstrated in multiple archaeological excavations and analyses showing that most platform *ahu* were continually modified through multiple construction events (e.g., Hamilton et al., 2008; Martinsson-Wallin, 1994; Skjølsvold, 1994; Smith, 1961a). This variability indicates that investment in constructing platform *ahu* occurred in different ways in different communities, with some continually investing in and renovating single structures and others building new *ahu* over time.

Figure 6.3: Ahu Vai Mata (top) and Maitaki te Moa (bottom) showing massive dressed slabs of basalt.

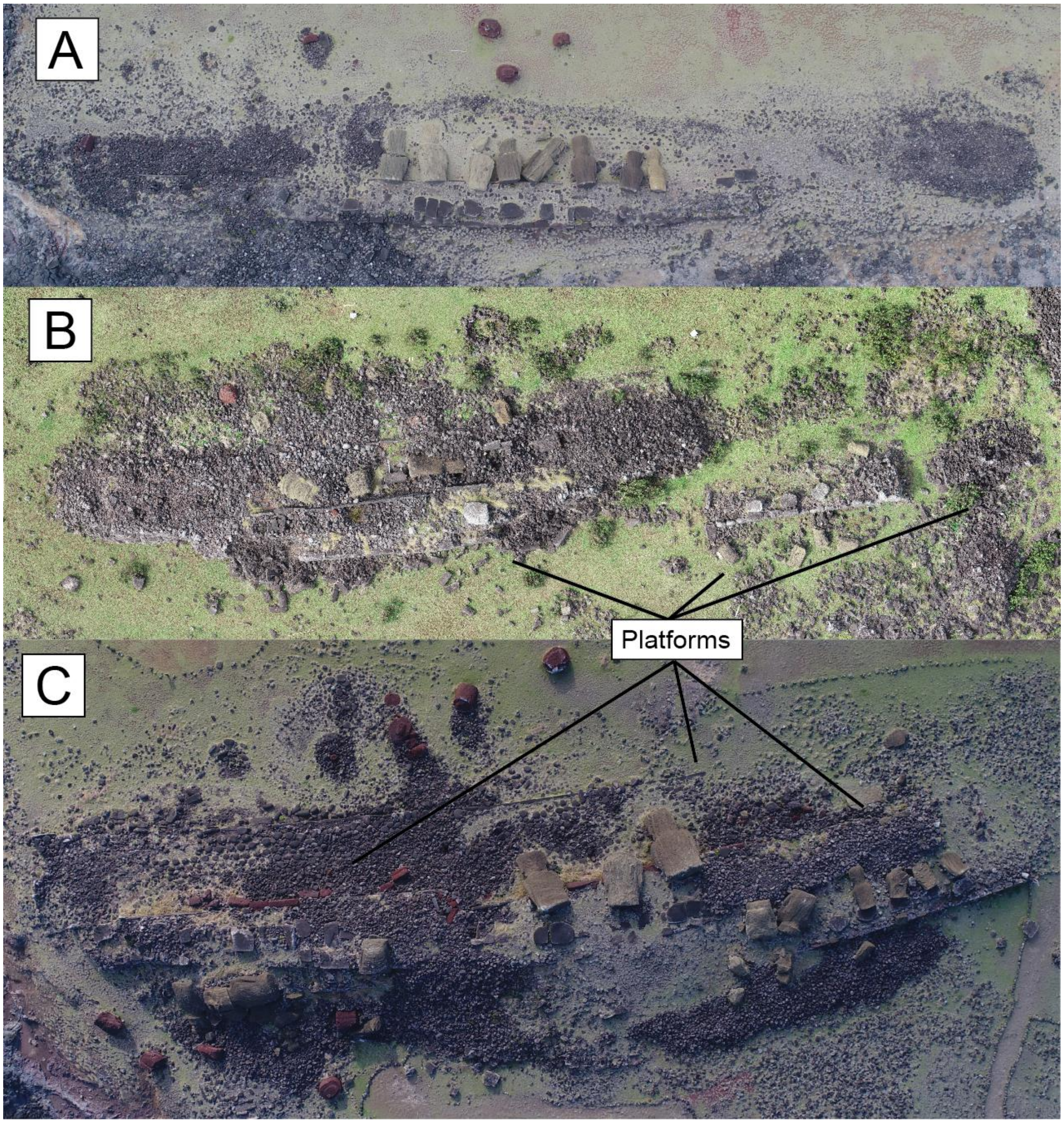

Figure 6.4: Aerial photos of unrestored Ahu Vaihu (A), Ahu Te Peu (B), and Ahu Akahanga (C), showing platforms, *moai*, and *pukao*.

These platform *ahu* typically include one or more *moai* statues with most weighing several metric tons (Martinsson-Wallin, 1994; Shepardson, 2013, 2006; Van Tilburg, 1994). The vast majority of the ca. 1000 *moai* were carved from volcanic tuff, and though many still remain at the statue quarry of Rano Raraku, around 400 of these were “walked” several kilometers along roads from the quarry to be erected upon *ahu* (Hochstetter et al., 2011; Lipo et al., 2013; Lipo and Hunt, 2005). In addition, many *moai* also once donned massive ‘hats’ of red-scoria called *pukao*. Most of these were quarried at Puna Pau, weigh as much as 12 metric tons, and were transported to their *ahu* several kilometers away (Hixon et al., 2018, 2017; Seager Thomas, 2014). These figures attest to the impressive degree of community cooperation and investment in the construction of ritual monuments on this small island, unique not just in the Pacific, but in world archaeology more broadly.

While detailed archaeological investigation of Rapa Nui’s monuments has been ongoing for more than a century (e.g., Routledge, 1919; Thomson, 1891), there have been limited attempts to systematically quantify their size or labor investment. The work of Martinsson-Wallin (1994) and Shepardson (2013, 2006) represent the main attempts to quantify the investment in Rapa Nui’s monuments. Shepardson (2013, 2006) focused his efforts on estimating energetic investment in *moai* over time, and quantified volume based on morphometric characteristics of the statues, specifically base depth × base-width × statue height. His results of comparing the volume of statues with transport distance from the quarry at Rano Raraku suggest that *moai* volume decreases with distance from the quarry (Shepardson, 2013, p. 143 Fig. 8.04). Shepardson (2006, p. 140) attempted to quantify the “work or energy…expressed in person-hours, or the amount of work that can be performed by an average worker in one hour.” Work is calculated based on the costs of carving, transporting, and erecting statues using assumed constants and the results scale with the overall size of the *moai*. Based on the results of his ‘optimal path seriation,’ Shepardson (2006, p. 150, Figure 4.7) argues that statue volume increased over time, particularly around AD 1400-1600 and then dropped off. In addition, overall energy investment in both carving and transportation of *moai* is argued to have gradually increased between AD 1000-1300, was greatest between AD 1400-1500, and then “declines rapidly” from AD 1500-1700 (Shepardson, 2006, pp. 151-152, Table 4.1, Figure 4.8).

Martinsson-Wallin’s (1994) work currently represents the most comprehensive survey and description of Rapa Nui *ahu*. As part of her analyses of formal variability in *ahu*, Martinsson-Wallin (1994) documented basic surface area characteristics of these features (e.g., height, width, length), though for many features, comprehensive measurements are lacking. In a series of Chi-square tests, Martinsson-Wallin (1994, p. 63) argues that large *ahu* tend to have a dressed-stone seawalls and ramps, whereas smaller *ahu* tend to have mostly unworked boulders and tend to lack *pukao*. Though not explicitly elaborated upon by Martinsson-Wallin (1994), one interpretation of this pattern is that larger *ahu* show a greater degree of labor investment not only in raw amount of stone, but also in terms of additional investment in moving and carving large seawall slabs and *pukao*. Along with the results of previous surveys, Martinsson-Wallin’s (1994) work clearly demonstrates that, among the different types of *ahu*, image-*ahu* or platform *ahu* represent by far the largest, most complex, and most labor intensive form. Matinsson-Wallin (1994, p. 95) also analyzed the spatial distribution of platform *ahu* based on four size classes. The largest size-class (group 4) only includes a single feature, *ahu* Tongariki in the southeastern portion of the island, and large *ahu* of group 3 are argued to occur all along the coast of the island, which Martinsson-Wallin (1994, p. 95) interprets as the locations of “elite centres” (see e.g., Kirch, 2017, 1984b; Stevenson, 2002, 1986 for similar interpretations).

Researchers have long thought that *ahu* construction likely began shortly following Polynesian arrival; however, the overall tempo of construction following this initial onset has been debated. While previous studies suggested that platform *ahu* construction ceased around ca. AD 1600 (e.g., Martinsson-Wallin et al., 2013b; Wallin and Martinsson-Wallin, 2008), Bayesian re-analysis of all radiocarbon dates from *ahu* contexts demonstrates that platform *ahu* continued to be built and modified up to and beyond European contact in AD 1722 (DiNapoli et al., 2020). The results of this analysis indicate that there was a rapid period of platform construction from ca. AD 1350-1450 followed by a relatively steady rate of construction events through AD 1750. While these Bayesian estimates are most directly related to the chronologies of individual *ahu* components, such as platforms, wings, and ramps, they provide relative estimates for *moai* and *pukao* construction and emplacement as well. In addition to the fact that the statues likely antedate the platform they were erected upon, it is hypothesized that *ahu* ramps and wings were used to transport *moai* and *pukao* on top of platforms (Hixon et al., 2018; Lipo et al., 2013, p. 2862; Thomson, 1891, p. 449). Thus, this revised chronology for *ahu* construction provides a relative chronology for *moai* and *pukao* as well. Recent excavations at Rano Raraku statue quarry also support this extended chronology for monument construction activities (Sherwood et al., 2019; Simpson et al., 2018a).

The role of monument construction in Rapa Nui culture history has been the focus of prolonged speculation and debate. In addition to their widely accepted religious and ritual roles, the elaboration of *ahu* and *moai* have commonly been explained as the outcome of territorial activities whereby these monuments served as markers of each clan's (or their elites) control over limited land or critical subsistence resources (e.g., Barber, 1996, pp. 877–878; Beardsley, 1996; Cauwe, 2016; DiNapoli et al., 2019; Kirch, 2017, 1984b; Kolb, 2012; Sahlins, 1955; Shepardson, 2005; Simpson, 2009; Stevenson, 2002, 1986; Van Tilburg, 1994; Wallin and Martinsson-Wallin, 2011). The particular focus of this territoriality is debated, with suggestions that competition was possibly over limited marine resources (e.g., Kirch, 2017, p. 236; McCoy, 1976, p. 124), agricultural production (e.g., Stevenson et al., 2006, 1999; Wallin et al., 2005), or freshwater (DiNapoli et al., 2019, p. e.g.,, 2018; Hunt and Lipo, 2018; Martinsson-Wallin, 1994, p. 105; McCoy, 1976). Furthermore, several authors have suggested that monuments were constructed in highly visible locations to broadcast control of territory and resources (e.g., Kirch, 2017, p. 236; Kolb, 2020, pp. 206–207; Martinsson-Wallin and Wallin, 2000, p. 39; Simpson, 2009). Kirch, for example, claims that (2017, p. 236 emphasis added),

> "[t]he oldest *ahu*—those that through continued rebuilding gradually became the largest, with the greatest number of statues—*are found at the best embayments around the island*. Each of these marked the center of a territorial unit (*kainga*) constituting the estate of a "tribe" or descent group…. As these social groups splintered, subsidiary temples were built at distances to either side flanking the coast, marking subgroup territories. The statues represented deified ancestors. The chiefly elite constructed their houses with foundations of cut and dressed basalt immediately inland of the *ahu* plazas, and thus literally under the gaze of the ancestors. Stretching inland from these elite centers—*dominating the bays and visually "controlling" access to the limited marine resources*—were the habitations and gardens of the common people."

Van Tilburg (1994, p. 94 emphasis added), has also argued,

> "the archaeological evidence illustrates clearly that the *control of subsistence production in agriculture and marine resources* was intimately and strongly linked to the typical Polynesian scheme of hereditary land use rights…The need constantly to restate that ownership, generation after generation and in the context

> of a growing population and a changing natural environment, seems to have been *one of the driving forces of* ahu *construction*, although other social and religious motivations obviously existed."

Similarly, McCoy (1976, p. 130) argues that there was likely intense competition over water and marine resources and that, "[e]laboration of…ahu…would, from present knowledge, provide a rough index of success in competition between lineages…based ultimately on the free time that could be allotted to such non-vital activities." Here McCoy seems to be eluding to a costly signaling role for *ahu* construction and elaboration, wherein investment in monuments provides an index of the potential collective action of the community.

Conventional archaeological narratives have asserted that the intensified period of monument construction ultimately led to the outbreak of internecine warfare as part of a self-induced ecological and societal collapse (e.g., Bahn and Flenley, 2017; Kirch, 2017, 1984b; Kolb, 2020 see further discussion in Chapter 5). However, given recent mounting evidence contradicting core components of this collapse narrative, several researchers have instead proposed that monument construction was a key factor in the long-term sustainability and peaceful interaction between communities. This new perspective has drawn explicitly from CST as an explanatory framework to better understand the dynamics of monument construction and social interaction on Rapa Nui (e.g., DiNapoli et al., 2019, 2018; DiNapoli and Morrison, 2017; Hunt and Lipo, 2018, 2011; Morrison, 2012). Specifically, these researchers have hypothesized that the construction of monumental architecture had multi-scalar benefits to Rapa Nui populations. Individual construction efforts potentially fostered greater community cooperation needed on this risky and marginal island by providing an honest signal of in-group devotion (Hunt and

Lipo, 2018, 2011). Community-scale investments in monuments potentially also reliably signaled collective action potential between communities to control and defend critical resources, leading to reduced violent conflict between groups (DiNapoli et al., 2018; Hunt and Lipo, 2018). This multi-level signaling dynamic may have been particularly beneficial in a risky and uncertain environment like Rapa Nui where,

> …signalling through the construction of monuments would have transmitted a reliable message about the political and militaristic power, potential alliance partners, and resource holding potential in contexts where this information would otherwise be difficult and potentially costly to acquire…we might expect signalling through monumental architecture to help individuals assess which social groups are likely to make strong alliance partners, as well as to evaluate the outcome of potentially aggressive interactions (DiNapoli and Morrison, 2017, p. 8)

Similarly, Hunt and Lipo (2018, pp. 439–440) have argued that,

> …the archaeological record reflects relatively small and low-density populations with evidence of cooperation consistent with visible group-level costly signaling. The patterns of *moai* production, transport, and display on monumental architecture fit these expectations…Such efforts involve cooperative visual endeavors in which group members participate to "walk" the statue from the quarry at Rano Raraku to their positions at *ahu*…*ahu* building and *moai* transport likely served multiple purposes related to decreasing the threat of conflict over unevenly distributed resources…and enforcing information sharing through communal activities…the expectation is that *moai* and *ahu* reflect a response to unpredictability and the need to share information and resources and mitigate potential violence. Investment in *ahu* and *moai* activities, therefore, is explicable as being related to costly signaling where individuals simultaneously compete by demonstrating access to resources, while also gaining benefits from group membership needed to build and sustain such monuments…

While there is agreement that Rapa Nui's monuments at least partially served as territorial displays, and some have suggested CST as an explanatory framework, explicit quantitative tests of these claims have been largely lacking. The most direct assessment of the CST hypothesis involved recent spatial modeling of the relationship between *ahu* and critical subsistence resources, which indicates that *ahu* construction locations are predicted by where freshwater occurs (DiNapoli et al., 2019). These results suggest that if Rapa Nui's monuments served a costly signaling role, then the island's limited and critical freshwater sources were likely an important focus of signaling (DiNapoli et al., 2019, p. 19). However, additional analyses are needed to more fully evaluate this hypothesis, which is crucial to resolving several unusual aspects of Rapa Nui culture history, such as its elaborated monumentality, low incidence of violent conflict, and highly localized settlement pattern. Drawing on the insights of CST, I hypothesize that platform *ahu* served as conspicuous displays of communities' competitive ability to control and defend their limited critical resources, which was adaptive in fostering intra-community cooperation, mitigating inter-community violence, which also resulted in relative isolation between communities. In the section below, I derive several archaeological predictions from CST to test against Rapa Nui's archaeological record.

6.4. Archaeological Predictions of the Costly Signaling Model.

Given the immense labor and resources that were undoubtedly required to build Rapa Nui's monuments, it may appear self-evident that they represent a form of costly signaling display. However, moving beyond this kind of 'just-so story' requires generating hypotheses from a CST model that can be empirically tested (Quinn, 2019). The goal here is not to simply show whether or not Rapa Nui monument construction is or is not a form of costly signaling, but rather whether CST helps explain particular patterns of monument construction and other aspects of Rapa Nui culture history. Building meaningful explanations of the archaeological record from this CST model thus requires explicit expectations that can be measured using empirical data suited to this theoretical framework (Conolly, 2017; DiNapoli et al., 2018; Hunt et al., 2001; Lewontin, 1974; Neiman, 1997, p. 285; Quinn, 2019).

Here, I evaluate five archaeological expectations of the CST model for Rapa Nui:

Expectation 1: To meet the definition of a costly signal, there must be demonstrable costs of signal production, such as in energy or resources, and variability in those costs, given that not all communities are capable of signaling at the same level/magnitude (Conolly, 2017, p. 442; McAndrew, 2002; Quinn, 2019, p. 289; Smith and Bird, 2000). I evaluate the costs of constructing monumental architecture using structure-from-motion photogrammetry. *Ahu* construction costs are quantified in terms of construction stone volume (m^3), which provides a measurement of the relative differences in the costs of monument investment between Rapa Nui communities.

Expectation 2: Monumental signals are expected to be highly visible and built in locations to maximize the chance that they be viewed by the intended audience, which in this case includes both the local community and rival communities (Conolly, 2017, p. 442; McAndrew, 2002; Neiman, 1997; Quinn, 2019, p. 289; Smith and Bird, 2000). Using a 'total viewshed' analysis, I evaluate the visibility of monuments through spatially explicit tests of (1) the visibility of *ahu* locations on the landscape and (2) the visibility of *moai* transport roads. It is expected that *ahu* were constructed in locations to maximize their visibility to a large audience of receivers. In addition to the construction of *ahu*, the transport of *moai* along the statue roads from Rano Raraku was potentially also an important component of community-level signaling (Hunt and Lipo, 2018, 2011; Lipo and Hunt, 2005). Specifically, the synchronized and coordinated activities required to 'walk' *moai* from the statue quarry to their destinations at *ahu* were a potentially potent display of the community's resource holding potential and capacity for collective action (DiNapoli et al., 2018; Fessler and Holbrook, 2016). As such, one additional expectation is that the *moai* transport roads were situated along routes that would maximize the visibility of these activities to potential competitors. That is, one possibility is that more costly routes were taken, such as steeper slopes, to increase visibility of *moai* transport.

Expectation 3: The signal must accurately index some underlying quality of the signaler(s), such as health, access to or ability to defend critical resources, or cooperative potential (Bliege Bird and Smith, 2005; McAndrew, 2002, p. 81; Quinn, 2019, p. 289; Smith and Bird, 2000). One expectation in the case of monuments, is that their construction location and magnitude of investment be related to access to contested resources (Conolly, 2017, p. 442; DiNapoli et al., 2018; DiNapoli and Morrison, 2017; Glatz and Plourde, 2011). If monuments signal the communities' ability to control and defend some resource, we should expect greater investments in areas with the highest quality or access to these resources (i.e., the cost of the signal should reliably index and covary with the underlying quality being signaled). This prediction is tested through statistical modeling of the relationship between the location/size of *ahu* and access to three most critical subsistence resources on Rapa Nui: freshwater, agricultural gardens, and marine resources.

Expectation 4: Given that the stability of the signaling strategy is contingent upon their being multiple signalers and receivers interacting contemporaneously (i.e., it is frequency-dependent strategy), it is expected that patterns of monument construction will be spatio-temporally associated across the island (Neiman, 1997). To assess this prediction, I introduce two Bayesian methods for examining the overall duration and spatial association of monument construction events over the course of Rapa Nui culture history.

Expectation 5: The costs of signaling should result in some benefit to the signaler and receiver, such as a reduction in lethal violence, exclusion of competitors for continued access to contested resources, optimal group sizes for managing conflicts of interest, or community longevity (Bliege Bird and Smith, 2005; Conolly, 2017; McAndrew, 2002; Roscoe, 2009; Smith and Bird, 2000; Wandsnider, 2015). These predictions are assessed by critically evaluating the archaeological evidence for lethal violence, inter-community interaction, and spatio-temporal modeling of the duration of monument construction.

6.5. Methods

6.5.1. Quantifying Labor Investment using Structure-From-Motion Photogrammetry

To quantify variability in the costs of constructing platform *ahu*, construction stone volume was calculated from 3D models created using structure-from-motion (SfM) photogrammetry. SfM uses overlapping sets of 2D images to reconstruct a 3D point cloud of object dimensions based on principles of stereoscopy, analogous to human visual perception (Westoby et al., 2012). While previous studies have explored monument size, they used rudimentary measurements (e.g., W×L×H) unable to capture the irregular geometry of *ahu*. SfM is well-suited to this objective through the ability to rapidly capture data and calculate volume using the 3D point cloud (e.g., Green et al., 2014; Hixon et al., 2017; Jaklič et al., 2015; López et al., 2016).

SfM was conducted on 90 platform *ahu* (Figure 6.5). The SfM survey did not cover structures in the modern town of Hanga Roa because of historic destruction of archaeological features and reconstruction of several *ahu*. Select structures outside of Hanga Roa that were completely reconstructed in the 20th century, such as Ahu Tongariki, were not modeled given that their current stone volume is potentially different from the original feature. Several inland *ahu* were also not covered in the survey due to limited access to these sites. The *ahu* covered by the survey represent a near continuous sample distributed along the south, northwest, and northeast coasts of the island (Figure 6.5). As *moai* were placed upon *ahu*, volume estimates of *ahu* include both the platform and statues.

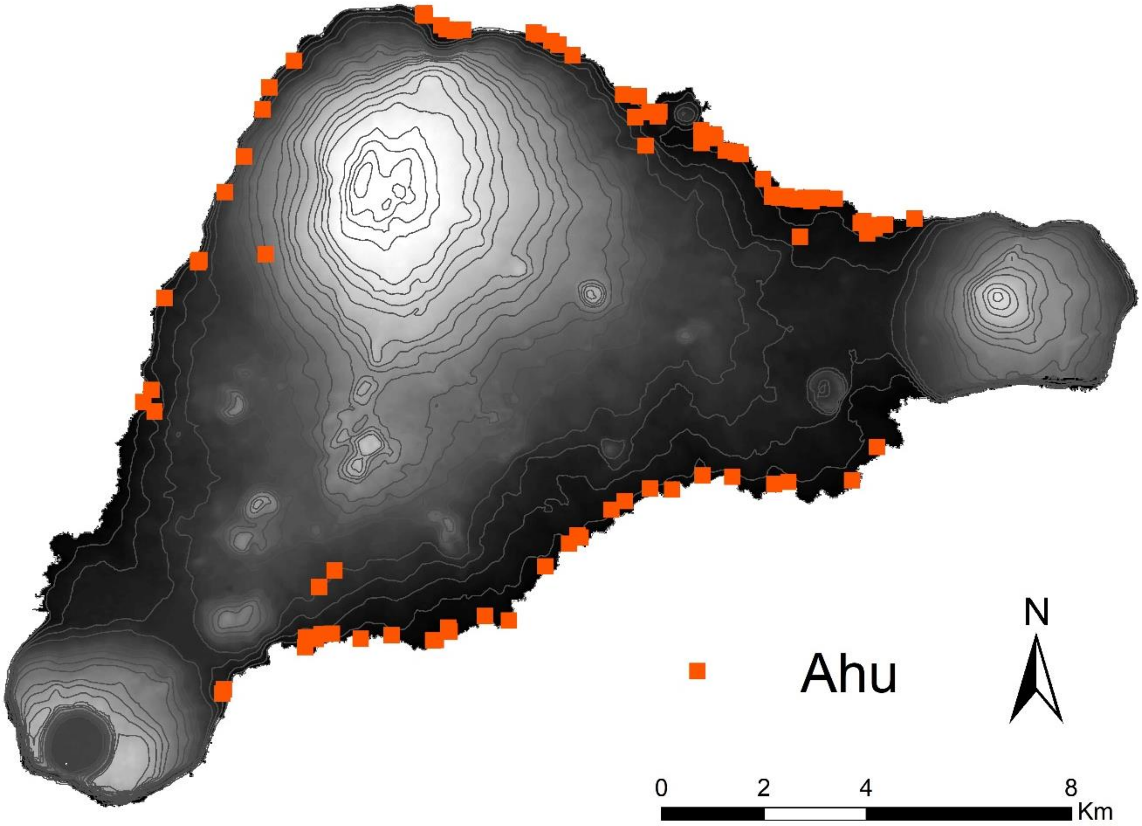

Figure 6.5: Locations of platform *ahu* covered by the SfM survey.

SfM was conducted using large sets of images (e.g., hundreds to thousands depending on feature size) captured using a 20-megapixel digital camera onboard a DJI Phantom 4 Pro unmanned aerial vehicle (UAV). Images were captured using Pix4d Mapper mission planning software by flying grid patterns over each structure with the camera oriented at nadir and 70° oblique angles and with a minimum of 80% overlap between images. Models were scaled using a combination of geolocations provided by the onboard GPS, scale constraints, or ground control points (GCPs) using a Trimble Geo 7x GPS differentially corrected using a second sub-cm unit as a base station. Image sets were then processed in Pix4D Desktop SfM software following standard workflow protocols (Figure 6.6) to yield 3D digital surface models (DSM) as well as basal area (m^2) and volume (m^3) calculations. To obtain area and volume estimates, a series of vertices were plotted around the extent of each feature, resulting in a polygon that defines the *ahu* base (Figure 6.7). Basal area calculations are simply the surface area enclosed by this polygon. *Ahu* volume is calculated using the DSM by projecting a fine grid of cells on this polygon and calculating the volume (m^3) based on the length×width×height of each cell. The sum of the volumes of each cell then yields a total volume estimate.

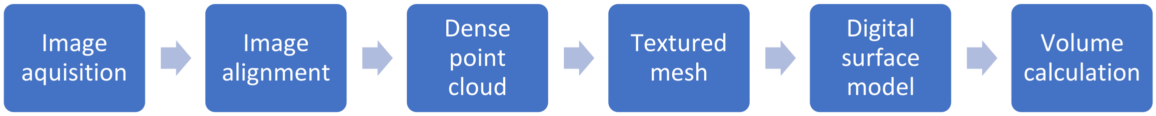

Figure 6.6: Workflow for *ahu* model generation.

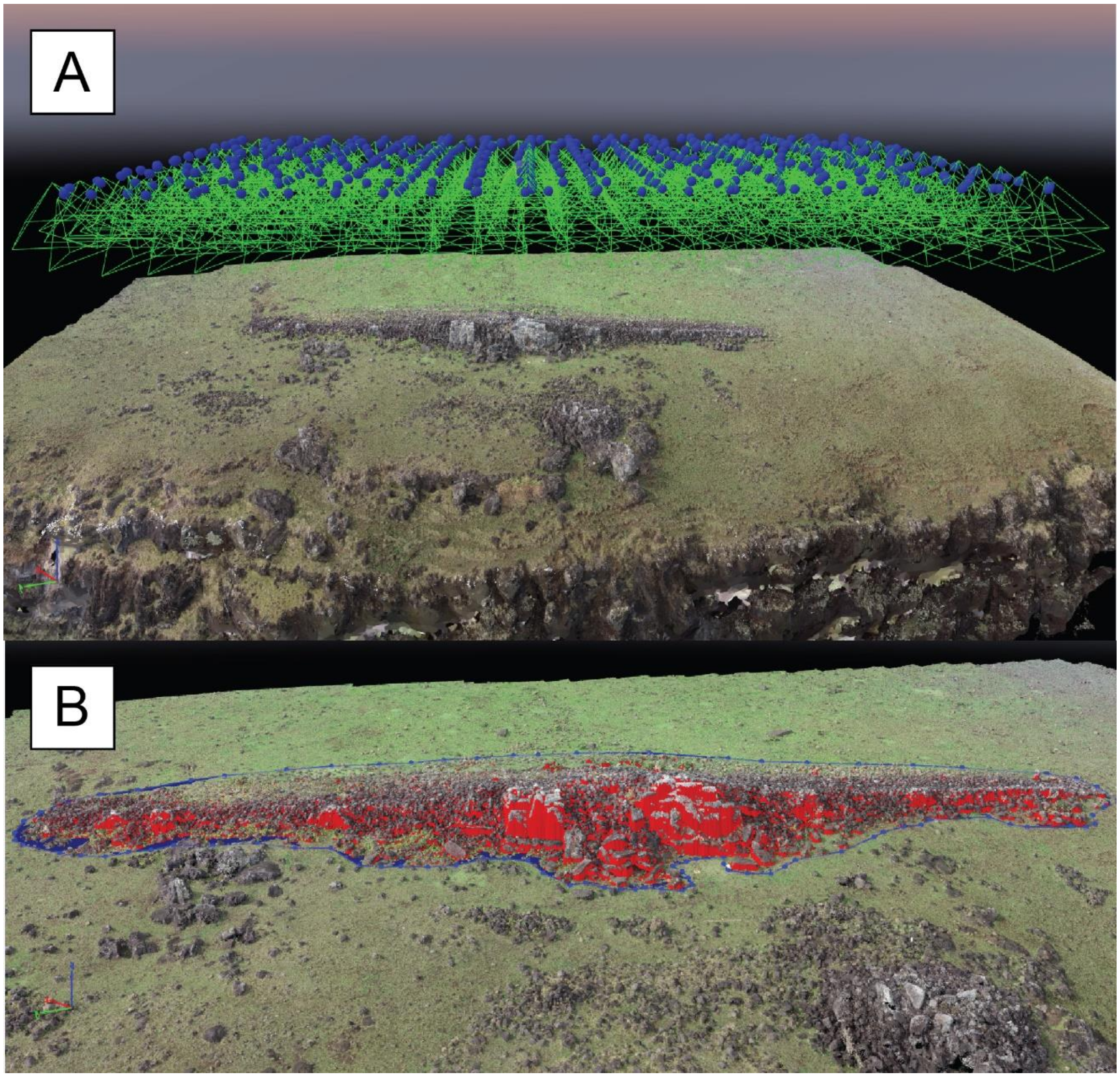

Figure 6.7: Example SfM model used for volume calculation for Ahu Maitaki te Moa. (A) DSM for Mataki te Moa showing UAV camera locations (blue dots). (B) Polygon defining basal area (blue) and structure volume (red).

6.5.2. Visibility Analyses

To explore whether *ahu* were preferentially built in high visibility locations, I created a ‘total viewshed’ for Rapa Nui. A basic viewshed analysis determines what locations are visible to a user-defined set of observer points based on local topography, or other obstructions, usually provided by a digital elevation model (DEM) (Gillings, 2017).

A total viewshed, in contrast, calculates visibility values for every location in a study area, resulting in a raster layer where each cell value is equal to the sum of other cells that can view that point (Llobera, 2003; Llobera et al., 2010). By characterizing the visibility of the entire landscape, a total viewshed is useful for statistical hypothesis testing as it allows comparison of the visibility of locations of interest (e.g., archaeological features) relative to random background locations from the same study area (e.g., Dungan et al., 2018, p. 908; Eve and Crema, 2014).

A total viewshed was created for Rapa Nui using the 30 m SRTM DEM used in DiNapoli et al. (2019). While a 30 m resolution DEM may seem coarse, given the relatively high degree of spacing between *ahu* along the coastline (e.g., < 200-300 meters on average), this 30 m resolution is suitable for the current analysis and comparable to similar recent studies (e.g., Dungan et al., 2018). The total viewshed was created by first plotting a series of observer points (n=188,354) at the center of each cell in the DEM and then calculating the number of observer points that have a viewshed of each cell. The output from this analysis is a raster map where high values represent highly visible locations and lower values are less visible locations. The total viewshed was created in ArcGIS 10.7 using the ‘visibility’ tool in the spatial analyst toolbox with analysis type set to ‘frequency’ and defaults for all other settings.

To test the hypothesis is that *ahu* were built in highly visible locations to maximize the potential audience of receivers, I analyzed *ahu* locations as a function of the total viewshed using a spatial Kolmogorov-Smirnov test (SKS), non-parametric smoothing, and point-process modeling. Two samples of *ahu* were analyzed. First, the total sample of *ahu* was analyzed in relation to the total viewshed to examine whether visibility predicts *ahu* construction location at an island-wide scale. The second iteration of the visibility analysis uses a subset of *ahu* within the study area in the eastern portion of Rapa Nui analyzed in DiNapoli et al. (2019) where we have near complete survey data on freshwater sources. DiNapoli et al. (2019) presented a multi-model selection analysis of the distribution of *ahu* in eastern Rapa Nui that used point processing modeling to identify which important environmental variables (rock gardens, marine resource locations, freshwater) best explain *ahu* locations. This analysis indicated that freshwater is the best predictor of *ahu* location. While this result supports the predictions of the CST model, analyses of the relationship between *ahu* location and visibility are needed. Because the results of DiNapoli et al. (2019) strongly indicate that *ahu* are associated with freshwater locations, I built a series of point-process models to evaluate whether visibility is a meaningful predictor in addition to freshwater locations.

Next, I compared the locations of *moai* roads with the total viewshed to test the hypothesis that statue transport routes were related to signaling. Using the known *moai* road locations mapped by Lipo and Hunt (2005; see Figure 6.1 above), I created a series of evenly spaced points at 10 m intervals along the road line segments and compared the visibility and slope values at these points with the background sample of the slope and visibility values from the entire island. I use SKS tests and graphical models to test these hypotheses. These statistical analyses were conducted in R (R Core Team, 2019) using the spatstat (Baddeley et al., 2015) package.

6.5.3. Modeling Signal Magnitude as a Function of Access to Critical Resources

While the results of DiNapoli et al. (2019) strongly indicate a spatial dependence between *ahu* location and freshwater sources, analyses of the relationship between *ahu* volume and environmental variables are needed. To test whether the magnitude of investment in *ahu* is related to critical subsistence resources, in particular freshwater, I examined the relationship between community investment in *ahu* and access to freshwater sources, marine resources, and rock gardens using a generalized linear model (GLM). In these analyses, I use the same marine resource and rock mulch datasets analyzed in DiNapoli et al. (2019; rock garden data from Ladefoged et al., 2013). The freshwater dataset has been slightly expanded to include ca. 20 newly identified water sources, which include caves with seeping groundwater, coastal seeps, and *puna* (i.e., traditional ‘wells’).

Given the hypothesis of community-level signaling and variability in patterns of *ahu* construction discussed above, locations with multiple *ahu* built directly adjacent to one another were treated as single cases of *ahu* investment. This was conducted by performing hierarchical clustering on a Euclidian distance matrix where *ahu* within 300 m of each other were grouped together to yield a total volume estimate for that community. The location of this new point is the mean center of each of the *ahu* contributing to this community-level investment estimate. I then compared this community-level labor investment to access to freshwater, marine resources, and rock gardens. To select which variable, or combination of variables, best explain the magnitude of *ahu* investment, I compare the GLMs using the Akaike and Bayesian information criteria (AIC and BIC). The models with the smaller difference in information criterion score (ΔAIC and ΔBIC) and highest weight indicate the best-fitting model.

One important consideration in modeling spatial data like the *ahu* used here is the potential for spatial autocorrelation to influence the results of the models. In particular, spatial autocorrelation, either in the response variable or residuals, can introduce bias by increasing the chances for Type I error (i.e., failure to reject the null hypothesis of no dependence between *ahu* volume and the environmental variables). If spatial autocorrelation exists in the response variable or residuals from an aspatial model, then spatial autocorrelation can be incorporated into a spatially explicit model, such a simultaneous autoregressive or geographically weighted regression model (Bivand et al., 2013). I test for spatial autocorrelation in *ahu* volumes and the residuals from the GLM using a Moran's *i* test. Following Beale et al. (2010), I evaluate the potential for spatial autocorrelation using a range of nearest-neighbor- and distance-based neighborhood definitions, as well as a simultaneous autoregressive model.

6.5.4. Spatio-Temporal Models of Ahu Construction

Expectation #4 of the CST model predicts that multiple *ahu* were being built and used contemporaneously, as the stability of a costly signaling strategy is frequency-dependent, meaning that it is only viable if there are sets of interacting signalers and receivers (Neiman, 1997). Furthermore, expectation #5 of the CST model predicts that signaling should result in some benefit to the signaler, such as a reduction in lethal violence, exclusion of competitors for continued access to contested resources, or community longevity (Bliege Bird and Smith, 2005; Conolly, 2017; McAndrew, 2002;

Smith and Bird, 2000; Wandsnider, 2015). The analyses in DiNapoli et al. (2020) present a chronological model of the aggregate tempo of monument construction over time. The patterns in the tempo plot Figure's 4.16 and 4.17 suggest contemporaneous construction at different locations on the island, consistent with expectation #4, and potentially long durations of construction at particular sites, consistent with expectation #5. However, to further assess expectation #4, what is needed are models of both spatial-temporal patterns that show spatial associations of construction events. In addition, one way to assess the longevity of communities on Rapa Nui is the creation of chronological models for the overall duration of monument construction at different sites.

I use two methods for characterizing the overall duration of *ahu* use and spatial patterns of *ahu* construction. First, I compute the interval of time between the onset and end of *ahu* construction activities at each *ahu* that was modeled in DiNapoli et al. (2020) (Figure 6.8). I then compute and plot the 95% Bayesian credible interval of the cumulative probability density function for the start of *ahu* construction, later construction events, and end of construction at the 11 sites. Rather than showing the date range for a single radiocarbon date or estimated posterior Boundary, this 'duration plot' shows the cumulative probability density function for all dated construction events at each *ahu*. These 'duration plots' are similar to methods recently suggested by Bronk Ramsey (2017b) and were produced using the ArchaeoPhases R package (Philippe et al., 2019). While this method is useful for showing contemporaneity and overall duration of construction at different *ahu*, it does not explicitly show spatial patterns.

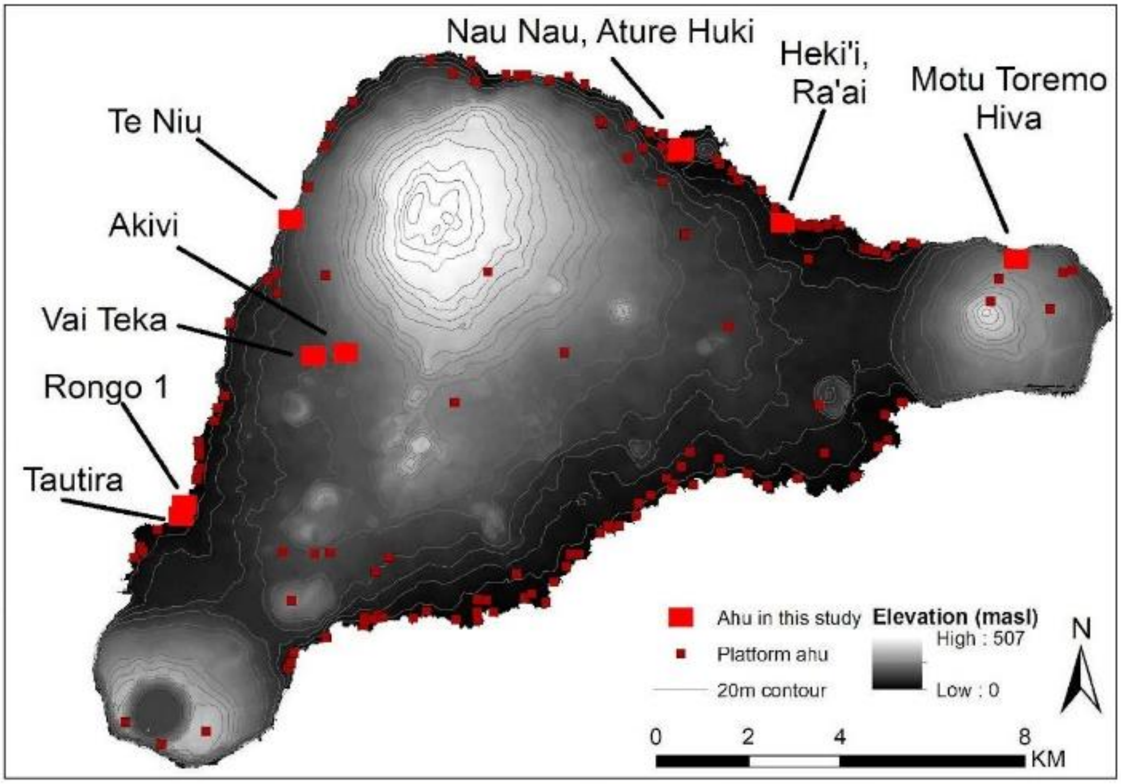

Figure 6.8: Locations of 11 ahu with sufficient radiocarbon data. Note that the location of Nau Nau is represented by the main structure (Nau Nau I) and a smaller adjacent *ahu* Nau Nau IV.

For the second method, I introduce a technique for visualizing the results of Bayesian radiocarbon calibration models across space using weighted kernel density estimation (KDE)[5]. I use the 95% Bayesian posterior density estimates (HPD) for the

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[5] There have been several recent applications of spatio-temporal modeling of radiocarbon dates using kernel density estimate (KDE) (e.g., McLaughlin, 2019). These methods rely on weighing the KDE by the summed probability distributions of radiocarbon dates (SPDRD). While this technique may be a robust approach with very large sample sizes, geographic regions, and time-scales, they are problematic for the current analysis. Specifically, the SPDRD approach assumes a direct association between the dated event (death of dated sample) and the target event (e.g., artifact, archaeological feature, etc.). However, in the case of *ahu* (and certainly many other contexts) the dated events typically do not have a direct association with the target events (*ahu* construction). Instead, *ahu* construction represents an undated event that must be estimated through stratigraphic association with radiocarbon dates that either pre- or post-date the platform. In a Bayesian analysis this is not problematic, indeed it is precisely the situation the technique was designed for. However, an SPDRD of *ahu* would instead aggregate all radiocarbon dates not directly associated with *ahu* construction and thus yield chronological estimates not clearly associated with the

timing of initial platform construction, later construction events, and end of construction for the 11 *ahu* discussed in DiNapoli et al. (2020). For each *ahu*, I then subsetted the posterior probabilities into 50-year bins (from AD 1300-1750) and calculated the cumulative posterior probability that construction was occurring at each location within each bin, such that each *ahu* location has an associated probability value for each time period. I then plot the KDE of these 11 sites in 50-year bins (AD 1300-1750), with the KDE weighted by the cumulative posterior probability that *ahu* construction was occurring at each location and time period[6]. The result of this analysis is a series of density maps where high-density locations are areas with a high probably of *ahu* construction. If *ahu* construction only occurs in isolated locations and time periods, this would question the expectations of the CST model, whereas a high probability of multiple contemporaneous and adjacent construction events would offer support for the notion of contemporaneous signaling (Neiman, 1997).

6.6. Results

6.6.1. Volume Estimates for Platform Ahu

There is a high degree of variation in the volume of *ahu* surveyed. The smallest *ahu* in this study is Mata Ketu at 12.5 m^3, whereas Heki‘i 1 is the largest measuring 4,629 m^3. Aerial images of these two *ahu* are shown in Figures 6.9 and 6.10.

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target events. SPDRD also currently does not have clearly defined ways of dealing with in-built age, outliers, or stratigraphic relationships.

[6] Unlike SPDRD approaches which treat the radiocarbon dates as the events of interest, this method uses the actual Bayesian estimates for the target archaeological events.

Figure 6.9: Aerial image of Ahu Mata Ketu showing small platform and single *moai*. Scale bar is 2 m.

Figure 6.10: Aerial images of Ahu Heki‘i 1 on the northeast coast.

Figure 6.11 shows a histogram of *ahu* volumes. The overall distribution of *ahu* volumes is highly right-skewed, and the median volume is 297 m^3. Of the *ahu* surveyed, most (n=45) are relatively small and less than or equal to ca. 300 m^3, a large portion (n=28) are between 300-1000 m^3, and 17 are greater than 1000 m^3.

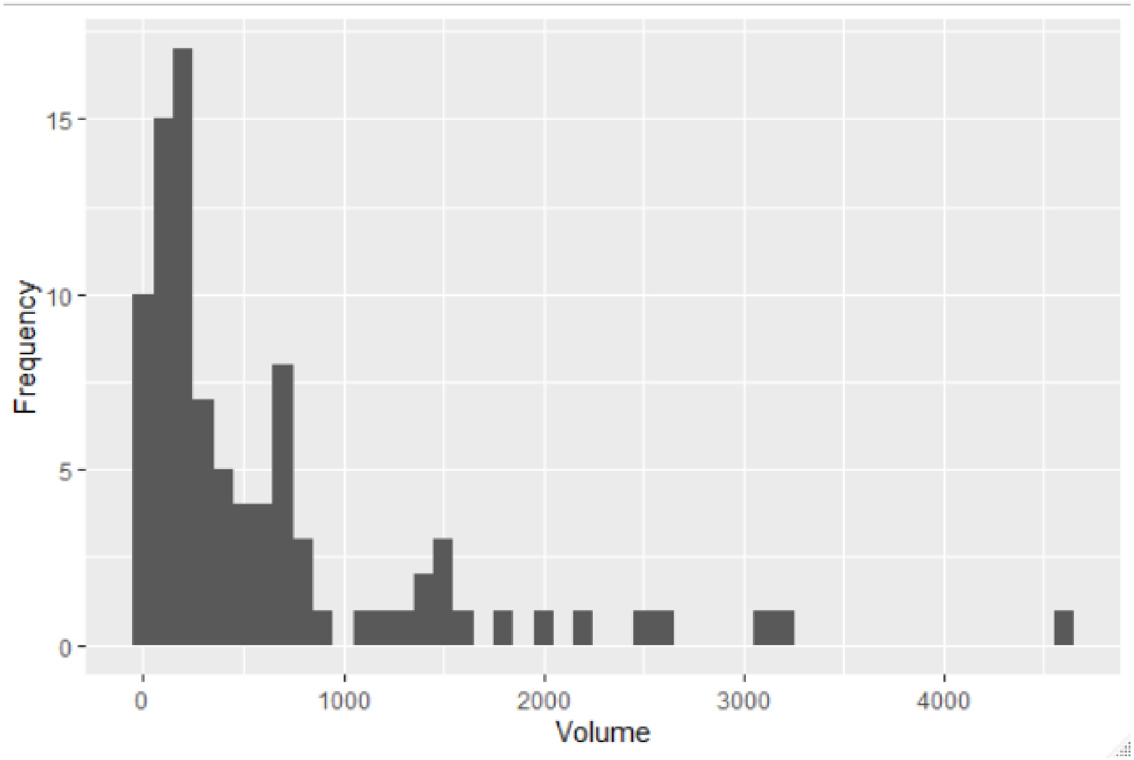

Figure 6.11: Distribution of volume (m^3) estimates for 90 *ahu*

Figure 6.12 shows the spatial distribution of *ahu* of different sizes broken up into three arbitrary size classes: <300 m^3, 300-1000 m^3, and >1000 m^3. The results indicate that the largest *ahu* are widely dispersed around the coast.

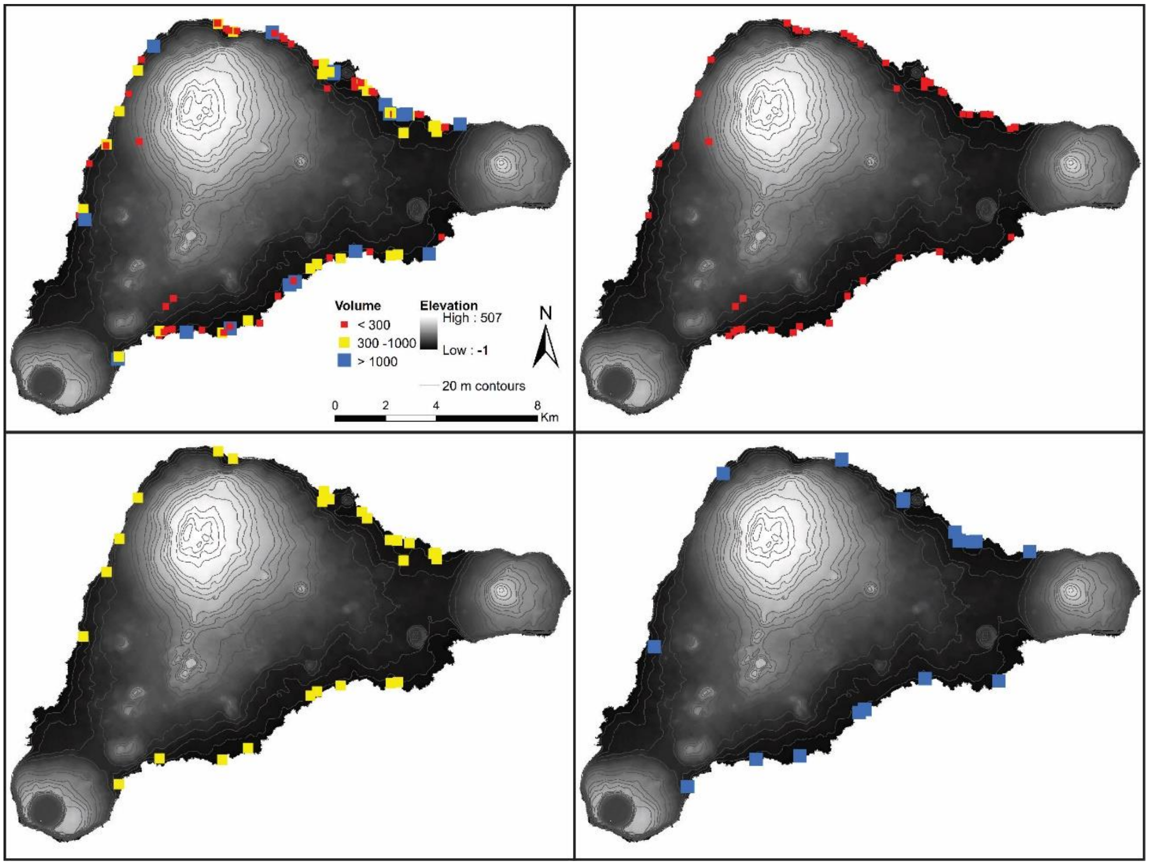

Figure 6.12. Spatial variation in the distribution of ahu volumes in three size classes: < 300 m^3 (red), 300-1000 m^3 (yellow), and > 1000 m^3 (blue).

6.6.2. Spatial Patterns of Ahu *Investment*

Figure 6.13 shows the total viewshed for Rapa Nui. This shows that the most visible locations on Rapa Nui are the western slope of Poike, northern and eastern slopes of Rano Kau, southern slopes of Terevaka, Rano Raraku, and various other cinder cones throughout the island.

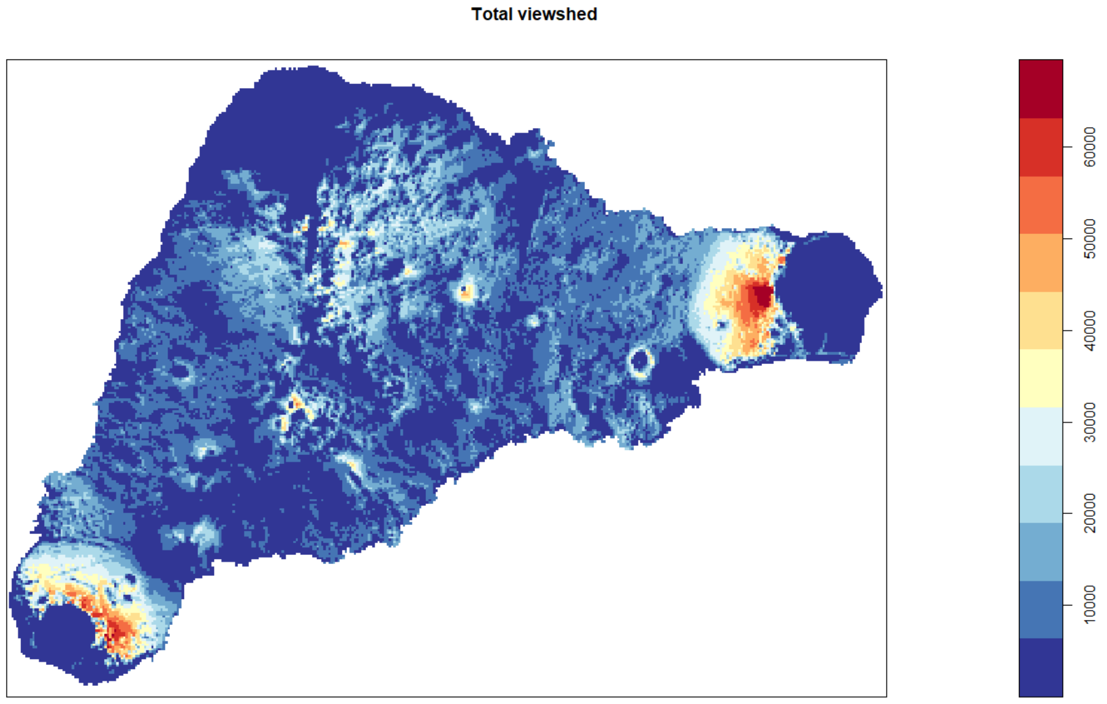

Figure 6.13: Total viewshed for Rapa Nui. Red= high visibility, yellow=medium, blue=low.

Figure 6.14 shows a series of summary functions for the relationship between *ahu* construction location and visibility. Figure 6.14a shows the probability density function for the distribution of visibility values for the entire island and Figure 6.14b shows the distribution of visibility values at *ahu* construction locations. Figure 6.14a shows that the majority of locations on Rapa Nui have visibility values <5000 and that there are few highly visible locations, which is likely a result of the lack of topographic relief on the island. Figure 6.14c shows a smooth estimate of the spatial intensity of *ahu* as a function of visibility (with 95% confidence intervals), which indicates a non-linear relationship between *ahu* and visibility. The intensity function rises steeply between visibility values of ca. 1000-3000 and then plateaus through values of ca. 7000, declines through ca.

12000, rises through ca. 15000, then sharply declines after this. There are three *ahu* in very high visibility locations; however, the majority of *ahu* are not located in the highest visibility locations on the island, but their intensity is greatest in the ca. 3000-7000 visibility value range. An SKS test of the relationship between *ahu* locations and visibility suggests that *ahu* are not in the most visible locations on the island ($D^{-}=0.05$, $p=0.42$).

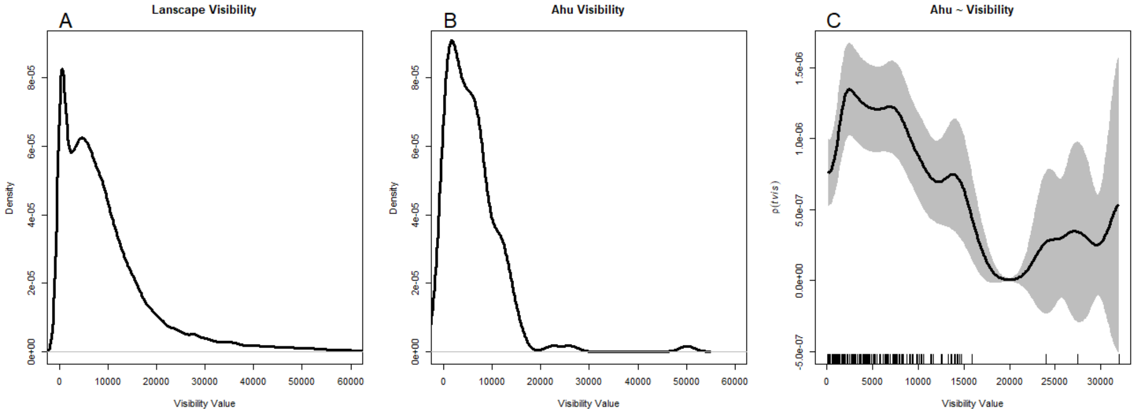

Figure 6.14: Summary functions for the relationship between *ahu* construction location and landscape visibility: (A) probability density function for visibility values for the entire island, (B) probability density function for visibility of *ahu* construction locations, (C) smoothed estimate of the intensity of *ahu* as a function of landscape visibility (with 95% confidence intervals).

The next component of the visibility analysis is focused on assessing whether visibility is strong predictor of *ahu* location in addition to freshwater sources. The analyses in DiNapoli et al. (2019) indicate that *ahu* locations are best explained by distance from freshwater sources. Table 6.1 shows the results of comparing three point process models of the relationship between *ahu* and (1) distance from freshwater sources, (2) visibility, and (3) both freshwater sources and visibility. Given that Figure 6.14c indicates that the relationship between *ahu* intensity and visibility is non-linear, I fit these models using generalized additive Poisson point process using a B-spline with 4 knots (Baddeley et al., 2015, p. 340). Four knots were selected based on the shape of the empirical function in Figure 6.14c above. The results indicate that a model incorporating both distance from freshwater and visibility fits best, with ΔAIC=0, AIC weight=0.994 and ΔBIC=0 and weight=0.51.

Table 6.1: Model selection results for the relationship between *ahu* construction locations and landscape visibility and distance from freshwater sources.

Model	**df**	**ΔAIC**	**AIC weight**	**ΔBIC**	**BIC weight**
Water + visibility	6	0	0.994	0	0.51
Water	2	10.12	0.006	0.08	0.49
Visibility	2	184.43	0	181.92	0

Table 6.2 shows a summary of the results for the best fitting model incorporating distance from freshwater sources and visibility. Figure 6.15a shows the fitted intensity of *ahu* as a function of distance from freshwater and Figure 6.15b shows the fitted intensity of *ahu* as a function of visibility. The results show a non-linear relationship between *ahu* and visibility: there is evidence for a significant positive relationship between *ahu* and visibility up to values of ca. 5000, but beyond this the relationship becomes negative and weak.

Table 6.2: Covariate estimates for best-fitting generalized additive point process model.

Coefficient	**Estimate**	**S.E.**	**95% C.I. low**	**95% C.I. High**	**Ztest**	**Zval**
(Intercept)	-12.09	0.37	-12.81	-11.36	<0.0001	-32.55
Water	-0.004	0.0004	-0.005	-0.003	<0.0001	-9.29
Visibility,bs1	1.37	0.57	0.26	2.49	<0.05	2.42
Visibility,bs2	-1.65	1.23	-4.06	0.77	>0.1	-1.34
Visibility,bs3	-1.44	3.43	-8.17	5.29	>0.1	-0.42
Visibility Bs4	4.94	2.03	0.96	8.92	<0.05	2.43

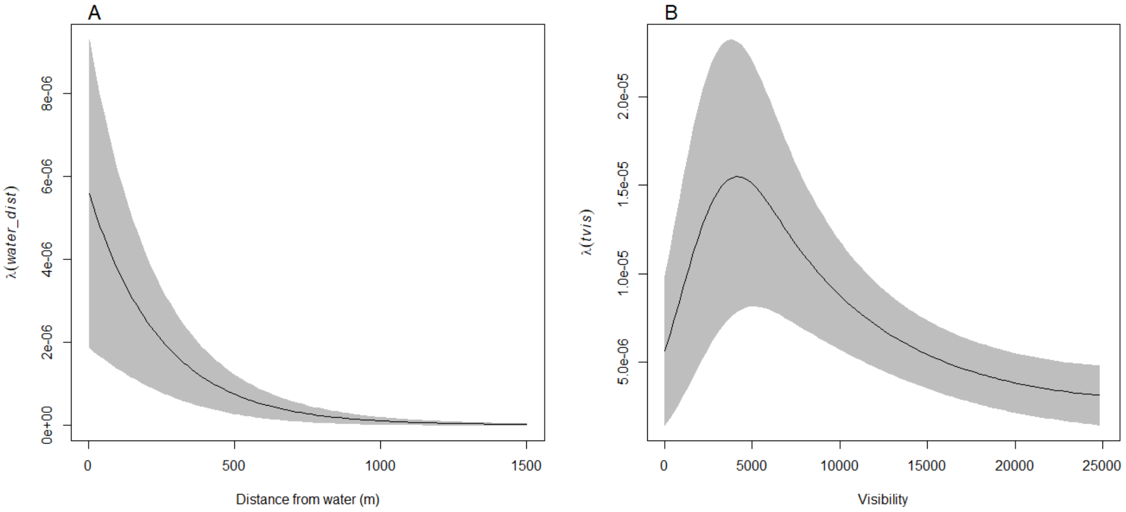

Figure 6.15: (A) Fitted intensity of *ahu* as a function of distance from freshwater, and (B) fitted intensity of *ahu* as a function of landscape visibility (after controlling for distance from water). Grey shaded regions represent the 95% confidence intervals.

Figure 6.16 shows the relationship between the fitted model and the data. Figure 6.16a shows the empirical intensity estimate for *ahu* with smoothing bandwidth selected using likelihood cross-validation. Figure 6.16b shows the predicted intensity as a function of distance from water and visibility, and Figure 6.16c shows the standard errors from the model at each location. The results suggest a good fit between the trend component of the model and the data, though the model appears to be overestimating the intensity of *ahu* in locations such as Tongariki, Rano Raraku, and on the slopes of Terevaka near Rano Aroi, which are each locations with either high visibility, high density of water sources, or both, but where the density of *ahu* is relatively low. Together these results indicate that *ahu* are located in relatively high visibility locations near freshwater sources.

6.6.3. Location of Moai *Roads*

Figure 6.17 shows the results of comparing the locations of *moai* transport roads with terrain slope and landscape visibility. Figure 6.17a and 6.17c show the probability density functions characterizing the terrain slope values and visibility for the entire island, and Figures 6.17b and 6.17d show the probability density functions for slope and visibility values along the *moai* roads. Comparison of the slope values along the *moai* roads with the background sample from the entire island suggests that the *moai* roads are located on slopes roughly equal to or slightly less than random locations. A spatial Kolmogorov-Smirnov test (SKS) suggests that the *moai* roads are on significantly flatter slopes ($D^{+}=0.103$, $p<0.0001$). Comparison of the visibility values along *moai* roads with the background visibility values from the entire island appears to show that the *moai* roads are in slightly higher visibility locations, which is supported by the results of the SKS test ($D^{-}=0.03$, $p=0.007$).

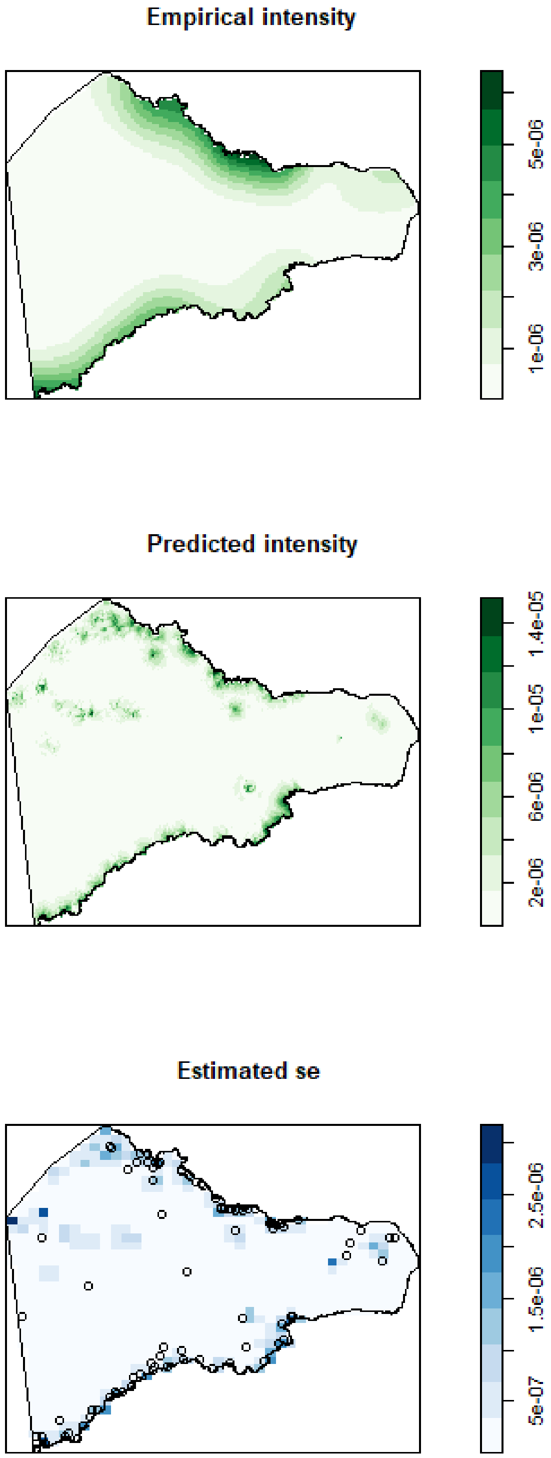

Figure 6.16: Relationship between generalized additive point process model incorporating distance from freshwater and landscape visibility and the empirical *ahu* spatial pattern.

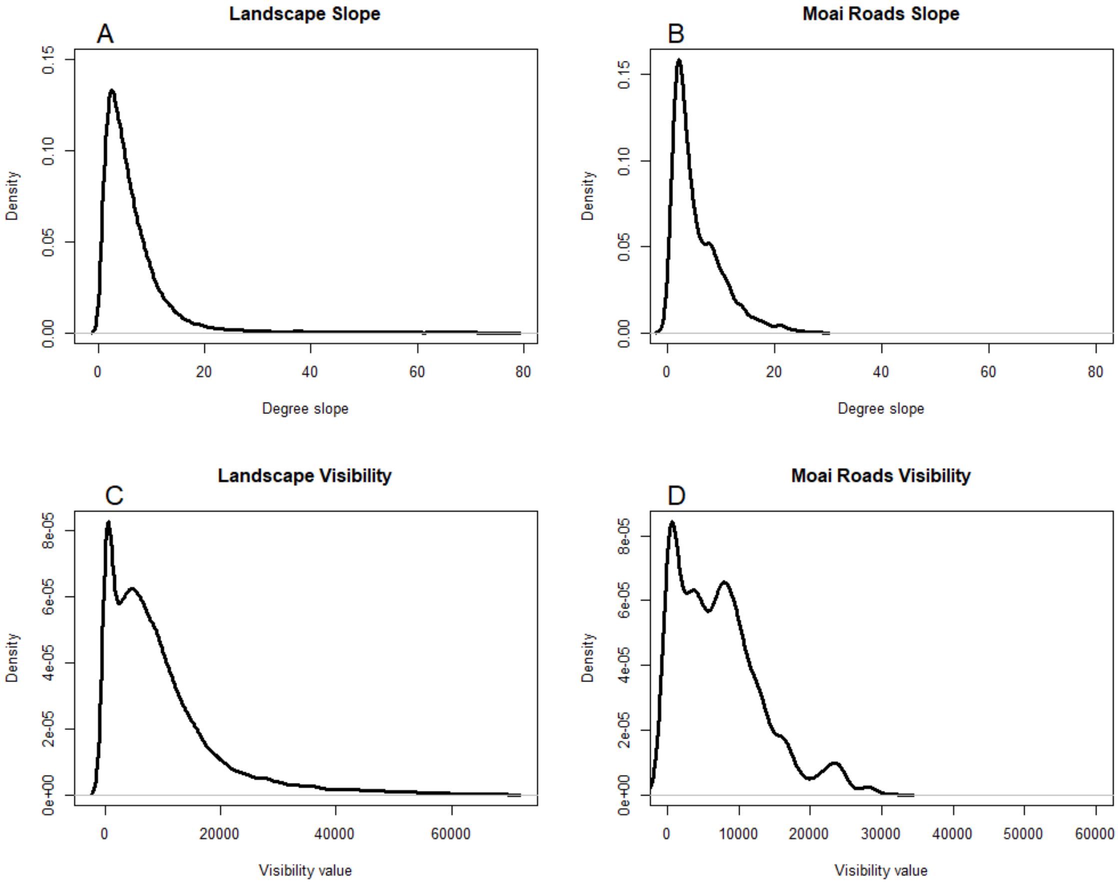

Figure 6.17: Relationship between the location of *moai* roads and landscape slope and visibility.

6.6.4. Community-Level Investment in Ahu *as a Function of Access to Critical Resources*

Given the highly right-skewed distribution of *ahu* volumes shown in Figure 6.11, I evaluated the relationship between *ahu* volume and subsistence resources using an inverse Gaussian GLM with a log link[7]. Table 6.3 shows the results of a series of GLMs comparing the relationship between community investment in *ahu* and access to freshwater, marine resources, and rock gardens. Given the relatively small number of

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[7] Inverse Gaussian models incorporating rock gardens would not converge and were instead fitted using a Gamma GLM with a log link.

observations, I used the second order *AICc* for smaller sample sizes (Burnham and Anderson, 2010). The results indicate that access to freshwater is the best predictor of community-level investment in *ahu,* with *ΔAIC*=0 and weight=0.692 and *ΔBIC*=0 and weight=0.806.

Table 6.3: Model selection results for the relationship between *ahu* volume and important subsistence resources.

Model	**df**	**ΔAICc**	**AICc weight**	**ΔBIC**	**BIC weight**
Water	3	0	0.692	0	0.806
Water + marine	4	1.81	0.281	3.06	0.175
Water + rock gardens	4	8.04	0.012	9.29	0.008
Marine	3	9.11	0.007	9.11	0.008
Water + marine + rock gardens	5	10.07	0.005	12.43	0.002
Marine + rock gardens	4	11.22	0.003	12.48	0.002
Rock gardens	3	18.92	0	18.92	0

Table 6.4 shows the covariate estimates, standard errors, and confidence intervals for the best fitting model. Figure 6.18 shows a smoothed estimate of this fitted effect, with 95% confidence intervals. The negative form of the freshwater coefficient indicates that *ahu* volume decreases with less access to freshwater sources.

Table 6.4: Results for best-fitting inverse Gaussian generalized linear model incorporating access to freshwater sources.

Coefficient	**Estimate**	**S.E.**	**95% C.I. low**	**95% C.I. High**	**T value**	**P-value**
(Intercept)	-7.38	0.22	7.00	7.89	33.91	<0.0001
Water	-0.004	0.0007	-0.005	-0.003	-6.59	<0.0001

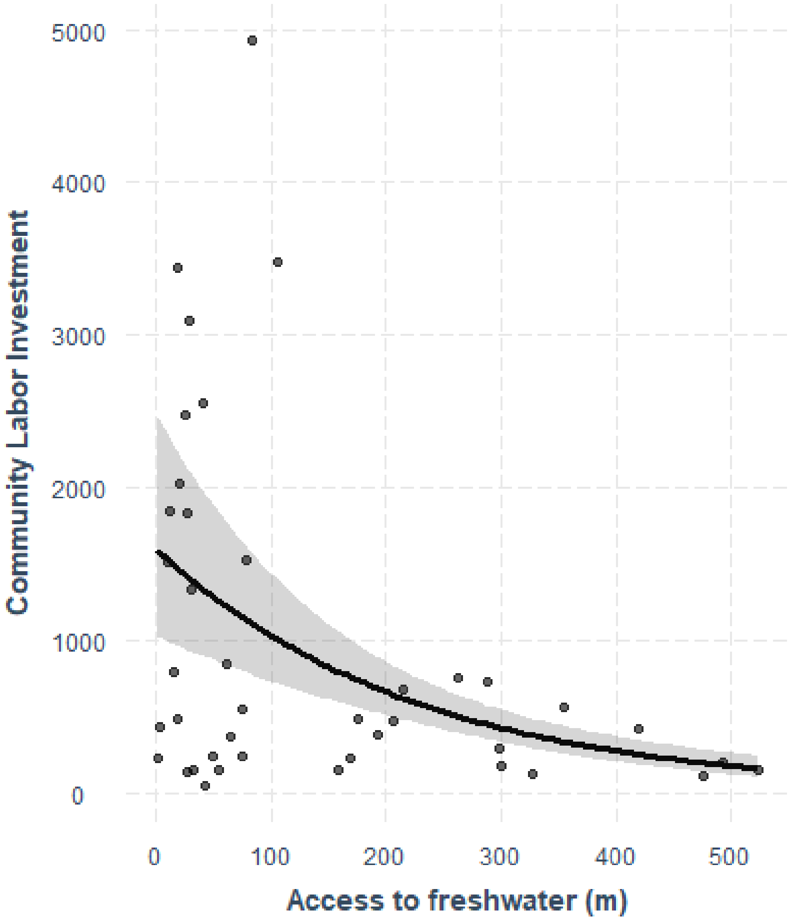

Figure 6.18: Smoothed estimate of the effect of access to freshwater on the magnitude of community-level investment in *ahu*.

Table 6.5 shows the results of testing for spatial autocorrelation in *ahu* volumes and residuals from the model using Moran's *i* with a series of nearest-neighbor and distance-based neighborhood definitions. Overall, the results provide little indication of spatial autocorrelation in the response variable or residuals from the GLM. However, the significance values of Moran's *i* with a distance-based neighborhood of 500 m appears to suggest weak positive spatial autocorrelation at this scale, with a value of 0.19 (*p=0.102*) for volume and 0.12 (*p=0.19*) for the residuals. To test whether this spatial autocorrelation has a meaningful impact on the modelled coefficients, I built a simultaneous autoregressive model (SAR) using the 500 m distance-based neighborhood. The results of the SAR model similarly suggest that *ahu* volume has a significant relationship with access to water, but the results indicate there is no significant autocorrelation in the residuals (*λ=0.06, LR test value = 0.45, p=0.5*). Furthermore, model selection indicates that the SAR model (*ΔAICc =60.67, w=0; ΔBIC=61.93, w=0*) is a poor fit relative to the best fitting GLM (*ΔAICc=0, w=1; ΔBIC=0, w=1*).

Table 6.5: Moran's i tests for spatial autocorrelation in the response variable (volume) and residuals from the best fitting GLM using both k-nearest neighbors and distance-based neighborhood definitions. Cells show values of the Moran's *i* test statistic and associated *p* values in parentheses.

k-nearest	***K=2***	***K=3***	***K=4***	***K=5***	***K=10***
Response	-0.02 (p=0.49)	-0.05 (p=0.58)	-0.03 (p=0.53)	-0.05 (0.63)	-0.05 (0.71)
Residuals	-0.07 (p=0.45)	-0.06 (p=0.61)	-0.04 (p=0.56)	-0.08 (p=0.78)	-0.07 (p=0.8)
Distance	***300***	***500***	***1000***	***1500***	***2000***
Response	0.11 (p=0.22)	0.19 (p=0.10)	-0.06 (p=0.64)	-0.09 (p=0.80)	-0.12 (p=0.94)
Residuals	0.02 (p=0.36)	0.12 (p=0.19)	-0.16 (p=0.91)	-0.09 (p=0.79)	-0.09 (p=0.84)

6.6.5. Spatio-Temporal Patterns of Ahu Construction

Figure 6.19 shows the ‘duration plots’ with 95% Bayesian credible intervals (gray shading) for construction activity at 10 locations on the island. Note that these intervals are not the calibrated ranges for individual model boundaries or radiocarbon dates, but the cumulative probabilities for the duration of all dated construction events at each location. The results indicate a high probability of contemporaneous construction activity from the ca. 15th century through European arrival at Ature Huki, Nau Nau, Te Niu, Akivi, Motu Toremo Hiva, Raʻai, Tautira, and Vai Teka. Based on the available radiocarbon data, Hekiʻi 1 and Rongo 1 appear to have earlier durations of construction activity than the other *ahu.*

Figure 6.20 shows the results of the spatio-temporal Bayesian models for *ahu* construction at 11 locations on the island. The results show that *ahu* construction was occurring simultaneously at multiple locations on the island throughout Rapa Nui’s culture history. The highest probabilities of contemporaneous *ahu* construction appear to be between ca. AD 1600 to 1700 with a reduction of construction probability following European arrival in AD 1722.

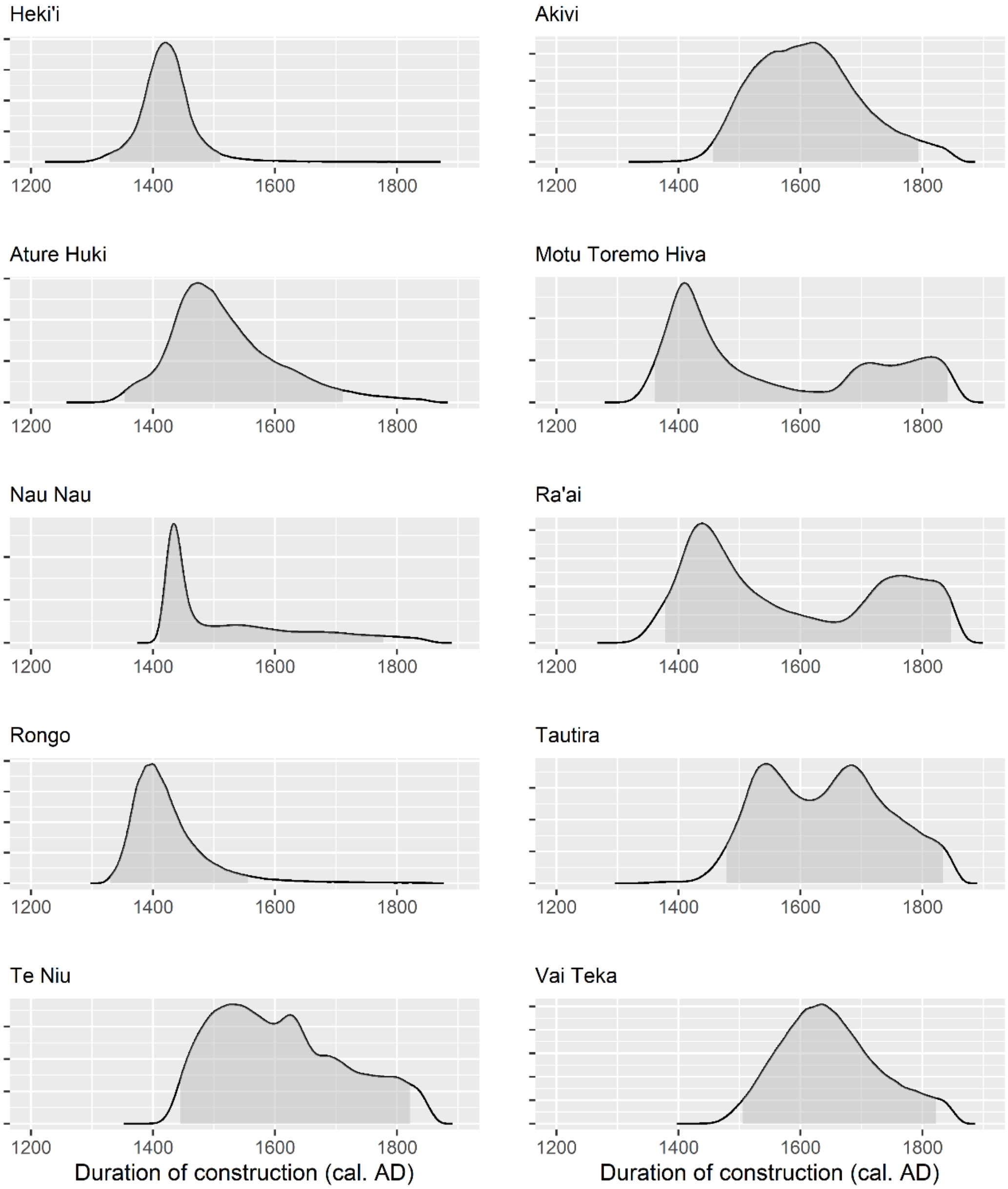

Figure 6.19: Duration plots of *ahu* construction at 10 locations across Rapa Nui. Note that Ahu Nau Nau and Nau Nau IV are combined. Gray shading represents the 95.4% Bayesian credible intervals between the start and end of *ahu* construction activities.

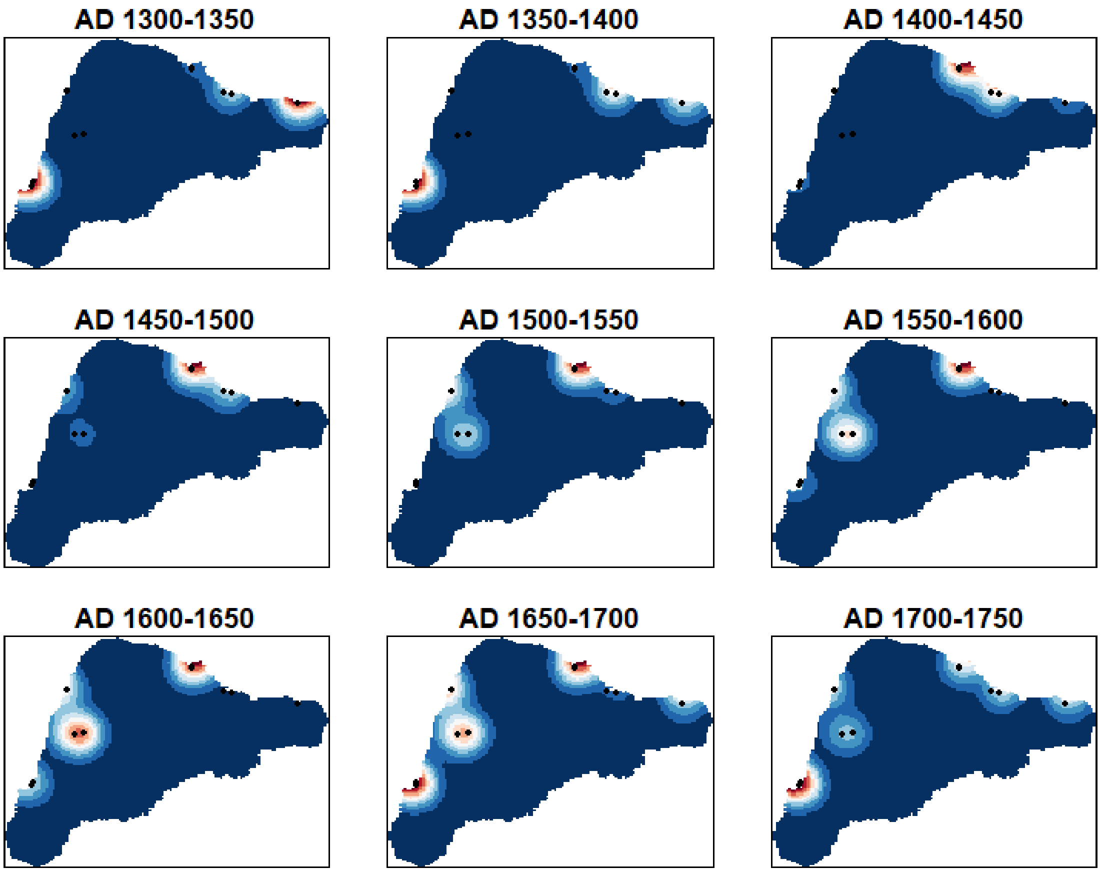

Figure 6.20: Spatio-temporal intensity of monument construction at 11 *ahu* on Rapa Nui from cal AD 1300-1750 (95.4% HPD).

6.7. Discussion

The majority of the *ahu* surveyed are relatively small structures ≤ 300 m^3, a large proportion are within the 300-1000 m^3 range, and 17 *ahu* are larger than 1000 m^3, with Heki‘i 1 being the largest[8] surveyed at 4,629 m^3. These results indicate substantial variability in community labor investment in constructing *ahu*. If we apply the average specific gravity of oceanic basalts used by Kolb (1991, p. 132) of approximately 3

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[8] Ahu Tongariki on the southwest coast is likely larger; however, it was not modeled given a lack of access and that the feature was completely reconstructed in the 20th century.

gm/cm^3, then the total weight of stone used in the construction of Heki‘i 1 is approximately 14,000 metrics tons. The typical *ahu* composed of ca. 300 m^3 of construction stone represents a total weight of approximately 900 metric tons. While the labor costs of building the largest structures would have been immense, the smaller *ahu* clearly would have required a high degree of investment as well, not just in terms of stone transportation and assembly, but also carving of dressed stone, erection of *moai* and *pukao*, as well as continuous maintenance over time. Even some of the smallest architectural components—the water-worn *poro* pavement boulders—would have required substantial labor to collect and transport from the rocky shorelines to *ahu*. While much previous discussion has focused on the coordination and labor requirements for *moai*, and some have claimed that *ahu* were “relatively easy to construct given the fact that most were built using stacks of locally available rock” (Kolb, 2020, p. 207), these features nevertheless represent a large cumulative investment by Rapa Nui communities, not just in terms of the costs of time and energy needed to construct them, but also the missed opportunity costs of not diverting time and resources to additional essential activities.

The time and energy invested in the activities of constructing and maintaining these monuments would have broadcasted community cohesion and cooperation in a way that would be difficult to fake. While the quarry locations for *ahu* stone have not been clearly resolved, and are thought to derive from local sources (but see P. C. McCoy, 2014), the fact that nearly all *moai* and *pukao* come from single quarries provides another line of evidence of signal honesty—the only way to have these monuments in a community was through a labor intensive transportation and construction process. While more energetically efficient methods for moving them did emerge over time (Hixon et al., 2018; Lipo et al., 2013), transporting and placing them on *ahu* was energetically costly, required a high degree of group-level coordination, and was virtually impossible to fake.

The results of the visibility analyses support the hypothesis that both *ahu* and *moai* roads were constructed in high visibility locations. While *ahu* were clearly not built in the most visible locations on the island, their distribution is in part predicted by landscape visibility. Previous point process modeling showed that *ahu* construction locations are predicted by the locations of freshwater sources (DiNapoli et al., 2019). The point process models and multi-model selection results reported here indicate that a model with both distance from freshwater sources and landscape visibility best accounts for *ahu* construction locations. These results suggest that landscape visibility was an important consideration in where communities constructed *ahu*, but only with respect to proximity and access to a critical, limited, and likely contested resource—freshwater.

The exploratory analysis examining the locations of known *moai* transport roads indicates that statues were transported along routes that are more visible than would be expected if communities were simply taking the most direct or least costly pathways. This suggests that *moai* transportation activities were also conducted in ways to increase their visibility to a larger audience of receivers in other communities. These results also potentially apply to the transportation of *pukao* if they were transported along similar roads, though more research on this topic is needed. In addition, the visibility of the *moai* roads is best treated as a hypothesis in need of future testing. Specifically, the relatively low resolution of the DEM used in this analysis likely obscures smaller-scale, local topographic variation in the *moai* road routes, so additional work should be directly at further exploring these visibility patterns with a higher resolution DEM once these data becomes available.

Previous interpretations of patterns of variability in *ahu* size have commonly explained the larger structures as being the central places of territorial districts, ‘multiple lineage centers,’ or ‘elite centers,’ whereas smaller *ahu* represent subsidiary temples of adjacent communities that were patrons to the dominant groups (e.g., Kirch, 2017, 1984b; Martinsson-Wallin, 1994; Martinsson-Wallin and Wallin, 2014; Simpson, 2009; Stevenson, 2002, 1986). While the current evidence for low-degrees of settlement/social hierarchy and elite control of lithic resources in pre-contact Rapa Nui does not support their interpretation as the centers of hierarchical chiefdoms (e.g., Lipo et al., 2010; Lipo and Hunt, 2005; McCoy, 1976; Morrison, 2012; Simpson et al., 2018a; Simpson and Dussubieux, 2018a), the larger *ahu* were undoubtedly the focus of more intense ritual activity. The CST model provides a potential explanation for why monument construction and ritual activity were more intense in some locations than others.

The CST model predicts that investment in monuments accurately indexes some underlying quality of the community, such as access/control of resources and collective action potential. The results of comparing the degree of community-level labor investment in *ahu* with critical subsistence resources indicates that variability in the costs of constructing monuments is partially explained by access to critical subsistence resources. The GLM and model selection results indicate that, of the variables explored, access to freshwater is the best predictor of the scale of community labor investment in monuments. All of the largest structures >1000 m^3 occur within ca. 100 m of freshwater sources, and all but two of these are <50 m from a freshwater source. While many smaller structures were also built near freshwater, more than half of the smaller *ahu* are situated at much greater distances. These results provide support for the notion that variability in the magnitude of investment in platform *ahu* covaries with community access to freshwater resources. Agriculture and marine foods were undoubtedly important for community survival; however, these resources are widely and homogeneously dispersed throughout or around the island (DiNapoli et al., 2019). As such, there was likely little long-term benefit to signaling access or excluding non-community members from these resources (DiNapoli et al., 2018). Water, on the other hand, was a critically limited resource on the island.

That *ahu* were constructed directly adjacent to freshwater sources, that variability in the scale of investment in *ahu* covaries with access to water, and that *ahu* were constructed in high visibility locations close to these resources, provides support for the CST model. These results suggest that the religious and ritual activities centered around the construction, maintenance, and use of *ahu* also involved signaling access and control of critical resources, as well as broadcasting the group's collective action potential to defend their territory from other communities (Figure 6.21). The cooperative activities necessary to construct and maintain these features were focused around a critical resource for the community, and a dense and predictable resource that was likely the focus of inter-group competition (DiNapoli et al., 2018; Dyson-Hudson and Smith, 1978). That is, greater investment in *ahu* potentially provided an honest signal of the community's collective action to control and defend their territory and its resources.

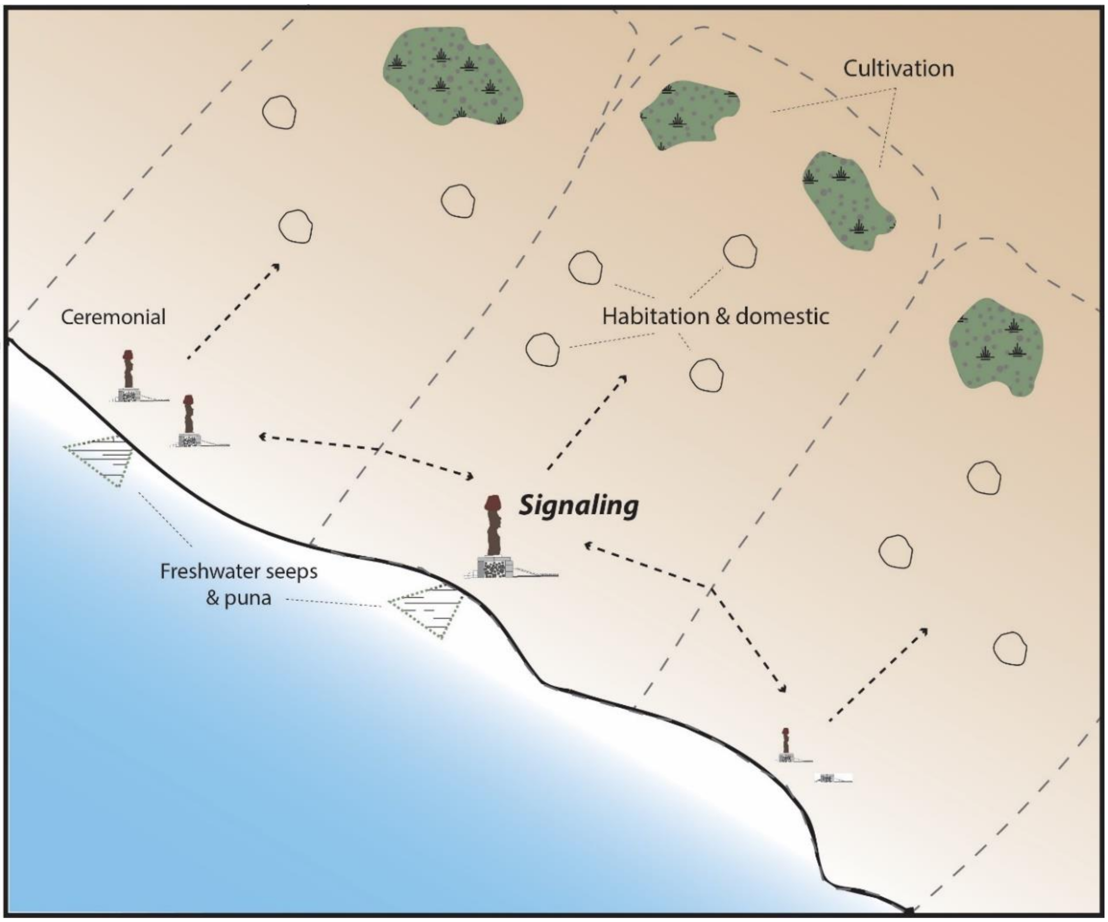

Figure 6.21: A model of community-level signaling on Rapa Nui. Communities live ca. 200 m inland of *ahu,* where they frequently gather for ceremonial activities, resource pooling and information sharing. Monument activities occur adjacent to freshwater sources, signaling cooperation and collective action within and between communities.

A potential hypothesis for this pattern is that as competition for fresh water increased overtime with population and settlement expansion, groups preferentially constructed *ahu* in visible locations near freshwater sources as a way of signaling access and willingness to defend these resources. One result could have been the competitive exclusion of non-community members from this territory, such that there was less benefit to signaling at a high level at communities situated at greater distances from freshwater sources. In locations with more access to this resource, and where competition was likely greater, there were greater payoffs from costlier signals, resulting in more investment in monumental architecture overtime. While there is a considerable amount of settlement pattern data available for Rapa Nui, the requisite chronological data needed to examine spatio-temporal patterns of settlement expansion in relation to freshwater sources do not yet exist. Future studies should be directed at gathering detailed chronological data to examine patterns of intra-island settlement expansion to further test this hypothesis.

One of the central predictions of the CST model is that signaling must provide a benefit to both the signalers and receivers. While there may be many benefits to community-level signaling, two hypothesized benefits in the case of Rapa Nui are a reduction in lethal violence and greater community longevity. Rapa Nui is arguably quite distinctive among many Polynesian societies in that, despite previous claims, there is a remarkable lack of empirical evidence for large-scale violent conflict, including no known fortifications, few instances of lethal trauma, and limited evidence for lethal weaponry (Chapter 5; DiNapoli et al., 2018; Hunt and Lipo, 2011). Despite this lack of evidence for large-scale warfare, the available data do indicate a relatively high-degree of non-lethal violent conflict on Rapa Nui, with much of the violence being healed cranial trauma attributed to rock throwing (Owsley et al., 2016). If, as hypothesized, some component of signaling relates to communicating formidability in a physical contents, then the presence of some level of physical conflict on Rapa Nui is not unexpected—the potential for physical violence between individuals or subgroups must have the potential for actually occurring and be periodically tested. In their comprehensive analysis of the evidence for skeletal trauma on Rapa Nui, Owsley et al. (2016, pp. 246–249) concluded that, “most injuries resulted from frequent personal confrontations, family disputes, or occasional small-scale conflict where the intention was to harm, but not necessarily to kill." The fact that nearly all known physical violence was non-lethal is a critical piece of information. In reviewing similar forms of multi-level social signaling in the small-scale societies of contact-era New Guinea, Roscoe (2009, pp. 93–94) notes how the inevitable conflicts of interest within communities might result in actual fighting, but when physical aggression did occur, conflicts were almost always settled using non-lethal means, which served to mitigate a potential breakdown of community cooperation. This comparative ethnographic and skeletal evidence provides an explanation for patterns of interpersonal aggression on Rapa Nui (Chapter 5)—more intense, lethal conflict was avoided through costly signaling that served as a form of 'ritualized fighting' within and between communities. As Hunt and Lipo (2018, p. 440) argued, "costly signaling enabled populations to compete yet succeed over the long run without systematic violence".

The structure of Rapa Nui communities also provides interesting support for this CST model—bioarchaeological, cultural transmission, and settlement pattern analyses all indicate low degrees of settlement hierarchy and surprisingly little interaction between groups. These patterns likely showcase Roscoe's (2009) prediction that multi-level social signaling results in selection for smaller-scale, modular forms of communities—Rapa Nui's 'hyper-local' community structure may thus also be in part explained as a result of the signaling dynamic. Specifically, signaling through monument construction activities could have provided an honest indication of the community's collective action potential in an actual physical contest and a deterrent from encroaching on the territory of other communities while simultaneously selecting for optimally-sized groups to manage conflicts of interest at multiple scales (DiNapoli and Morrison, 2017, p. 8; Morrison, 2012). Over time, as more communities adopted this form of ritualized fighting, monumental signaling and hyper-local social organization may have become the evolutionarily stable strategy.

The duration and spatio-temporal Bayesian models (Figure 6.19 & 6.20) show that monument construction was occurring contemporaneously and over long durations at multiple locations on the island. With the exception of Heki‘i 1 and Rongo 1, all other *ahu* have a 95% probability of contemporaneous construction and modification over the course of Rapa Nui culture history. This provides support for the predictions that monumental signaling was a frequency-dependent strategy and potentially led to increased community longevity. In addition, even though the current models most clearly show earlier periods of construction at Heki‘i 1 and Rongo 1, these estimates provide *termini post quos* for erection of *moai* and *pukao* at these locations, so it is likely that monument construction activities post-date these estimates by some amount of time. However, additional chronological data from these and additional *ahu* are needed to more thoroughly evaluate these predictions. For example, one prediction of the model is that largest structures should have longer durations of construction and use, whereas smaller structures should be more limited in duration, as lower-quality signalers should not be able to sustain signaling at the same level as higher-quality signalers (Conolly, 2017). The requisite chronological data, however, are currently not available to test this prediction.

The spatio-temporal Bayesian results in Figure 6.20 suggest that the highest probability of contemporaneous monument construction appears to be between ca. AD 1600-1700. Based on paleoenvironmental analyses of lake cores from Rano Kau and

Rano Raraku, the period between ca. AD 1570-1720 is thought to be the time of an intense drought on the island (Cañellas-Boltà et al., 2013). Rull and colleagues (e.g., 2020b, 2016; Rull et al., 2018) have recently claimed that this drought caused a large-scale intra-island migration from coastal settlements to the crater lake at Rano Kau, with the assumption being that Rano Kau provided the only viable freshwater source. The results presented here seem to falsify this hypothesis, as settlement and ritual activity in coastal areas is demonstrably consistent across Rapa Nui culture history (see also, e.g., McCoy, 1976; Morrison, 2012; Mulrooney, 2013b; Stevenson et al., 2015; Vargas et al., 2006). However, the timing of this drought period is interesting given that it co-occurs with the highest probabilities of contemporaneous signaling at different communities. Recent climatic conditions on Rapa Nui highlight the impact of droughts on the island's hydrogeology. Rapa Nui has recently been experiencing a prolonged drought since 2018, and one effect of this has been the drying of the crater lakes, yet the main coastal groundwater sources used in pre-contact times remain viable. Figure 6.22 shows the crater lake at Rano Raraku in May 2019, and Figure 6.23 shows a thermal image of an active coastal freshwater seep at Vaihu, where cooler water indicates abundant seeping groundwater. The salinity of this seep at Vaihu was measured with a Vernier salinity probe to be just slightly saltier than freshwater, and we measured several other locations on the island that had active coastal seeps at this time. This indicates that prolonged droughts likely first impact the availability of lake water while discharge from the island's groundwater aquifer remains active.

Figure 6.22: The crater lake at Rano Raraku completely dry in May 2019.

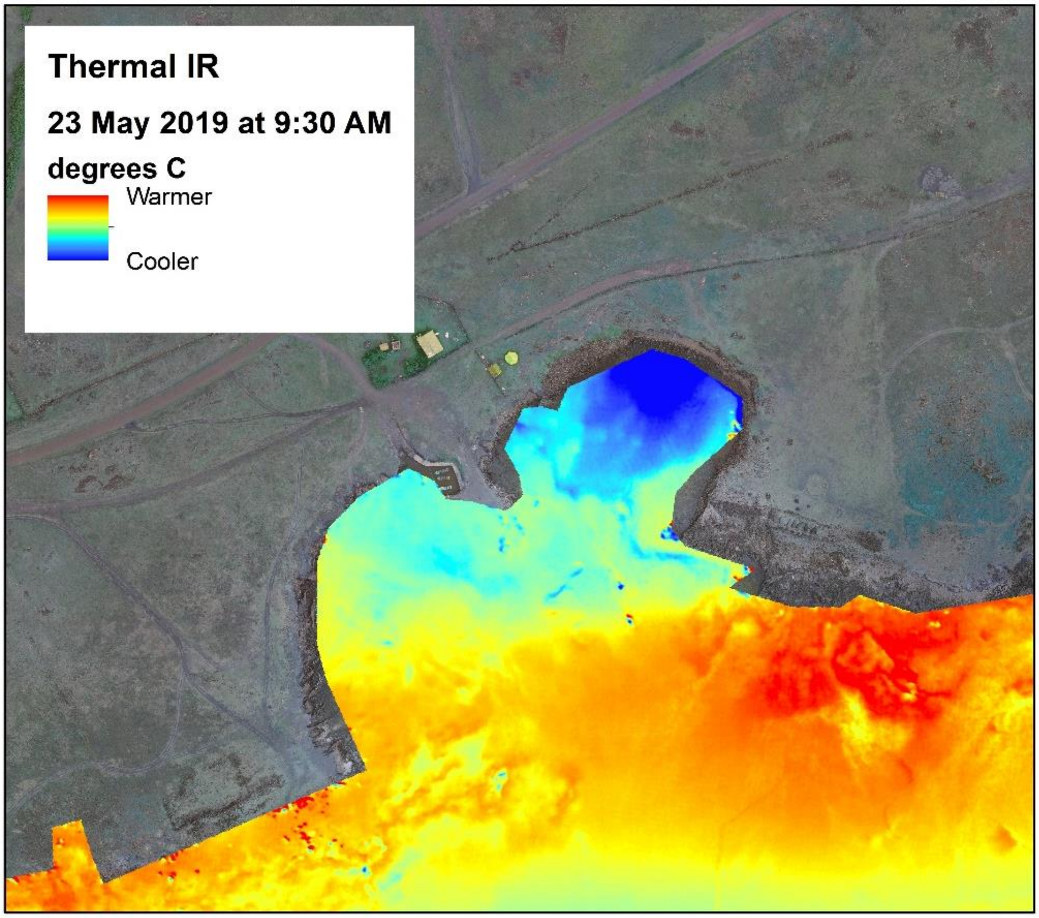

Figure 6.23: Thermal infrared image of an active coastal groundwater seep at Hanga Te'e in May 2019. Ahu Tarakiu and Ahu Vaihu can be seen the lower right and left of the image. Image created by Tim DeSmet.

These findings are significant as they suggest that, if the islands hydrogeology has remained similar in the last few centuries (e.g., Brosnan et al., 2019; DiNapoli et al., 2019; Hixon et al., 2019), then the prolonged pre-contact drought may have made the coastal groundwater sources even more important—and this is precisely the time when we see the highest probability of contemporaneous monument construction. This suggests that signaling was most intense between communities at a time when competition over freshwater was likely the highest. Coupled with the island's already marginal and unpredictable environment (DiNapoli et al., 2018; Morrison, 2012), times of increased resource stress would have made intra-group cooperation vital to community longevity. While there does not appear to be a strong spatial relationship between investment in monuments and cultivated resources, this prolonged drought would have also led to reduced and unpredictable yields from rain-fed agriculture (e.g., Louwagie et al., 2006; Morrison, 2012). As Wandsnider (2015, p. 81) predicts, signaling would be most important during exactly these kinds of stressful situations where individuals can broadcast their prosociality within the group as well as collective action to other communities with whom they compete for limited resources. With this island-wide reduction in available surface water and crop yields, the communal activities centered around *ahu*, such as information sharing, pooling of resources, and ritual practices, would have been critical for community maintenance and longevity during times of resource stress (Hunt and Lipo, 2018, 2011; Wandsnider, 2015).

…

Religious monumental architecture is a widespread component of the archaeological record of many human societies. However, the ecological influences behind the emergence of monument construction remain poorly understood, which is currently a major limiting factor in our understanding of societal evolution. For example, why is it that in multiple independent times and places in world history, human cooperation, competition, communication, and religiosity manifest themselves as large architectural features (Neiman, 1997; Trigger, 1990)? CST potentially helps resolve this question in that monument construction helps solve cooperative and competitive issues inherent to in living in human groups (e.g., Gintis et al., 2001; Norenzayan et al., 2016; Norenzayan and Shariff, 2008; Smith and Bliege Bird, 2005; Sosis and Alcorta, 2003; Watson-Jones and Legare, 2016). While there have been a limited number of successful applications of CST to monumental architecture (e.g., De Souza et al., 2016; Glatz and Plourde, 2011; Kantner and Vaughn, 2012; Neiman, 1997; Roscoe, 2009; Wandsnider, 2015), assessing the general explanatory power of CST for the emergence and dynamics of monument construction requires additional archaeological case studies (Atran and Henrich, 2010; Conolly, 2017; Norenzayan et al., 2016).

From the perspective of comparing Rapa Nui to other places in East Polynesia, why do we see such intense and elaborated monumentality on this small, isolated, and ecologically marginal island (DiNapoli et al., 2018)? The CST model evaluated here provides support for the notion that monument construction on Rapa Nui is in part explained by multi-level cooperative and competitive signaling within and between communities. Importantly, the CST model aids in understanding and explaining several puzzling aspects of Rapa Nui culture history—its intensified monumentality centered around water sources, hyper-local settlement structure, and low incidence of lethal violence—under a coherent evolutionary ecological framework. This case study from

Rapa Nui can thus serve as a model for comparative, theoretically oriented studies elsewhere by showing how CST can help explain some of the factors underlying why humans build monumental architecture in both resource-rich and poor environments.

While several the central predictions of the CST model are supported, the results presented here also offer a number of hypotheses that should be tested with additional research. In particular, the current analysis has largely focused on patterns of monument construction on the eastern portion of Rapa Nui. Future studies should thus be focused on gathering additional data on freshwater sources from the western portion of the island to test whether this CST hypothesis is supported at an island-wide scale. In addition, reliable radiocarbon dates are only available for 11 *ahu* locations and therefore many of the chronological interpretations presented here should be treated as hypotheses in need of future testing. To evaluate the CST model, more radiocarbon dates from additional *ahu*, as well as multiple contexts within these features, are needed to further examine the patterns of monument construction events over time and space.

CHAPTER VII

CONCLUSIONS

In this dissertation, I have explored several of the hypothesized factors and consequences of monument construction on Rapa Nui (Easter Island). Rapa Nui provides one of the most surprising and highly debated cases of intensified monument construction in world history. The two most common views of the role of monument construction in Rapa Nui culture history are strongly opposed. On the one hand, there are those who assume that an unrestricted period of intensified *ahu* and *moai* construction led to warfare, monument destruction, and ‘collapse’ during a late pre-contact ‘Huri Moai’ period on Rapa Nui, asserted to be sometime between ca. AD 1500-1680 (e.g., Bahn and Flenley, 2017; Kirch, 2017; Kolb, 2020; Smith, 1961a; Wallin and Martinsson-Wallin, 2011). According to this ‘Huri Moai’ narrative, unchecked natural resource use for monument construction led to an ‘ecocide’ and the demise of Rapa Nui’s complex, hierarchical society, and the small-scale communities observed upon European arrival in AD 1722 were simply the remnants of a previously grander society and more prosperous island. As discussed throughout this dissertation, many aspects of this collapse hypothesis, however, have been refuted in recent years, leading others to propose an alternative model for Rapa Nui culture history. This new emerging model draws from a human behavioral ecology (HBE) model known as costly-signaling theory (CST) and proposes that monument construction was instead an adaptive response to the constrained environmental conditions on the island and a key factor in long-term community cooperation and non-violent competition (DiNapoli and Morrison, 2017; Hunt and Lipo, 2018, 2011; Morrison, 2012). In this dissertation, I have focused on empirically testing this CST hypothesis and critically evaluating some unresolved, but critical components of the Huri Moai narrative for Rapa Nui.

In Chapter 2, I introduced a comparative HBE approach for examining the divergent histories of East Polynesian societies in terms of the type and scale of cooperation and competition and their implications for social group formation. One of the most conspicuous and well recognized archaeological correlates of large-scale cooperation and competition in East Polynesia are the records of investment in monumental construction projects, specifically defensive fortifications and ceremonial sites (e.g., Cochrane, 2015; Field, 2008; Field and Lape, 2010; Graves and Ladefoged, 1995; Graves and Sweeney, 1993; Kirch, 1984b). Drawing from the insights of HBE, I argued that the varying level of investment and divergence in intensity of construction of these kinds of features are best explained as the outcome of similar forms of cooperation and competition in different kinds of environments. This discussion led to the formulation of a series of testable hypotheses for costly signaling on Rapa Nui, in particular that the locations and magnitude of investment in monuments be spatially associated with access to limited and contested subsistence resources.

Chapter 3 presented a series of spatially explicit statistical models designed to assess previous hypotheses about how Rapa Nui monument construction might be related to territorial competition over the island’s limited agricultural land, marine resources, or freshwater (e.g., Barber, 1996; Beardsley, 1996; Cauwe, 2016; Hunt and Lipo, 2018, 2011; Kirch, 2017, 1984b; Kolb, 2012; Martinsson-Wallin, 1994; McCoy, 1976; Sahlins, 1955; Shepardson, 2005; Simpson, 2009; Stevenson, 2002; Stevenson et al., 2006, 1999;

Van Tilburg, 1994; Wallin et al., 2005; Wallin and Martinsson-Wallin, 2011). Using point process modeling and multi-model selection, these results suggest that *ahu* construction locations are best explained by proximity to freshwater sources. These results indicate that if a costly signaling strategy provides a useful explanatory model for Rapa Nui monument construction, then the island's freshwater sources were likely an important focus of signaling both inter-community cooperation and inter-group competition. One limitation of this study is the lack of comprehensive freshwater data from the western cost of Rapa Nui, and, therefore, future studies should be directed at gathering additional data to test whether these patterns hold elsewhere on the island.

Chapter 4 presented a re-evaluation of the chronology of *ahu* construction over the course of Rapa Nui culture history as a means of evaluating core components of the Huri Moai narrative. Using all available radiocarbon dates from *ahu* contexts and a series of multi-phase Bayesian models, the results indicate that *ahu* construction began very soon after initial Polynesian settlement, perhaps within as little as 55 years, increased rapidly between ca. AD 1350-1450, and with a relatively steady rate of construction activities that continued beyond European arrival in AD 1722. While these Bayesian models are most clearly related to estimates for the construction of *ahu* components, the models also provide *termini post quos* estimates for the erection of *moai* and *pukao* at these sites, suggesting that statue carving and transport continued later than previously assumed as well (see also Sherwood et al., 2019; Simpson et al., 2018a). These results are significant as they suggest that a pre-contact 'collapse' of monument construction, a core component of the Huri Moai narrative (e.g., Bahn and Flenley, 2017; Kirch, 2017; Kolb, 2020; Smith, 1961a; Wallin and Martinsson-Wallin, 2011), did not occur but continued despite the disruptive impacts of European arrival. The analyses in this chapter also include revised Bayesian estimates for the timing of initial Polynesian settlement of the island, estimated to be sometime between *1150-1280 cal AD* (95.4% HPD), which bolsters previous estimates for a late colonization of Rapa Nui (Hunt and Lipo, 2006; Lipo and Hunt, 2016; Wilmshurst et al., 2011).

Chapter 5 presented a critical reevaluation of the Huri Moai phase through a comprehensive review of all the available archaeological and ethnohistoric evidence for warfare and monument destruction. Drawing on the insights from the revised *ahu* chronology presented in Chapter 4 as well as ethnohistoric accounts, I concluded that there is currently no unambiguous evidence for a cessation of *ahu* or *moai* construction prior to European arrival, but that the sequence of '*moai* toppling' is an entirely post-contact phenomenon that is likely explained by a number of factors. As reviewed in this chapter, the available archaeological, osteological, and ethnohistorical data provide little support for the notion that lethal violence or warfare were widespread at any point in Rapa Nui's past, suggesting that the expectations of the pre-contact Huri Moai narrative are not empirically supported. While there are a number of oral traditions of inter-community warfare, these are argued to be more recent in origin, likely post-dating the disease epidemics, slave-raids, and arrivals of missionaries in the late 19th century (e.g., Fischer, 2005; Maude, 1981).

Given the tenuous evidence for this Huri Moai phase, one might ask how or why this narrative has been so persistent in scholarly work on Rapa Nui or popular media (e.g., Diamond, 2005) . A potential answer lies in the common theoretical approach to monumental architecture in Polynesia, where the overarching theme has been to view the record of monument construction as a material indicator of the dynamics in social stratification, with many archaeologists approaching this issue through the lens of the Spencerian neo-evolutionary (i.e., orthogenetic) framework, as some have pointed out (e.g., Graves and Ladefoged, 1995; Graves and Sweeney, 1993; Hunt and Lipo, 2001; see also Dunnell, 1980; Yoffee, 1993). As it has been applied in the Pacific, especially popularized by the work of Sahlins (1958, 1955), Goldman (1970), Kirch (2017, 2010, 1990a, 1984b), and Earle (1997, 1993; Earle and Spriggs, 2015), this neo-evolutionary approach is based on the assumption, sometimes tacit, that there is an innate tendency for societies to increase in organizational complexity from simple to complex (e.g., tribes→ simple to complex chiefdoms→ archaic states), which is driven by the agency of ambitious elites for more economic, political, and ideological power. In this way, the emergence and variability of investment in monuments is seen as a sign of rapid transformations from one societal type to another, or as evidence of the actions of elite individuals, such as chiefly competition and imposition of greater amounts of ritual, social, and resource control.

This dominant approach in Polynesian archaeology thus assumes that monuments, and in particular monument size and elaboration, are unambiguously correlated with social stratification and the agency of ambitious elites. While in some historical cases it is clear that the construction of large monuments was associated with powerful rulers, such as many *heiau* in Hawai‘i (e.g., Kirch, 2010), such examples should not be uncritically extended into other Polynesian cases studies that have not been substantiated with unambiguous archaeological or ethnohistoric data. Critically, because the place of monument construction within the transformation from simple to complex societies is axiomatic, the existence of large monuments in societies that were otherwise not so stratified upon European arrival can only be explained by ‘cultural regression,’ ‘devolution and decadence,’ ‘reversal of the universal trend,’ or ‘collapse.’ Rapa Nui, a relatively unstratified society at European contact by nearly all accounts, stands out in this regard, where the presence of hundreds of massive *ahu* and *moai* was a ‘mystery’ explicable only by the ‘devolution’ of a previously more complex society (e.g., Kirch, 2017, 1984b; Wallin and Martinsson-Wallin, 2011)[9]. In this way, the neo-evolutionary approach is pervasive throughout the Pacific in how cultural variability is explained and at times denied (e.g., Spriggs, 2008).

Together, the results presented in Chapters 4 and 5 cast considerable doubt on the validity of a late pre-contact ‘Huri Moai’ or ‘decadent’ period defined by warfare, monument destruction, and societal breakdown. Abandoning this Huri Moai narrative that assumes a more complex, warring society must have existed in past that then collapsed indicates that the current culture historical model for Rapa Nui needs substantial revision. One important implication of these chapters is that rather than being remnants of collapsed society, the peoples encountered and described by the first European visitors likely represent an accurate of reflection of late pre-contact Rapa Nui communities—relatively small-scale social groups dispersed around the island’s coastline centered around ceremonial *ahu* structures. An alternative view of Rapa Nui culture history, and one that better fits the available archaeological and ethnohistoric data, is that the characteristics of the so-called ‘Ahu Moai’ phase continued up to the point of

---

[9] Such thinking has also been applied to other regions in the Pacific (e.g., Clark and Martinsson-Wallin, 2007; Rainbird, 2006), such as the work of Sand (1996a, 1996b, 1996c), who in discussing monuments in New Caledonia, states that there must have been a more stratified society in the past that then collapsed.

European arrival. This revision of Rapa Nui's culture history requires a potential explanation for why this relatively small-scale, non-stratified, and apparently peaceable society invested so much time and energy in the construction of hundreds of megalithic *ahu* and *moai* over the course of several centuries.

Chapter 6 presented a test of a new emerging model of Rapa Nui culture history that explains the intensified patterns of monument construction as being the result of multi-level costly signaling within and between communities. This CST model proposes that monument construction served to foster intra-group cooperation and non-violent inter-group competition in the face of severe environmental and climatic conditions. The analyses in this chapter focused on modeling how the construction locations and costs of building *ahu* covary with landscape visibility and the distribution of critical and potentially contested subsistence resources. The results indicate that while *ahu* were not built in the most visible locations on the island, they were constructed in visible locations relative to close proximity to freshwater sources, which is interpreted as being the outcome of cooperative and territorial signaling over this limited yet critical resource. Variability in the costs of community-level investment in *ahu*, measured through photogrammetric estimates of construction stone volume, are also explained by access to freshwater sources. In areas with greater access to freshwater, we see greater investment in monumental architecture over time, consistent with the CST prediction that the magnitude of investment (i.e., cost) of the signal covaries with the underlying quality being communicated. One interpretation of this finding is that variability in investment in *ahu* construction served as a reliable index of the community's collective action potential to control and defend their limited resources. As discussed in Chapter 6, this interpretation provides a potential explanation for both the modular, or ‘hyper-local,’ organization of Rapa Nui communities and the overall lack of evidence for lethal violence.

In Chapter 6, I also introduced two Bayesian methods for characterizing the overall duration and spatio-temporal patterns of monumentality, which demonstrate relatively long and contemporaneous *ahu* construction activity at the various locations on the island, consistent with the predictions of the frequency-dependent nature of the costly signaling strategy. One important finding of these spatio-temporal models is that the period of greatest contemporaneous monument construction coincides with an intense period of drought on the island (e.g., Cañellas-Boltà et al., 2013; Rull, 2020b; Rull et al., 2018), suggesting that signaling was particularly beneficial during times of increased resource stress. One of the central limitations of this chapter is the lack of a large suite of reliable radiocarbon dates associated with monument construction. Future research should thus be focused on gathering additional radiocarbon dates associated with monument construction, which are critically needed to more thoroughly test the findings and hypotheses presented in this dissertation. Nevertheless, the results presented in Chapter 6 provide a series of model-based hypotheses for the dynamics of monument construction that may be tested or, importantly, falsified with additional research.

The approach I have outlined in the chapters of this dissertation might usefully serve as a template for future studies of monumentality elsewhere in the Pacific and the world more generally, specifically studies focused on the application of explicit HBE models designed to generate testable hypotheses about the distribution of monuments through time and space. CST, which sees monuments as fundamentally communicative phenomena designed to transmit otherwise unobservable information, such as competitive ability, social status, resource control, or other qualities, from signalers to receivers in ways that benefit both, provides a potentially productive model for Polynesian monument construction (DiNapoli and Morrison, 2017). CST makes several explicit predictions about the spatiotemporal occurrence and variability of investment in monuments that can be tested using archaeological data. For example, CST predicts that monuments be built in highly visible locations, in politically contested spaces or in times of increased competition, and that the magnitude of investment directly covaries with the hypothesized underlying quality being signaled, such as control of contested resources (e.g., Conolly, 2017; De Souza et al., 2016; Glatz and Plourde, 2011; Neiman, 1997; Quinn, 2019; Roscoe, 2009; Wandsnider, 2015). In addition, while CST hypotheses can be framed in terms of elite competition in appropriate cases (e.g., Neiman, 1997), this is not a necessary assumption and allows researchers to potentially explain why monumental architecture occurs in relatively non-hierarchical groups or how monument construction can provide benefits to the *communities* that constructed them by promoting prosocial behavior (e.g., Boone, 2000; De Souza et al., 2016; Kantner and Vaughn, 2012; Roscoe, 2009; Wandsnider, 2015). Moreover, CST is unique among evolutionary ecology models in that it can be explicitly linked to the religious nature of most monuments in Polynesia (Atran and Henrich, 2010; Henrich, 2009; Norenzayan et al., 2016; Sosis and Alcorta, 2003).

CST may hold potential for explaining the archaeology of Hawaiian *heiau*, for example, as numerous studies have shown that they tend to occur in highly visible locations near *ahupuaʻa* territorial boundaries and ‘sweet spots’ for intensive dry-land cultivation, and with many archaeologists asserting that these temples largely served a communicative function (e.g., Baer, 2016; Field et al., 2011, 2010; Kirch, 2007a, 1990a; Kolb, 1992; Kolb et al., 1994; M. McCoy, 2014; McCoy et al., 2011; Mulrooney and Ladefoged, 2005; Phillips et al., 2015). Some have also argued that the largest and most numerous *heiau* occur in the agriculturally risky and uncertain leeward areas (e.g., Graves and Ladefoged, 1995; Hunt and Lipo, 2001), suggesting their distribution may in part be explained by a response to competition in areas that frequently experienced resource stress. In addition, an expanded view of monuments beyond ceremonial architecture coupled with insights from CST may help us explain the occurrence of some large, non-fortified *pā* in New Zealand as community-level investments in features designed to communicate group-cohesion and competitive ability (e.g., Barber, 1996; McIvor, 2015; Sutton et al., 2003).

Monuments represent one of the most ubiquitous and intensively studied aspects of the archaeological record in Polynesia. Valuable knowledge has been gained through the accumulation of empirical data on the chronology, spatial patterns, and formal variability in these features. However, as pointed out some years ago (e.g., Graves and Ladefoged, 1995; Graves and Sweeney, 1993; Hunt and Lipo, 2001), and discussed above, the continued reliance on the neo-evolutionary paradigm, for Rapa Nui and elsewhere, has produced a suite of assumptions and narratives that at times fail to account for the great range of variability seen in Pacific Island societies. One way to approach explaining aspects of this variability is through the use of theoretical models, like those offered by HBE, to examine the divergence in Polynesian social dynamics as the outcome of similar strategies in different kinds of environments. To be clear, this discussion should not be misconstrued as suggesting that CST or other HBE models hold all the answers, but simply that they provide potentially useful explanations derived from well-established concepts in population ecology and game theory that are amenable to direct testing and falsification using archaeological data. I hope this dissertation serves as a useful example for these kinds of studies in the future.

APPENDIX A

SUPPLEMENTARY ANALYSES FOR CHAPTER III

R markdown for point process models

Load packages

Load the necessary R packages.

```
library(spatstat) #for point process modeling
library(maptools) #for handling spatial data
library(raster) #for handling spatial data
library(rgdal) #for handling spatial data
library(sp) #for handling spatial data
library(MuMIn) #for multi-model selection
```

Load and convert data

Import necessary shapefiles and rasters. Ensure that data files are in the current working directory.

```
ahu <- readShapeSpatial("ahu_clipped.shp")

water <- readShapeSpatial("water_clipped.shp")

survey_area <- readShapeSpatial("survey_area_corrected_proj.shp")

rock_mulch_dist <- raster("mulch_dens_100_dist_clipped.tif")
rock_mulch_med_dist <- raster("mulch_dens_med_100_dist_clipped.ti
f")
rock_mulch_max_dist <- raster("mulch_dens_max_100_dist_clipped.ti
f")
coast_dist <- raster("coast_dist_clipped.tif")
marine_poly <- readShapeSpatial("marine_res_poly_s_10_clipped.shp
")
```

Convert to formats interpretable by the spatstat package.

```
survey_win <- as.owin(survey_area)
ahu_pp <- ppp(ahu$POINT_X, ahu$POINT_Y, window=survey_win)
water_pp <- ppp(water$POINT_X, water$POINT_Y, window=survey_win)
```

```
## Warning: data contain duplicated points

water_pp <- unique(water_pp) #remove the small number of duplicat
es
mulch_dist <- as.im(rock_mulch_dist)
mulch_dist_med <- as.im(rock_mulch_med_dist)
mulch_dist_max <- as.im(rock_mulch_max_dist)
marine_res <- as.owin(marine_poly)
coast_dist <- as.im(coast_dist)
```

Create distance maps for freshwater and marine resources.

```
water_dist <- distmap(water_pp)
marine_dist <- as.im(distfun(marine_res), W=survey_win)
```

Exploratory analyses and tests

Test of hypothesis 1. Perform L-function test and Inhomogeneous L-function test for ahu against the null hypothesis of Complete Spatial Randomness (CSR) with 39 simulations (equivalent to p=0.05). This code creates Fig 3.

```
ahu_L <- envelope(ahu_pp, fun=Lest, nsim=39, fix.n=T, global=T)

ahu_Linhom <- envelope(ahu_pp, fun=Linhom, nsim=39, fix.n=T, glob
al=T)

#plot both, Fig 3.
par(mfrow=c(1,2))
plot(ahu_L, main="", xlab="r (meters)", ylim=c(0,3500), legend=F)
plot(ahu_Linhom, main="", xlab="r (meters)",ylim=c(0,3500), legen
d=F)

par(mfrow=c(1,1))
```

Perform spatial Kolmogorov-Smirnov tests for the relationship between ahu and distance from the minimal, medial, and maximimal rock mulch classifications, freshwater, and marine resources. Null hypothesis is CSR, alternative is that ahu are more closely spaced than random (i.e., "greater"). This code creates Fig 4 and includes results for the minimal and medial rock mulch classifications not presented in the main text.

```
#minimal rock mulch classification
ahu_mulch_cdf <- cdf.test(ahu_pp, mulch_dist, alternative="greate
r")
ahu_mulch_cdf

##
##  Spatial Kolmogorov-Smirnov test of CSR in two dimensions
```

```
##
## data:  covariate 'mulch_dist' evaluated at points of 'ahu_pp'
##      and transformed to uniform distribution under CSR
## D^+ = 0.082774, p-value = 0.2649
## alternative hypothesis: the CDF of x lies above the null hypot
hesis
```

```
plot(ahu_mulch_cdf, style="cdf", lwd=2, lwd0=2, do.legend=F,
     main="Spatial KS test of ahu & rock mulch", ylab="Probabilit
y", xlab="Distance to Rock Mulch")
```

```
#medial rock mulch classification
ahu_mulch_med_cdf <- cdf.test(ahu_pp, mulch_dist_med, alternative
="greater")
ahu_mulch_med_cdf
```

```
##
##  Spatial Kolmogorov-Smirnov test of CSR in two dimensions
##
## data:  covariate 'mulch_dist_med' evaluated at points of 'ahu_
pp'
##      and transformed to uniform distribution under CSR
## D^+ = 0.20369, p-value = 0.0003677
## alternative hypothesis: the CDF of x lies above the null hypot
hesis
```

```
plot(ahu_mulch_med_cdf, style="cdf", lwd=2, lwd0=2, do.legend=F,
     main="Spatial KS test of ahu & rock mulch medial classificat
ion", ylab="Probability", xlab="Distance to Rock Mulch")
```

```
#maximal rock mulch classification
ahu_mulch_max_cdf <- cdf.test(ahu_pp, mulch_dist_max, alternative
="greater")
ahu_mulch_max_cdf
```

```
##
##  Spatial Kolmogorov-Smirnov test of CSR in two dimensions
##
## data:  covariate 'mulch_dist_max' evaluated at points of 'ahu_
pp'
##      and transformed to uniform distribution under CSR
## D^+ = 0.2413, p-value = 1.494e-05
## alternative hypothesis: the CDF of x lies above the null hypot
hesis
```

```
plot(ahu_mulch_max_cdf, style="cdf", lwd=2, lwd0=2, do.legend=F,
     main="Spatial KS test of ahu & rock mulch maximal classifica
tion", ylab="Probability", xlab="Distance to Rock Mulch")
```

```
#freshwater
ahu_water_cdf <- cdf.test(ahu_pp, water_dist, alternative="greate
r")
ahu_water_cdf

##
##  Spatial Kolmogorov-Smirnov test of CSR in two dimensions
##
## data:  covariate 'water_dist' evaluated at points of 'ahu_pp'
##      and transformed to uniform distribution under CSR
## D^+ = 0.58982, p-value < 2.2e-16
## alternative hypothesis: the CDF of x lies above the null hypot
hesis

plot(ahu_water_cdf, style="cdf", lwd=2, lwd0=2, do.legend=F,
     main="SKS of ahu & freshwater", ylab="Probability", xlab="Di
stance to Freshwater")
```

```
#marine resources
ahu_marine_cdf <- cdf.test(ahu_pp, marine_dist, alternative="grea
ter")
ahu_marine_cdf

##
##  Spatial Kolmogorov-Smirnov test of CSR in two dimensions
##
## data:  covariate 'marine_dist' evaluated at points of 'ahu_pp'
##      and transformed to uniform distribution under CSR
## D^+ = 0.65478, p-value < 2.2e-16
## alternative hypothesis: the CDF of x lies above the null hypot
hesis

plot(ahu_marine_cdf, style="cdf", lwd=2, lwd0=2, do.legend=F,
     main="SKS of ahu & marine resources", ylab="Probability", xl
ab="Distance to marine resources")
```

```
#plot together with Euclidean distance maps, Fig 4.
par(mfrow=c(3, 2))
plot(mulch_dist_max, main="Distance to rock mulch")
```

```
plot(ahu_pp, pch=15, add=T)
plot(ahu_mulch_max_cdf, style="cdf", lwd=2, lwd0=2, do.legend=F,
     main="SKS of ahu & rock mulch", ylab="Probability", xlab="Di
stance to rock mulch")
plot(marine_dist, main="Distance to marine resources")
plot(ahu_pp, pch=15, add=T)
plot(ahu_marine_cdf, style="cdf", lwd=2, lwd0=2, do.legend=F,
     main="SKS of ahu & marine resources", ylab="Probability", xl
ab="Distance to marine resources")
plot(water_dist, main="Distance to freshwater")
plot(ahu_pp, pch=15, add=T)
plot(ahu_water_cdf, style="cdf", lwd=2, lwd0=2, do.legend=F,
     main="SKS of ahu & freshwater", ylab="Probability", xlab="Di
stance to Freshwater")

par(mfrow=c(1,1))
```

Point process models and multimodel selection

Build PPMS. See end of document for models with medial mulch classification.

```
model_1 <- ppm(ahu_pp, ~coast_dist)
model_2 <- ppm(ahu_pp, ~water_dist)
model_3 <- ppm(ahu_pp, ~marine_dist)
model_4 <- ppm(ahu_pp, ~mulch_dist_max)
model_5 <- ppm(ahu_pp, ~coast_dist+water_dist)
model_6 <- ppm(ahu_pp, ~coast_dist+marine_dist)
model_7 <- ppm(ahu_pp, ~coast_dist+mulch_dist_max)
model_8 <- ppm(ahu_pp, ~water_dist+marine_dist)
model_9 <- ppm(ahu_pp, ~water_dist+mulch_dist_max)
model_10 <- ppm(ahu_pp, ~marine_dist+mulch_dist_max)
model_11 <- ppm(ahu_pp, ~water_dist+marine_dist+mulch_dist_max)
model_12 <- ppm(ahu_pp, ~coast_dist+water_dist+marine_dist)
model_13 <- ppm(ahu_pp, ~coast_dist+water_dist+mulch_dist_max)
model_14 <- ppm(ahu_pp, ~coast_dist+marine_dist+mulch_dist_max)
model_15 <- ppm(ahu_pp, ~coast_dist+water_dist+marine_dist+mulch_
dist_max)
```

Perform BIC ad AIC tests to choose model with parameter set that maximizes the tradeoff between model fit and complexity. Lowest delta-BIC/AIC and highest weight value indicate the best fitting model. This code creates Table 1.

```
MS_AIC <- model.sel(model_1, model_2, model_3, model_4, model_5,
model_6, model_7, model_8,
                    model_9, model_10, model_11, model_12, model_
```

```
13, model_14, model_15, rank=AIC)
MS_AIC
```

```
## Model selection table
##                         trend df    logLik    AIC  delta weigh
t
## model_5               c_d+w_d  3 -1255.246 2516.5   0.00  0.35
0
## model_12          c_d+w_d+mr_d  4 -1254.310 2516.6   0.13  0.32
8
## model_15 c_d+w_d+mr_d+ml_d_mx  5 -1254.087 2518.2   1.68  0.15
1
## model_13      c_d+w_d+ml_d_mx  4 -1255.162 2518.3   1.83  0.14
0
## model_8              w_d+mr_d  3 -1257.999 2522.0   5.51  0.02
2
## model_11     w_d+mr_d+ml_d_mx  4 -1257.989 2524.0   7.49  0.00
8
## model_14     c_d+mr_d+ml_d_mx  4 -1270.418 2548.8  32.34  0.00
0
## model_7           c_d+ml_d_mx  3 -1272.887 2551.8  35.28  0.00
0
## model_10         mr_d+ml_d_mx  3 -1280.500 2567.0  50.51  0.00
0
## model_6              c_d+mr_d  3 -1281.200 2568.4  51.91  0.00
0
## model_1                   c_d  2 -1282.318 2568.6  52.14  0.00
0
## model_2                   w_d  2 -1284.824 2573.6  57.16  0.00
0
## model_9           w_d+ml_d_mx  3 -1284.716 2575.4  58.94  0.00
0
## model_3                  mr_d  2 -1288.190 2580.4  63.89  0.00
0
## model_4               ml_d_mx  2 -1373.108 2750.2 233.72  0.00
0
## Abbreviations:
## trend: c_d = '~coast_dist', c_d+mr_d = '~coast_dist+marine_dis
t',
##        c_d+mr_d+ml_d_mx = '~coast_dist+marine_dist+mulch_dist_
max',
##        c_d+ml_d_mx = '~coast_dist+mulch_dist_max',
##        c_d+w_d = '~coast_dist+water_dist',
##        c_d+w_d+mr_d = '~coast_dist+water_dist+marine_dist',
##        c_d+w_d+mr_d+ml_d_mx = '~coast_dist+water_dist+marine_d
ist+mulch_dist_max',
```

```
##        c_d+w_d+ml_d_mx = '~coast_dist+water_dist+mulch_dist_ma
x',
##        mr_d = '~marine_dist',
##        mr_d+ml_d_mx = '~marine_dist+mulch_dist_max',
##        ml_d_mx = '~mulch_dist_max', w_d = '~water_dist',
##        w_d+mr_d = '~water_dist+marine_dist',
##        w_d+mr_d+ml_d_mx = '~water_dist+marine_dist+mulch_dist_
max',
##        w_d+ml_d_mx = '~water_dist+mulch_dist_max'
## Models ranked by AIC(x)
```

```
MS_BIC <- model.sel(model_1, model_2, model_3, model_4, model_5,
model_6, model_7, model_8,
                    model_9, model_10, model_11, model_12, model_
13, model_14, model_15, rank=BIC)
MS_BIC
```

```
## Model selection table
##                         trend df    logLik    BIC  delta weigh
t
## model_5               c_d+w_d  3 -1255.246 2524.1   0.00  0.67
5
## model_12         c_d+w_d+mr_d  4 -1254.310 2526.8   2.66  0.17
8
## model_13      c_d+w_d+ml_d_mx  4 -1255.162 2528.5   4.36  0.07
6
## model_8              w_d+mr_d  3 -1257.999 2529.6   5.51  0.04
3
## model_15 c_d+w_d+mr_d+ml_d_mx  5 -1254.087 2530.8   6.75  0.02
3
## model_11     w_d+mr_d+ml_d_mx  4 -1257.989 2534.1  10.02  0.00
5
## model_14     c_d+mr_d+ml_d_mx  4 -1270.418 2559.0  34.88  0.00
0
## model_7           c_d+ml_d_mx  3 -1272.887 2559.4  35.28  0.00
0
## model_1                   c_d  2 -1282.318 2573.7  49.61  0.00
0
## model_10         mr_d+ml_d_mx  3 -1280.500 2574.6  50.51  0.00
0
## model_6              c_d+mr_d  3 -1281.200 2576.0  51.91  0.00
0
## model_2                   w_d  2 -1284.824 2578.7  54.62  0.00
0
## model_9           w_d+ml_d_mx  3 -1284.716 2583.0  58.94  0.00
0
```

```
## model_3                 mr_d  2 -1288.190 2585.4  61.36  0.00
0
## model_4               ml_d_mx  2 -1373.108 2755.3 231.19  0.00
0
## Abbreviations:
## trend: c_d = '~coast_dist', c_d+mr_d = '~coast_dist+marine_dis
t',
##        c_d+mr_d+ml_d_mx = '~coast_dist+marine_dist+mulch_dist_
max',
##        c_d+ml_d_mx = '~coast_dist+mulch_dist_max',
##        c_d+w_d = '~coast_dist+water_dist',
##        c_d+w_d+mr_d = '~coast_dist+water_dist+marine_dist',
##        c_d+w_d+mr_d+ml_d_mx = '~coast_dist+water_dist+marine_d
ist+mulch_dist_max',
##        c_d+w_d+ml_d_mx = '~coast_dist+water_dist+mulch_dist_ma
x',
##        mr_d = '~marine_dist',
##        mr_d+ml_d_mx = '~marine_dist+mulch_dist_max',
##        ml_d_mx = '~mulch_dist_max', w_d = '~water_dist',
##        w_d+mr_d = '~water_dist+marine_dist',
##        w_d+mr_d+ml_d_mx = '~water_dist+marine_dist+mulch_dist_
max',
##        w_d+ml_d_mx = '~water_dist+mulch_dist_max'
## Models ranked by BIC(x)
```

Both AIC and BIC indicate model_5 is the best fitting model. Inspect model_5 coefficient estimates, standard errors, confidence intervals, and significance levels. This code creates Table 2.

```
model_5
```

```
## Nonstationary Poisson process
##
## Log intensity:  ~coast_dist + water_dist
##
## Fitted trend coefficients:
##   (Intercept)    coast_dist    water_dist
## -11.239422092  -0.001206134  -0.002534973
##
##                    Estimate         S.E.       CI95.lo       CI9
5.hi Ztest
## (Intercept) -11.239422092 0.1604265848 -11.553852420 -1.092499
e+01   ***
## coast_dist   -0.001206134 0.0002560682  -0.001708018 -7.042493
e-04   ***
## water_dist   -0.002534973 0.0004228176  -0.003363680 -1.706265
```

```
e-03   ***
##                    Zval
## (Intercept) -70.059598
## coast_dist   -4.710205
## water_dist   -5.995428
```

Plot 'effect function' showing the relationship between the fitted intensity of ahu and distance from water sources. This code creates Fig 5.

```
plot(effectfun(model_5, "water_dist", coast_dist=0, se.fit=T), ma
in="", xlab="Distance to freshwater (m)", ylab="Ahu intensity (λ)
")
```

To further assess the fit of Model 5 and explore whether additional parameters are needed (such as second-order interpoint interaction), the following code executes a series of Monte Carlo-based goodness-of-fit tests: residual L-function (Manuscript Fig 6), maximum absolute deviation (MAD), and DCLF tests to assess the fit between model 2 and the ahu patterns. All Monte Carlo tests are ran with 39 simulated realizations of Model 5, which is equivalent to significance testing at p=0.05. Note that because these are randomized Monte Carlo tests, plots and/or resulting values may be slightly different than presented in the manuscript but the overall results will be the same.

```
L_fit1 <- envelope(model_5, Lest, nsim=39, global=T)

## Generating 78 simulated realisations of fitted Poisson model (
39 to
## estimate the mean and 39 to calculate envelopes) ...
## 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18,
19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 3
5, 36, 37, 38,
## 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54
, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70,
71, 72, 73, 74, 75, 76,
## 77,  78.
## 
## Done.

L_fit1

## Simultaneous critical envelopes for L(r)
## and observed value for 'model_5'
## Edge correction: "iso"
## Obtained from 39 simulations of fitted Poisson model
## Theoretical (i.e. null) mean value of L(r) estimated from a se
parate set
## of 39 simulations
## Alternative: two.sided
```

```
## Significance level of simultaneous Monte Carlo test: 1/40 = 0.
025
## .............................................................
##       Math.label     Description
## r     r              distance argument r
## obs   hat(L)[obs](r) observed value of L(r) for data pattern
## mmean bar(L)(r)      sample mean of L(r) from simulations
## lo    hat(L)[lo](r)  lower critical boundary for L(r)
## hi    hat(L)[hi](r)  upper critical boundary for L(r)
## .............................................................
## Default plot formula:  .~r
## where "." stands for 'obs', 'mmean', 'hi', 'lo'
## Columns 'lo' and 'hi' will be plotted as shading (by default)
## Recommended range of argument r: [0, 2956.1]
## Available range of argument r: [0, 2956.1]
```

```
plot(L_fit1, main="", legend=F)
```

```
MAD1 <- mad.test(model_5, Lest, nsim=39, fix.n=T, global=T, alter
native="two.sided", use.theo=F)
```

```
## Generating 78 simulated realisations of fitted Poisson model w
ith fixed
## number of points (39 to estimate the mean and 39 to calculate
envelopes)
## ...
## 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18,
19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 3
5, 36, 37, 38,
## 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54
, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70,
71, 72, 73, 74, 75, 76,
## 77,  78.
##
## Done.
```

```
MAD1
```

```
##
##  Maximum absolute deviation test of fitted Poisson model
##  Monte Carlo test based on 78 simulations with fixed number of
##  points
##  Summary function: L(r)
##  Reference function: sample mean
##  Alternative: two.sided
##  Interval of distance values: [0, 2956.11269360199]
##  Test statistic: Maximum absolute deviation
```

```
##  Deviation = leave-one-out
##
## data:  model_5
## mad = 171.91, rank = 17, p-value = 0.2152
```

```
DCLF1 <- dclf.test(model_5, Lest, nsim=39, fix.n=T, global=T, alt
ernative="two.sided", use.theo=F)
```

```
## Generating 78 simulated realisations of fitted Poisson model w
ith fixed
## number of points (39 to estimate the mean and 39 to calculate
envelopes)
## ...
## 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18,
19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 3
5, 36, 37, 38,
## 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54
, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70,
71, 72, 73, 74, 75, 76,
## 77,  78.
##
## Done.
```

```
DCLF1
```

```
##
##  Diggle-Cressie-Loosmore-Ford test of fitted Poisson model
##  Monte Carlo test based on 78 simulations with fixed number of
##  points
##  Summary function: L(r)
##  Reference function: sample mean
##  Alternative: two.sided
##  Interval of distance values: [0, 2956.11269360199]
##  Test statistic: Integral of squared absolute deviation
##  Deviation = leave-one-out
##
## data:  model_5
## u = 41528000, rank = 14, p-value = 0.1772
```

Generate 20 simulated realization of the model. (Manuscript Fig 7). Note that the simulated realizations of the model will always appear slightly different than those presented in the manuscript (due to the functioning of the Metropolos-Hasting algortithm), though the overall results will be the same.

```
ahu_model_sim <- simulate(model_5, nsim=20)
```

```
## Generating 20 simulated patterns ...1, 2, 3, 4, 5, 6, 7, 8, 9,
10, 11, 12, 13, 14, 15, 16, 17, 18, 19,  20.
```

```
plot(ahu_model_sim, main="", pch=16)
```

Models using the medial mulch classification from Ladefoged et al. 2013

```
med_model_1 <- ppm(ahu_pp, ~coast_dist)
med_model_2 <- ppm(ahu_pp, ~water_dist)
med_model_3 <- ppm(ahu_pp, ~marine_dist)
med_model_4 <- ppm(ahu_pp, ~mulch_dist_med)
med_model_5 <- ppm(ahu_pp, ~coast_dist+water_dist)
med_model_6 <- ppm(ahu_pp, ~coast_dist+marine_dist)
med_model_7 <- ppm(ahu_pp, ~coast_dist+mulch_dist_med)
med_model_8 <- ppm(ahu_pp, ~water_dist+marine_dist)
med_model_9 <- ppm(ahu_pp, ~water_dist+mulch_dist_med)
med_model_10 <- ppm(ahu_pp, ~marine_dist+mulch_dist_med)
med_model_11 <- ppm(ahu_pp, ~water_dist+marine_dist+mulch_dist_me
d)
med_model_12 <- ppm(ahu_pp, ~coast_dist+water_dist+marine_dist)
med_model_13 <- ppm(ahu_pp, ~coast_dist+water_dist+mulch_dist_med
)
med_model_14 <- ppm(ahu_pp, ~coast_dist+marine_dist+mulch_dist_me
d)
med_model_15 <- ppm(ahu_pp, ~coast_dist+water_dist+marine_dist+mu
lch_dist_med)
#model selection
med_MS_AIC <- model.sel(med_model_1, med_model_2, med_model_3, me
d_model_4, med_model_5, med_model_6, med_model_7, med_model_8,med
_model_9, med_model_10, med_model_11, med_model_12, med_model_13,
med_model_14, med_model_15, rank=AIC)
med_MS_AIC

## Model selection table
##                              trend df    logLik    AIC  delta w
eight
## med_model_5                c_d+w_d  3 -1255.246 2516.5   0.00
0.345
## med_model_12         c_d+w_d+mr_d  4 -1254.310 2516.6   0.13
0.324
## med_model_15 c_d+w_d+mr_d+ml_d_md  5 -1254.026 2518.1   1.56
0.158
## med_model_13      c_d+w_d+ml_d_md  4 -1255.134 2518.3   1.78
0.142
## med_model_8               w_d+mr_d  3 -1257.999 2522.0   5.51
0.022
## med_model_11     w_d+mr_d+ml_d_md  4 -1257.980 2524.0   7.47
0.008
## med_model_14     c_d+mr_d+ml_d_md  4 -1269.712 2547.4  30.93
```

```
0.000
## med_model_7          c_d+ml_d_md  3 -1272.335 2550.7  34.18
0.000
## med_model_10        mr_d+ml_d_md  3 -1280.032 2566.1  49.57
0.000
## med_model_6            c_d+mr_d  3 -1281.200 2568.4  51.91
0.000
## med_model_1                 c_d  2 -1282.318 2568.6  52.14
0.000
## med_model_2                 w_d  2 -1284.824 2573.6  57.16
0.000
## med_model_9         w_d+ml_d_md  3 -1284.456 2574.9  58.42
0.000
## med_model_3                mr_d  2 -1288.190 2580.4  63.89
0.000
## med_model_4             ml_d_md  2 -1372.625 2749.2 232.76
0.000
## Abbreviations:
## trend: c_d = '~coast_dist', c_d+mr_d = '~coast_dist+marine_dis
t',
##        c_d+mr_d+ml_d_md = '~coast_dist+marine_dist+mulch_dist_
med',
##        c_d+ml_d_md = '~coast_dist+mulch_dist_med',
##        c_d+w_d = '~coast_dist+water_dist',
##        c_d+w_d+mr_d = '~coast_dist+water_dist+marine_dist',
##        c_d+w_d+mr_d+ml_d_md = '~coast_dist+water_dist+marine_d
ist+mulch_dist_med',
##        c_d+w_d+ml_d_md = '~coast_dist+water_dist+mulch_dist_me
d',
##        mr_d = '~marine_dist',
##        mr_d+ml_d_md = '~marine_dist+mulch_dist_med',
##        ml_d_md = '~mulch_dist_med', w_d = '~water_dist',
##        w_d+mr_d = '~water_dist+marine_dist',
##        w_d+mr_d+ml_d_md = '~water_dist+marine_dist+mulch_dist_
med',
##        w_d+ml_d_md = '~water_dist+mulch_dist_med'
## Models ranked by AIC(x)
```

```
med_MS_BIC <- model.sel(med_model_1, med_model_2, med_model_3, me
d_model_4, med_model_5, med_model_6, med_model_7, med_model_8,med
_model_9, med_model_10, med_model_11, med_model_12, med_model_13,
med_model_14, med_model_15, rank=BIC)
med_MS_BIC
```

```
## Model selection table
##                             trend df    logLik    BIC  delta w
```

```
eight
## med_model_5                  c_d+w_d  3 -1255.246 2524.1   0.00
0.672
## med_model_12            c_d+w_d+mr_d  4 -1254.310 2526.8   2.66
0.178
## med_model_13         c_d+w_d+ml_d_md  4 -1255.134 2528.4   4.31
0.078
## med_model_8                 w_d+mr_d  3 -1257.999 2529.6   5.51
0.043
## med_model_15 c_d+w_d+mr_d+ml_d_md  5 -1254.026 2530.7   6.62
0.025
## med_model_11       w_d+mr_d+ml_d_md  4 -1257.980 2534.1  10.00
0.005
## med_model_14       c_d+mr_d+ml_d_md  4 -1269.712 2557.6  33.46
0.000
## med_model_7              c_d+ml_d_md  3 -1272.335 2558.3  34.18
0.000
## med_model_10            mr_d+ml_d_md  3 -1280.032 2573.7  49.57
0.000
## med_model_1                      c_d  2 -1282.318 2573.7  49.61
0.000
## med_model_6                 c_d+mr_d  3 -1281.200 2576.0  51.91
0.000
## med_model_2                      w_d  2 -1284.824 2578.7  54.62
0.000
## med_model_9              w_d+ml_d_md  3 -1284.456 2582.5  58.42
0.000
## med_model_3                     mr_d  2 -1288.190 2585.4  61.36
0.000
## med_model_4                  ml_d_md  2 -1372.625 2754.3 230.22
0.000
## Abbreviations:
## trend: c_d = '~coast_dist', c_d+mr_d = '~coast_dist+marine_dis
t',
##        c_d+mr_d+ml_d_md = '~coast_dist+marine_dist+mulch_dist_
med',
##        c_d+ml_d_md = '~coast_dist+mulch_dist_med',
##        c_d+w_d = '~coast_dist+water_dist',
##        c_d+w_d+mr_d = '~coast_dist+water_dist+marine_dist',
##        c_d+w_d+mr_d+ml_d_md = '~coast_dist+water_dist+marine_d
ist+mulch_dist_med',
##        c_d+w_d+ml_d_md = '~coast_dist+water_dist+mulch_dist_me
d',
##        mr_d = '~marine_dist',
##        mr_d+ml_d_md = '~marine_dist+mulch_dist_med',
##        ml_d_md = '~mulch_dist_med', w_d = '~water_dist',
```

```
##        w_d+mr_d = '~water_dist+marine_dist',
##        w_d+mr_d+ml_d_md = '~water_dist+marine_dist+mulch_dist_
med',
##        w_d+ml_d_md = '~water_dist+mulch_dist_med'
## Models ranked by BIC(x)
```

Marine resources sensitivity analysis with a 5m threshold

```
marine_poly_5m <- readShapeSpatial("marine_res_poly_s_5_clipped.shp")

marine_res_5m <- as.owin(marine_poly_5m)

marine_dist_5m <- as.im(distfun(marine_res_5m), W=survey_win) #clip to

survey window



plot(marine_dist_5m)

marine5m_model_1 <- ppm(ahu_pp, ~coast_dist)

marine5m_model_2 <- ppm(ahu_pp, ~water_dist)

marine5m_model_3 <- ppm(ahu_pp, ~marine_dist_5m)

marine5m_model_4 <- ppm(ahu_pp, ~mulch_dist_max)

marine5m_model_5 <- ppm(ahu_pp, ~coast_dist+water_dist)

marine5m_model_6 <- ppm(ahu_pp, ~coast_dist+marine_dist_5m)

marine5m_model_7 <- ppm(ahu_pp, ~coast_dist+mulch_dist_max)

marine5m_model_8 <- ppm(ahu_pp, ~water_dist+marine_dist_5m)

marine5m_model_9 <- ppm(ahu_pp, ~water_dist+mulch_dist_max)

marine5m_model_10 <- ppm(ahu_pp, ~marine_dist_5m+mulch_dist_max)

marine5m_model_11 <- ppm(ahu_pp, ~water_dist+marine_dist_5m+mulch_dist_

max)

marine5m_model_12 <- ppm(ahu_pp, ~coast_dist+water_dist+marine_dist_5m)

marine5m_model_13 <- ppm(ahu_pp, ~coast_dist+water_dist+mulch_dist_max)
```

```
marine5m_model_14 <- ppm(ahu_pp, ~coast_dist+marine_dist_5m+mulch_dist_
max)
marine5m_model_15 <- ppm(ahu_pp, ~coast_dist+water_dist+marine_dist_5m+
mulch_dist_max)



marine5m_MS_AIC <- model.sel(marine5m_model_1, marine5m_model_2, marine
5m_model_3, marine5m_model_4, marine5m_model_5,
                    marine5m_model_6, marine5m_model_7, marine5m_model_
8, marine5m_model_9, marine5m_model_10,
                    marine5m_model_11, marine5m_model_12, marine5m_mode
l_13, marine5m_model_14, marine5m_model_15, rank=AIC)
marine5m_MS_AIC
```

```
## Model selection table
##                                    trend df    logLik    AIC  delta
weight
## marine5m_model_5                 c_d+w_d  3 -1255.246 2516.5   0.00
0.393
## marine5m_model_8              w_d+mr_d_5  3 -1256.079 2518.2   1.67
0.171
## marine5m_model_13        c_d+w_d+ml_d_mx  4 -1255.162 2518.3   1.83
0.157
## marine5m_model_12         c_d+w_d+mr_d_5  4 -1255.198 2518.4   1.90
0.152
## marine5m_model_11     w_d+mr_d_5+ml_d_mx  4 -1256.043 2520.1   3.59
```

```
0.065
## marine5m_model_15 c_d+w_d+mr_d_5+ml_d_mx  5 -1255.096 2520.2   3.70
0.062
## marine5m_model_7             c_d+ml_d_mx  3 -1272.887 2551.8  35.28
0.000
## marine5m_model_14     c_d+mr_d_5+ml_d_mx  4 -1272.096 2552.2  35.70
0.000
## marine5m_model_10         mr_d_5+ml_d_mx  3 -1276.755 2559.5  43.02
0.000
## marine5m_model_1                     c_d  2 -1282.318 2568.6  52.14
0.000
## marine5m_model_6              c_d+mr_d_5  3 -1281.626 2569.3  52.76
0.000
## marine5m_model_2                     w_d  2 -1284.824 2573.6  57.16
0.000
## marine5m_model_9             w_d+ml_d_mx  3 -1284.716 2575.4  58.94
0.000
## marine5m_model_3                  mr_d_5  2 -1286.258 2576.5  60.02
0.000
## marine5m_model_4                 ml_d_mx  2 -1373.108 2750.2 233.72
0.000
## Abbreviations:
## trend: c_d = '~coast_dist', c_d+mr_d_5 = '~coast_dist+marine_dist_5m
',
##        c_d+mr_d_5+ml_d_mx = '~coast_dist+marine_dist_5m+mulch_dist_m
```

```
ax',
##         c_d+ml_d_mx = '~coast_dist+mulch_dist_max',
##         c_d+w_d = '~coast_dist+water_dist',
##         c_d+w_d+mr_d_5 = '~coast_dist+water_dist+marine_dist_5m',
##         c_d+w_d+mr_d_5+ml_d_mx = '~coast_dist+water_dist+marine_dist_
5m+mulch_dist_max',
##         c_d+w_d+ml_d_mx = '~coast_dist+water_dist+mulch_dist_max',
##         mr_d_5 = '~marine_dist_5m',
##         mr_d_5+ml_d_mx = '~marine_dist_5m+mulch_dist_max',
##         ml_d_mx = '~mulch_dist_max', w_d = '~water_dist',
##         w_d+mr_d_5 = '~water_dist+marine_dist_5m',
##         w_d+mr_d_5+ml_d_mx = '~water_dist+marine_dist_5m+mulch_dist_m
ax',
##         w_d+ml_d_mx = '~water_dist+mulch_dist_max'
## Models ranked by AIC(x)
```

```
marine5m_MS_BIC <- model.sel(marine5m_model_1, marine5m_model_2, marine
5m_model_3, marine5m_model_4, marine5m_model_5,
                    marine5m_model_6, marine5m_model_7, marine5m_model_
8, marine5m_model_9, marine5m_model_10,
                    marine5m_model_11, marine5m_model_12, marine5m_mode
l_13, marine5m_model_14, marine5m_model_15, rank=BIC)
marine5m_MS_BIC
```

```
## Model selection table
##                                      trend df    logLik    BIC  delta
weight
```

```
## marine5m_model_5                   c_d+w_d  3 -1255.246 2524.1   0.00
0.583
## marine5m_model_8                w_d+mr_d_5  3 -1256.079 2525.8   1.67
0.253
## marine5m_model_13        c_d+w_d+ml_d_mx  4 -1255.162 2528.5   4.36
0.066
## marine5m_model_12         c_d+w_d+mr_d_5  4 -1255.198 2528.5   4.44
0.063
## marine5m_model_11     w_d+mr_d_5+ml_d_mx  4 -1256.043 2530.2   6.13
0.027
## marine5m_model_15 c_d+w_d+mr_d_5+ml_d_mx  5 -1255.096 2532.9   8.76
0.007
## marine5m_model_7             c_d+ml_d_mx  3 -1272.887 2559.4  35.28
0.000
## marine5m_model_14     c_d+mr_d_5+ml_d_mx  4 -1272.096 2562.3  38.23
0.000
## marine5m_model_10         mr_d_5+ml_d_mx  3 -1276.755 2567.1  43.02
0.000
## marine5m_model_1                     c_d  2 -1282.318 2573.7  49.61
0.000
## marine5m_model_6              c_d+mr_d_5  3 -1281.626 2576.9  52.76
0.000
## marine5m_model_2                     w_d  2 -1284.824 2578.7  54.62
0.000
## marine5m_model_3                  mr_d_5  2 -1286.258 2581.6  57.49
```

```
0.000
## marine5m_model_9            w_d+ml_d_mx  3 -1284.716 2583.0  58.94
0.000
## marine5m_model_4                ml_d_mx  2 -1373.108 2755.3 231.19
0.000
## Abbreviations:
## trend: c_d = '~coast_dist', c_d+mr_d_5 = '~coast_dist+marine_dist_5m
',
##         c_d+mr_d_5+ml_d_mx = '~coast_dist+marine_dist_5m+mulch_dist_m
ax',
##         c_d+ml_d_mx = '~coast_dist+mulch_dist_max',
##         c_d+w_d = '~coast_dist+water_dist',
##         c_d+w_d+mr_d_5 = '~coast_dist+water_dist+marine_dist_5m',
##         c_d+w_d+mr_d_5+ml_d_mx = '~coast_dist+water_dist+marine_dist_
5m+mulch_dist_max',
##         c_d+w_d+ml_d_mx = '~coast_dist+water_dist+mulch_dist_max',
##         mr_d_5 = '~marine_dist_5m',
##         mr_d_5+ml_d_mx = '~marine_dist_5m+mulch_dist_max',
##         ml_d_mx = '~mulch_dist_max', w_d = '~water_dist',
##         w_d+mr_d_5 = '~water_dist+marine_dist_5m',
##         w_d+mr_d_5+ml_d_mx = '~water_dist+marine_dist_5m+mulch_dist_m
ax',
##         w_d+ml_d_mx = '~water_dist+mulch_dist_max'
## Models ranked by BIC(x)
```

APPENDIX B

SUPPLEMENTARY DATA AND ANALYSES FOR CHAPTER IV

Table B1: Radiocarbon determinations used in colonization models.

Lab ID	**CRA**	**Error**	**13C/12C**	**Sample Type**	**Notes**	**Location**	**Provenience**	**Source**
Short-lived plant remains								
Beta-209903	870	80	-23.8	Charcoal	Small twig	Anakena	Unit 5 Base	Hunt and Lipo 2006
Beta-209904	870	40	-23.8	Charcoal	Small twig	Anakena	Unit 5 Base	Hunt and Lipo 2006
SRR-2430	820	40	-21.2	Carbonized palm nut	rat-gnawed, *Jubaea* sp.	Poike (east) cave near Ana Ana Okeke	Floor of cave	Dransfield et al. 1984
KIA-17107	731	25	Not reported	Charred palm nut	Jubaea sp	Poike (east)	burnt layer	Mieth and Bork 2010
Beta-196716	720	60	-24.7	Charcoal	Small twig	Anakena	Unit 1 Layer 12	Hunt and Lipo 2006
Beta-196715	710	40	-22.5	Charcoal	Small twig	Anakena	Unit 1 Layer 11	Hunt and Lipo 2006
Beta-196712	680	60	-25.6	Charcoal	Small twig	Anakena	Unit 1 Layer 5	Hunt and Lipo 2006
Beta-196713	670	60	-24.8	Charcoal	Small twig	Anakena	Unit 1 Layer 8	Hunt and Lipo 2006

Beta-196711	660	40	-24.9	Charcoal	Small twig	Anakena	Unit 1 Layer 8	Hunt and Lipo 2006
High inbuilt age potential								
T-7346	810	70	not reported	Unidentified charcoal		Anakena, settlement east of Nau Nau	sample from Trench N Pit feature 25	Skjølsvold 1994
T-7345	810	80	not reported	Unidentified charcoal		Anakena, settlement east of Nau Nau	sample from bottom of Trench N	Skjølsvold 1994
KIA-18835	951	32	not reported	Charcoal	charred palm root, high inbuilt age potential	SW Poike	Charred palm root from burn layer	Mieth and Bork 2010
KIA-17569	659	33	not reported	Unidentified charcoal		West of Rano Raraku	charred wood from burn layer	Mieth and Bork 2010
KIA-17110	654	22	not reported	Unidentified charcoal		SW Poike	Agricultural site	Mieth et al. 2002, Mulrooney 2013
Beta-47281	760	80	not reported	Unidentified charcoal		Poike	Poike ditch	Vargas et al. 2006
Beta-47173	860	100	-26.7	Unidentified charcoal		Anakena	Excavation 10 meters N of Nau Nau	Steadman et al. 1994

Beta-47171	660	80	-24.7	Unidentified charcoal	Anakena	Excavation 10 meters N of Nau Nau	Steadman et al. 1994
Beta-47170	900	60	-26.7	Unidentified charcoal	Anakena	Excavation 10 meters N of Nau Nau	Steadman et al. 1994
Beta-47169	900	80	-25.5	Unidentified charcoal	Anakena	Excavation 10 meters N of Nau Nau	Steadman et al. 1994
Beta-237462	670	40	not reported	Unidentified charcoal	Hiva Hiva	Site 15-233H, TU2	Stevenson et al. 2008
Beta-237459	840	40	not reported	Unidentified charcoal	Hiva Hiva	Site 15-68, TU105	Stevenson et al. 2008
Beta-199324	1110	40	not reported	Unidentified charcoal	Vaitea	Site 18-473G, Feature 20, TU1	Stevenson et al. 2007
Beta-144310	780	50	not reported	Unidentified charcoal	Maunga Puko Puhi	Site 20-52 Ext, Unit 1, F.6	Wozniak and Stevenson 2008
Beta-144308	740	40	not reported	Unidentified charcoal	Maunga Puko Puhi	CS2, F.3	Wozniak and Stevenson 2008
Beta-144307	840	40	not reported	Unidentified charcoal	Maunga Puko Puhi	CS4, Unit 2, F.3	Wozniak and Stevenson 2008
Beta-144306	790	80	not reported	Unidentified charcoal	Maunga Puko Puhi	CS4, Unit 2, F.1	Wozniak and Stevenson 2008
AZ-7	680	45	-27	Unidentified charcoal	Te Niu	Site 26-6c	Wozniak 2003

AZ-5	715	70	-28.5	Unidentified charcoal	Te Niu	Site 26-I0	Wozniak 2003

Table B2. Radiocarbon determinations used in *ahu* Bayesian models

Ahu_name	Lab_code	CRA	Error	c13	Sample_type	Material_dated	Delta_R	Calculated marine component	Provenience	Dated event ~ target event	Included in ahu model?	Notes	Reference
Akivi	M-1370	425	100	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from below south wing	pre-dates wing, post-dates platform	yes	"recovered from the surface on which the first construction phase south wing mantle was built and should be contemporaneous with its construction" (Mulloy and Figueroa 1978:119)	Crane and Griffith 1965:146; Mulloy and Figueroa 1978:118-121; Martinsson-Wallin and Crockford 2002
Akivi	M-1371	350	100	Not reported	Mixed	bone - human and wood charcoal	"-83 ± 34"	NA	Sample from crematorium 1, bottom of bone deposit in cyst g	post-dates platform construction, dates crematorium construciton	no: bulk sample		Crane and Griffith 1965:146; Mulloy and Figueroa 1978:118-121, 178, Fig20; Martinsson-Wallin and Crockford 2002
Akivi	M-1374	580	100	Not reported	Mixed	bone - human and wood charcoal	"-83 ± 34"	NA	Sample from crematorium 1, at top of bone deposit between	post-dates platform construction, dates crematorium construciton	no: bulk sample		Crane and Griffith 1965:146; Mulloy and Figueroa 1978:118-121, 178, Fig20;

									cyst f and central platform wall				Martinsson-Wallin and Crockford 2002
Akivi	I-456	460	75	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from filled aroyo under south wing	pre-dates platform construction	yes	"recovered from the bottom of the natural arroyo under the south wing should date the refilling required to level the surface before the south wing, and by extension the rest of the structure, could be built" (Mulloy and Figueroa 1978:119)	Mulloy and Figueroa 1978:118-121; Martinsson-Wallin and Crockford 2002
Akivi	TBN-348-1	2216	96	Not reported	Terrestrial	Unidentified charcoal	NA	NA	ramp pavement	unclear	no: rejected by authors	noted as 'questionable date' by Martinsson-Wallin and Crockford 2002, Rejected by Mulloy and Figueroa 1978	Martinsson-Wallin and Crockford 2002

Ature Huki	T-7979	510	80	-26.1	Terrestrial	Unidentified charcoal	NA	NA	Sample from trench behind platform wall, sample from charcoal lens stratigraphically pre-dating platform wall	pre-dates platform construction	yes	Martinsson-Wallin and Crockford 2002 present very different provenience information from the primary source	Skjølsvold 1994: 86-87, 106, fig. 11, 77
Ature Huki	Ua-1144	580	85	-25	Terrestrial	Unidentified charcoal	NA	NA	Sample from trench within ramp/plaza, sample from underneath pavement within ramp fill	dates ramp, pre-dates plaza, post-dates platform	yes	Martinsson-Wallin and Crockford 2002 present very different provenience information from the primary source	Skjølsvold 1994: 85-87, 106, fig. 11, 76
Heki'I 1	Ua-11700	705	45	-22.2	Terrestrial	Carbonized nutshell	NA	NA	Trench 1, under plaza/ramp pavement directly in front of central platform, sample taken from "a small partly stone-lined fireplace"	Dates before ramp/plaza construction. Likely pre-dates platform construction.	yes		Martinsson-Wallin 1998:172; Martinsson-Wallin and Crockford 2002; Wallin and Martinsson-Wallin 2008
Heki'I 1	Ua-11701	700	45	-23.88	Terrestrial	Carbonized nutshell	NA	NA	Trench 2, sample from pit feature at same level as foundation stones of plaza wall	Possibly dates construction of plaza pavement?	no: likely residual material in pit fill		Martinsson-Wallin 1998:172; Martinsson-Wallin and Crockford 2002; Wallin and

												Martinsson-Wallin 2008
Heki'I 1	Ua-11702	465	45	-22.77	Terrestrial	Carbonized nutshell	NA	NA	Trench 2, southwestern edge of ahu, sample taken from charcoal concentration 10cm below foundation stones of plaza wall	Predates construction of SW wall of plaza, which is relatively younger than the central platform. Likely dates later construction phase.	yes	Martinsson-Wallin 1998:172; Martinsson-Wallin and Crockford 2002; Wallin and Martinsson-Wallin 2008
Heki'I 1	Ua-11703	555	50	-22.17	Terrestrial	Carbonized nutshell	NA	NA	Trench 2, sample taken from bottom of the cultural layer preceding Ua-11702	Predates construction of SW wall of plaza, which is relatively younger than the central platform. Likely dates later construction phase.	yes	Martinsson-Wallin 1998:172; Martinsson-Wallin and Crockford 2002; Wallin and Martinsson-Wallin 2008
Viri o Tuki	Beta-155732	610	60	Not reported	Terrestrial	Carbonized nutshell	NA	NA	'found in close relationship with the annex structure (both on the inside and outside).'	unlcear	no: insufficient provenience information	Huyge and Cauwe 2005

Viri o Tuki	Beta-155733	595	65	Not reported	Terrestrial	Carbonized nutshell	NA	NA	'found in close relationship with the annex structure (both on the inside and outside).'	unclear	no: insufficient provenience information	Huyge and Cauwe 2005
Viri o Tuki	GrA-25870	640	35	Not reported	Terrestrial	Carbonized nutshell	NA	NA	'found in close relationship with the annex structure (both on the inside and outside).'	unclear	no: insufficient provenience information	Huyge and Cauwe 2005
Viri o Tuki	GrA-25872	410	35	Not reported	Terrestrial	Unidentified charcoal	NA	NA	from hearth feature in layer post-dating the ahu	post-dates ahu construction	no: unclear relationship with any target events, not enough other usable dates from site	Huyge and Cauwe 2006
Motu Toremo Hiva	KIA-26452	675	20	Not reported	Terrestial	Unidentified charcoal	NA	NA	Sample taken from platform fill	dates platform construction	yes	Cauwe et al. 2006: 33; Cauwe et al. 2010: 52; Fig. 9
Motu Toremo Hiva	KIA-26453	675	25	Not reported	Terrestial	Unidentified charcoal	NA	NA	Sample from beneath platform foundation stones	pre-dates platform construction	yes	Cauwe et al. 2006; ; Cauwe et al. 2010: 52

Motu Toremo Hiva	KIA-26461	630	25	Not reported	Terrestial	Unidentified charcoal	NA	NA	sample taken from base of platform fill	dates platform construction	yes	Cauwe et al. 2006: 33; Cauwe et al. 2010: 52, Fig. 9
Motu Toremo Hiva	KIA-26464	700	25	Not reported	Terrestial	Unidentified charcoal	NA	NA	Sample from beneath platform foundation stones	pre-dates platform construction	yes	Cauwe et al. 2006; ; Cauwe et al. 2010: 52
Motu Toremo Hiva	KIA-26483	150	20	Not reported	Mixed	Bone - human	"-83 ± 34"	NA	Sample taken from Burial feature found in trench 2 with "inhumation posterior to use of" ahu.	post-dates platform construction	no: outlier	Cauwe et al. 2006: 33; Cauwe et al. 2010: 52
Motu Toremo Hiva	KIA-29812	630	25	Not reported	Terrestial	Unidentified charcoal	NA	NA	Sample from beneath platform foundation stones	pre-dates platform construction	yes	Cauwe et al. 2006; ; Cauwe et al. 2010: 52
Motu Toremo Hiva	KIA-29813	610	25	Not reported	Terrestial	Unidentified charcoal	NA	NA	Sample taken from platform fill	dates platform construction	yes	Cauwe et al. 2010: 52, Fig. 9
Motu Toremo Hiva	KIA-26487	240	20	Not reported	Terrestial	Unidentified charcoal	NA	NA	Sample from west posthole stratigraphically associated with ramp	dates ramp construction	yes	Cauwe et al. 2010: 52
Motu Toremo Hiva	KIA-29814	325	25	Not reported	Terrestial	Unidentified charcoal	NA	NA	Sample from west posthole stratigraphically associated with ramp	dates ramp construction	yes	Cauwe et al. 2010: 52

Nau Nau	UG-20801	490	25		Mixed	Human rib	"-83 ± 34"	38.4	Trench K behind seawall right under petroglyphs and associated with crematorium; 120-140 cmbs.	unclear	no: upper portion of deposit is heavily mixed, unclear association with platform construction	Sample RN035 in Jarman et al. 2017	Jarman et al. 2017, Catrine Jarman personal communication; Skjoslvold 1994: 54-56
Nau Nau	UG-20802	440	25		Mixed	Human rib	"-83 ± 34"	56.4	Trench K behind seawall right under petroglyphs and associated with crematorium, 40-60 cmbs	unclear	no: upper portion of deposit is heavily mixed, unclear association with platform construction	Sample RN035 in Jarman et al. 2017	Jarman et al. 2017, Catrine Jarman personal communication; Skjoslvold 1994: 54-56
Nau Nau	UG-20803	110	25		Mixed	Human rib	"-83 ± 34"	49.4	Trench K behind seawall right under petroglyphs and associated with crematorium, 60-80 cmbs	unclear	no: upper portion of deposit is heavily mixed, unclear association with platform construction	Sample RN035 in Jarman et al. 2017	Jarman et al. 2017, Catrine Jarman personal communication; Skjoslvold 1994: 54-56
Nau Nau	T-6678	860	130	-26.1	Terrestrial	Unidentified charcoal	NA	NA	Trench C1, Sample from the	Dates plaza construction	yes	Mulrooney 2013 says this is a bone sample but	Martinsson-Wallin and Crockford 2002; Wallin et al.

									early plaza fill, plaza floor upper			Skjoslvold 1994: 106 says unid. Charcoal	2010; Skjoslvold 1994:25, 106
Nau Nau	T-7342	710	70	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Trench C1, Sample from top of the early plaza floor, plaza floor upper	Dates plaza construction	yes		Martinsson-Wallin and Crockford 2002; Wallin et al. 2010; Skjoslvold 1994:25, 106
Nau Nau	Ua-4626	710	75	-17.3	Mixed	Bone - Rattus exulans	"-83 ± 34"	NA	Sample from bottom of Trench C1 dark brown layer beneath plaza	pre-dates ahu	yes		Martinsson-Wallin and Crockford 2002; Wallin et al. 2010:38-39
Nau Nau	Ua-34183	535	35	Not reported	Terrestrial	Carbonized nutshell	NA	NA	Sample from Trench C1 beneath green clay lens layer atop plaza floor and adjacent to plaza pavement	Post-dates plaza construction	yes		Wallin et al. 2010:42-43
Nau Nau	Ua-34184	640	65	Not reported	Mixed	Bone - Rattus exulans	"-83 ± 34"	NA	Sample Trench C1 from beneath green clay lens layer atop plaza floor and adjacent to plaza pavement	Post-dates plaza construction	yes		Wallin et al. 2010:42-43
Nau Nau	Ua-34185	610	50	Not reported	Mixed	Bone - Rattus exulans	"-83 ± 34"	NA	Sample from Trench C1 from	Dates plaza construction	yes		Wallin et al. 2010:42-43

									within plaza floor cobbles				
Nau Nau	Ua-34186	555	35	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from Trench C1, top of brown sand layer beneath plaza	pre-dates ahu	yes		Wallin et al. 2010
Nau Nau	Ua-34187	915	60	Not reported	Mixed	Bone - Rattus exulans	"-83 ± 34"	NA	Sample from Trench C1, bottom of brown sand layer beneath plaza	pre-dates ahu	no: outlier		Wallin et al. 2010
Nau Nau	Ua-34188	655	30	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from Trench C1, bottom of brown sand layer beneath plaza	pre-dates ahu	yes		Wallin et al. 2010
Nau Nau	Ua-34189	565	35	Not reported	Terrestrial	Carbonized nutshell	NA	NA	Sample from Trench C1, top of dark brown layer beneath plaza	pre-dates ahu	yes		Wallin et al. 2010
Nau Nau	Ua-34190	665	35	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from Trench C1, top of dark brown layer beneath plaza	pre-dates ahu	yes		Wallin et al. 2010
Nau Nau	Ua-34191	565	35	Not reported	Terrestrial	Carbonized nutshell	NA	NA	Sample from Trench C1, bottom of dark brown layer beneath plaza	pre-dates ahu	yes		Wallin et al. 2010

Nau Nau	Ua-1740	1290	100	-21	Marine?	Bone - aquatic bird	Unclear	NA	Sample from Trench C1, bottom of dark brown layer beneath plaza	Pre-dates plaza, but unclear how to calibrate this sample	no: uncertain calibration		Skjoslvold 1994:26, 106; Wallin et al. 2010
Nau Nau	Ua-3007	1015	65	-21	Mixed	Bone - Rattus exulans	"-83 ± 34"	NA	Sample from Trench C1, bottom of dark brown layer beneath plaza	pre-dates ahu	no: outlier		Skjoslvold 1994:26, 106; Wallin et al. 2010
Nau Nau	T-6679	1170	140	-26.1	Terrestrial	Unidentified charcoal	NA	NA	Sample from Trench C1, bottom of dark brown layer beneath plaza	pre-dates ahu	yes		Skjoslvold 1994:26, 106; Wallin et al. 2010
Nau Nau	T-7341	900	120	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from Trench C1, bottom of dark brown layer beneath plaza	pre-dates ahu	yes		Skjoslvold 1994:26, 106; Wallin et al. 2010
Nau Nau	T-7959	510	40	-26.1	Terrestrial	Unidentified charcoal	NA	NA	Sample from Trench C1, bottom of dark brown layer beneath plaza	pre-dates ahu	yes		Skjoslvold 1994:26, 106; Wallin et al. 2010
Nau Nau	T-7347	720	120	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from Trench B4 within second phase plaza floor	Dates plaza construction	yes		Martinsson-Wallin and Crockford 2002; Skjølsvold 1994:106; Wallin et al. 2010:37

Nau Nau	Ua-617	610	85	-2.5	Terrestrial	Unidentified charcoal	NA	NA	Sample from Trench C1 within final phase plaza fill	Dates plaza construction	yes	Martinsson-Wallin and Crockford 2002; Skjølsvold 1994:25, 106; Wallin et al. 2010:37
Nau Nau	T-7348	200	80	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from Trench B6	unclear association with ahu	no: unclear relationship to ahu platform	Skjølsvold 1994:106-107, fig. 11; Martinsson-Wallin and Crockford 2002
Nau Nau	T-7975	710	40	-26.1	Terrestrial	Unidentified charcoal	NA	NA	Sample from Trench D umu at bottom dark brown clayish soil cultural layer	pre-dates platform construction	yes	Skjølsvold 1994:106-107, fig. 11, 39, 40 Martinsson-Wallin and Crockford 2002
Nau Nau	T-7343	750	100	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from Bottom of Trench E	pre-dates platform construction	yes	Skjølsvold 1994:106-107, fig. 11, 43
Nau Nau	T-7344	600	140	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from upper portion of Trench E,	unclear	no: unclear relationship to ahu platform	Skjølsvold 1994:106-107, fig. 11, 43
Nau Nau	T-7349	550	150	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from Trench K, NE corner of platform wall, from 'dark brown, clayish	pre-dates platform construction	yes	Skjølsvold 1994:54, 106-107, fig. 11, 44

									soil' layer at bottom of unit				
Nau Nau	T-7350	710	80	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from Trench K, NE corner of platform wall, from 'dark brown, clayish soil' layer at bottom of unit	pre-dates platform construction	yes		Skjølsvold 1994:54, 106-107, fig. 11, 44
Nau Nau IV	T-7958	340	100	-26.1	Terrestrial	Unidentified charcoal	NA	NA	Sample from Trench U, bottom of stone fill	Dates platform construction	yes	Nau Nau IV is a separate structure from the main Nau Nau complex but is directly adjacent to the east wing, in relative terms it appears to post-date the main complex	Skjølsvold 1994:59, 106-107, fig. 11
Nau Nau IV	T-7976	220	80	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from Trench U, pavement	Dates construction of pavement	yes	Martinsson-Wallin and Crockford 2002 and Mulrooney 2013 report this as 789 +/- 90	Skjølsvold 1994:59, 106-107, fig. 11

NO 31-286	Ua-11704	795	50	-19.81	Terrestrial	Unidentified charcoal	NA	NA	Trench 4, directly adjacent to seawall, sample taken from undernearth foundation stones	pre-dates platform construction	no: insufficient number of samples from ahu	**Martinsson-Wallin 1998: 175;** Martinsson-Wallin and Crockford 2002
Structure 1 at Orongo	T-193	540	70	Not reported	Terrestrial	Unidentified charcoal	NA	NA	From fire pit adjacent to SW edge of the later construction phase.	fie pit has an unclear association with the main structure	no: unclear relationship to main structure	Ferdon 1961: 226-229, Fig. 62; Smith 1961; Martinsson-Wallin and Crockford 2002; Mulrooney 2013
Ra'ai	Ua-13163	135	60	-23.83	Terrestrial	Unidentified charcoal	NA	NA	Trench 2, Sample in the plaza pavement fill	dates construction of plaza/pavement, post-dates platform	yes	Martinsson-Wallin and Wallin 1998, 2000; Martinsson-Wallin and Crockford 2002; Wallin and Martinsson-Wallin 2008
Ra'ai	Ua-13164	515	60	-26.02	Terrestrial	Unidentified charcoal	NA	NA	Trench 5, Sample from crematorium	Dates crematorium, post-dates platform	yes	Martinsson-Wallin and Wallin 1998, 2000; Martinsson-Wallin and Crockford 2002; Wallin and

													Martinsson-Wallin 2008
Ra'ai	Ua-13165	570	50	-26.67	Terrestrial	Unidentified charcoal	NA	NA	Trench 6, sample from combustion feature in platform fill	dates construction of platform	yes		Martinsson-Wallin and Wallin 1998, 2000; Martinsson-Wallin and Crockford 2002; Wallin and Martinsson-Wallin 2008
Ra'ai	Ua-13166	635	50	-26.49	Terrestrial	Unidentified charcoal	NA	NA	Trench 7, Sample from fire feature under wing and central platform	pre-dates construction of wing and central platform	yes		Martinsson-Wallin and Wallin 1998, 2000; Martinsson-Wallin and Crockford 2002; Wallin and Martinsson-Wallin 2008
Ra'ai	Ua-13167	645	50	-21.73	Terrestrial	Unidentified charcoal	NA	NA	Trench 8, Sample from fire feature under wing and central platform	pre-dates construction of wing and central platform	yes		Martinsson-Wallin and Wallin 1998, 2000; Martinsson-Wallin and Crockford 2002; Wallin and Martinsson-Wallin 2008

Rongo 1	GrN-26318	715	35	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from crematorium	Dates crematorium, post-dates platform	yes		Huyge and Cauwe 2002:14-15; Martinsson-Wallin and Crockford 2002
Rongo 1	GrA-18378	655	30	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from 'immediately below some of the stone blocks, contstituting the southern wing'	pre-dates construction of wing	yes		Huyge and Cauwe 2002:14-15; Martinsson-Wallin and Crockford 2002
Rongo 1	GrA-18380	655	30	Not reported	Terrestrial	Unidentified charcoal	NA	NA	sample from immediately below stone of south wall	pre-dates platform construction	yes		Huyge and Cauwe 2002:14-15; Martinsson-Wallin and Crockford 2002
Te Niu	AZ-23	685	50	-22.3	Terrestrial	Unidentified charcoal	NA	NA	Unit 26-1-1, 89 cmbs, from charcoal lens beneath ramp	pre-dates ramp, stratigraphically pre-dates platform	yes		Wozniak 2003:303-304, Fig. 32, Fig. 48
Te Niu	AZ-25	650	40	-26.7	Terrestrial	Unidentified charcoal	NA	NA	Unit 26-1-1, 90 cmbs, from charcoal lens beneath ramp	pre-dates ramp, stratigraphically pre-dates platform	yes		Wozniak 2003:303-304, Fig. 32, Fig. 48
Te Niu	Beta-95878	700	90	-21	Terrestrial	Unidentified charcoal	NA	NA	Unit 26-1-1, 90 cmbs, from charcoal lens beneath ramp	pre-dates ramp, stratigraphically pre-dates platform	yes		Wozniak 2003:303-304, Fig. 32, Fig. 48

Te Niu	AZ-14	230	60	-10.3	Terrestrial	Unidentified charcoal	NA	NA	Unit 26-1-2, 172 cmbs, below poro ramp pavement	may pre- or post-date ramp, post-dates platform	yes		Wozniak 2003:304, 307, Fig. 50 & 51
Te Niu	AZ-22	325	40	-11	Terrestrial	Nut endocarp	NA	NA	Unit 26-1-2, 180 cmbs, atop poro ramp pavement	Post-dates ramp	yes		Wozniak 2003:304, 307, Fig. 50 & 51
Te Niu	Beta-106319	570	50	-27.3	Terrestrial	Unidentified charcoal	NA	NA	Unit 26-1-3, 90 cmbs, from under rear platform wall	pre-dates platform	yes		Wozniak 2003:304, Fig. 45
Te Niu	AZ-24	535	40	-26.3	Terrestrial	Unidentified charcoal	NA	NA	Unit 26-1-3W, 85 cmbs, behind ahu	unclear	no: insufficient provenience information		Wozniak 2003:290, 304, Fig. 45
Te Niu	AZ-28	555	40	-25.7	Terrestrial	Nut endocarp	NA	NA	Unit 26-1-4, 100 cmbs, under rear platform wall	pre-dates platform	yes		Wozniak 2003:304, Fig. 46
Te Niu	Beta-95879	230	90	-23.9	Terrestrial	Unidentified charcoal	NA	NA	Unit 26-1-4, 100 cmbs, sample from charcoal lens adjacent to rear platform wall	post-dates platform	yes		Wozniak 2003:304, Fig. 46
Te Niu	AZ-13	535	50	-21.7	Terrestrial	Unidentified charcoal	NA	NA	Unit 26-1-4, 130 cmbs, under rear platform wall	pre-dates platform	yes		Wozniak 2003:304, Fig. 46

Te Niu	AZ-20	380	45	-16.9	Mixed	Bone - Human	"-83 ± 34"	NA	Unit 26-1-6, 20 cmbs, sample from crematorium	dates crematorium, post-dates platform	yes		Wozniak 2003:304
Te Niu	AZ-8	375	45	-25.3	Terrestrial	Unidentified charcoal	NA	NA	Unit 26-1-6, 20 cmbs, sample from crematorium	dates crematorium, post-dates platform	yes		Wozniak 2003:304
Te Peu	RN-026/M-870	330	150		Mixed	Human phalanx	"-83 ± 34"	54.6	From a burial within the ahu	Post-dates platform construction	no: insufficient samples from ahu contexts		Jarman et al. 2017
Te Peu	M-732	1640	250	NA	Terrestrial	Totora reed burial wrapping	NA	NA			no: outlier	Noted as 'questionable date' by Martinsson-Wallin and Crockford 2002, see Smith 1961 rejects it	Martinsson-Wallin 1998:177; Martinsson-Wallin and Crockford 2002
Te Peu	Beta-155725	modern		Not reported	Terrestrial	Unidentified charcoal	NA	NA			no: modern		Mulrooney 2013
Te Peu	Beta-155726	modern		Not reported	Terrestrial	Unidentified charcoal	NA	NA			no: modern		Mulrooney 2013
Tautira	Ua-13161	220	50	-22.79	Terrestrial	Unidentified charcoal	NA	NA	Sample from late building phase	post-dates platform	yes		Martinsson-Wallin and Crockford 2002

Tautira	Ua-13162	720	50	-26.95	Terrestrial	Unidentified charcoal	NA	NA	sample from crematorium	post-dates platform	yes		Martinsson-Wallin and Crockford 2002
Tautira	Ua-13284	475	60	-15.76	Terrestrial	Unidentified charcoal	NA	NA	sample from under ahu	pre-dates platform	yes		Martinsson-Wallin and Crockford 2002
Vai Teka	I-455	340	75	Not reported	Terrestrial	Unidentified Charcoal	NA	NA	sample from pre-occupation, burned, surface stratum	pre-dates platform construction	yes	"sample recovered from an oxidized buried surface stratum underlying the site and the surrounding area. It stratigraphically antedates construction" (Mulloy and Figueroa 1978:120)	Mulloy and Figueroa 1978:118-121; Martinsson-Wallin and Crockford 2002
Vai Teka	M-1372	330	100	Not reported	Terrestrial	Unidentified Charcoal	NA	NA	Sample from bottom of firepit in center of manavai-like enclosure attached to the rear of the ahu	unclear association with manavai/platform	no: unclear association with platform		Crane and Griffith 1965:146; Mulloy and Figueroa 1978:118-121; Martinsson-Wallin and Crockford 2002

Vai Teka	TBN-348-2	399	76	Not reported	Terrestrial	Unidentified Charcoal	NA	NA	sample recovered from platform fill	dates platform construction	yes	"sample recovered from the *ahu* platform fill was undoubtedly deposited at the time of construction" (Mulloy and Figueroa 1978:118-121)	Mulloy and Figueroa 1978:118-121; Martinsson-Wallin and Crockford 2002
Vinapu 1	K-523	440	100	Not reported	Terrestrial	Unidentified Charcoal	NA	NA	Sample from charcoal lens within ramp fill	Dates ramp construction	no: insufficient samples from ahu contexts	"Charcoal from the surface of the Early Period mantel, probably a Middle Period date" (Smith 1961:394)	Mulloy 1961:99; Smith 1961:394
Vinapu 1	M-709	120	200	Not reported	Terrestrial	Unidentified Charcoal	NA	NA	Sample from fire feature underneath fallen statue and loose boulder atop ramp surface	Post-dates platform construction	no: insufficient samples from ahu contexts	"Charcoal found on the Middle Period mantle, under and adjacent to a fallen statue. The sample is regarded as earlier than the depisition of *some* of the stones in the Late Period mantle." (Smith 1961:394)	Mulloy 1961:97; Smith 1961:394

Vinapu 1	M-711	730	200	Not reported	Mixed	Bone - human	"-83 ± 34"	NA	sample from crematorium	Post-dates platform construction	no: insufficient samples from ahu contexts	Mulloy 1961:100; Smith 1961:394
Vinapu 2	Ua-19463	610	40	Not reported	Terrestrial	Carbonized nutshell	NA	NA	Sample from under embankment	pre-dates construction of embankment	no: unclear relationship to platform	Martinsson-Wallin 2004
Vinapu 2	Ua-19464	605	45	Not reported	Terrestrial	Carbonized nutshell	NA	NA	Sample from under embankment	pre-dates construction of embankment	no: unclear relationship to platform	Martinsson-Wallin 2004
Vinapu 2	T-5175	570	120	Not reported	Terrestrial	Charcoal and ash	NA	NA	sample from crematorium	Post-dates platform construction, but is a bulk sample	no: bulk sample	Martinsson-Wallin 1994: 79
Vinapu 2	M-710	1100	200	Not reported	Terrestrial	Unidentified charcoal	NA	NA	Sample from under embankment	pre-dates construction of embankment	no: unclear relationship to platform	Mulloy 1961: 118; Smith 1961:394

OxCal code for Bayesian models

Colonization model with short-lived plant remains

```
Plot()
 {
  Outlier_Model("General", T(5), U(0,4), "t");
  Curve("SHCal13","SHCal13.14c");
  Sequence("Rapa Nui Colonization")
  {
   Boundary("Start Colonization SL");
   Phase("Colonization")
   {
    R_Date("Beta-209903", 870, 80)
    {
     Outlier("General", 0.05);
    };
    R_Date("Beta-209904", 870, 40)
    {
     Outlier("General", 0.05);
    };
    R_Date("SRR-2430", 820, 40)
    {
     Outlier("General", 0.05);
    };
    R_Date("KIA-17107", 731, 25)
    {
     Outlier("General", 0.05);
    };
    R_Date("Beta-196716", 720, 60)
    {
     Outlier("General", 0.05);
    };
    R_Date("Beta-196715", 710, 40)
```

```
    {
     Outlier("General", 0.05);
    };
    R_Date("Beta-196712", 680, 60)
    {
     Outlier("General", 0.05);
    };
    R_Date("Beta-196713", 670, 60)
    {
     Outlier("General", 0.05);
    };
    R_Date("Beta-196711", 660, 40)
    {
     Outlier("General", 0.05);
    };
   };
   Boundary("End");
  };
 };
```

Colonization model with short-lived plant remains and unidentified charcoal

```
Plot()
 {
  Outlier_Model("General", T(5), U(0,4), "t");
  Outlier_Model("Charcoal", Exp(1,-10,0), U(0,3), "t");
  Curve("SHCal13","SHCal13.14c");
  Sequence("Rapa Nui Colonization")
  {
   Boundary("Start Colonization Outlier");
   Phase("Colonization")
   {
    R_Date("Beta-209903", 870, 80)
    {
     Outlier("General", 0.05);
```

```
};
R_Date("Beta-209904", 870, 40)
{
 Outlier("General", 0.05);
};
R_Date("SRR-2430", 820, 40)
{
 Outlier("General", 0.05);
};
R_Date("KIA-17107", 731, 25)
{
 Outlier("General", 0.05);
};
R_Date("Beta-196716", 720, 60)
{
 Outlier("General", 0.05);
};
R_Date("Beta-196715", 710, 40)
{
 Outlier("General", 0.05);
};
R_Date("Beta-196712", 680, 60)
{
 Outlier("General", 0.05);
};
R_Date("Beta-196713", 670, 60)
{
 Outlier("General", 0.05);
};
R_Date("Beta-196711", 660, 40)
{
 Outlier("General", 0.05);
};
```

```
R_Date("T-7346", 810, 70)
{
 Outlier("Charcoal", 1);
};
R_Date("T-7345", 810, 80)
{
 Outlier("Charcoal", 1);
};
R_Date("KIA-18835", 951, 32)
{
 Outlier("Charcoal", 1);
};
R_Date("KIA-17569", 659, 33)
{
 Outlier("Charcoal", 1);
};
R_Date("KIA-17110", 654, 22)
{
 Outlier("Charcoal", 1);
};
R_Date("Beta-47281", 760, 80)
{
 Outlier("Charcoal", 1);
};
R_Date("Beta-47173", 860, 100)
{
 Outlier("Charcoal", 1);
};
R_Date("Beta-47171", 660, 80)
{
 Outlier("Charcoal", 1);
};
R_Date("Beta-47170", 900, 60)
```

```
{
 Outlier("Charcoal", 1);
};
R_Date("Beta-47169", 900, 80)
{
 Outlier("Charcoal", 1);
};
R_Date("Beta-237462", 670, 40)
{
 Outlier("Charcoal", 1);
};
R_Date("Beta-237459", 840, 40)
{
 Outlier("Charcoal", 1);
};
R_Date("Beta-199324", 1110, 40)
{
 Outlier("Charcoal", 1);
};
R_Date("Beta-144310", 780, 50)
{
 Outlier("Charcoal", 1);
};
R_Date("Beta-144308", 740, 40)
{
 Outlier("Charcoal", 1);
};
R_Date("Beta-144307", 840, 40)
{
 Outlier("Charcoal", 1);
};
R_Date("Beta-144306", 790, 80)
{
```

```
     Outlier("Charcoal", 1);
    };
    R_Date("AZ-7", 680, 45)
    {
     Outlier("Charcoal", 1);
    };
    R_Date("AZ-5", 715, 70)
    {
     Outlier("Charcoal", 1);
    };
   };
   Boundary("End");
  };
 };
```

Ahu Ra‘ai

```
Plot()
 {
  Outlier_Model("Charcoal", Exp(1,-10,0), U(0,3), "t");
  Curve("SHCal13","SHCal13.14c");
  Sequence("Ra'ai")
  {
   After()
   {
    Prior("Start_Colonization","Start_Colonization.prior");
   };
   Boundary("Start TPQs");
   Phase("TPQ")
   {
    R_Date("Ua-13167", 645, 50)
    {
     Outlier("Charcoal", 1);
    };
    R_Date("Ua-13166", 635, 50)
```

```
    {
     Outlier("Charcoal", 1);
    };
   };
   Boundary("Start Ra'ai");
   Phase("Targets")
   {
    R_Date("Ua-13165", 570, 50)
    {
     Outlier("Charcoal", 1);
    };
   };
   Boundary("Start TAQs");
   Phase("TAQ")
   {
    R_Date("Ua-13164", 515, 60)
    {
     Outlier("Charcoal", 1);
    };
    R_Date("Ua-13163", 135, 60)
    {
     Outlier("Charcoal", 1);
    };
   };
   Boundary("End Ra'ai");
   Before("Moai Fall")
   {
    Date(""Moai Fall"", U(1838, 1868));
   };
  };
 };
```

Ahu Rongo 1

```
Plot()
```

```
{
 Outlier_Model("Charcoal", Exp(1,-10,0), U(0,3), "t");
 Curve("SHCal13","SHCal13.14c");
 Sequence("Rongo 1")
 {
  After()
  {
   Prior("Start_Colonization","Start_Colonization.prior");
  };
  Boundary("Start TPQs");
  Phase("TPQ")
  {
   R_Date("GrA-18380", 655, 30)
   {
    Outlier("Charcoal", 1);
   };
   R_Date("GrA-18378", 655, 30)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End TPQs");
  Date("Start Rongo 1");
  Boundary("Start TAQs");
  Phase("TAQ")
  {
   R_Date("GrN-26318", 715, 35)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End Rongo 1");
  Before("Moai Fall")
```

```
   {
    Date(""Moai Fall"", U(1838, 1868));
   };
  };
 };
```

Ahu Te Niu

```
Plot()
 {
  Outlier_Model("Charcoal", Exp(1,-10,0), U(0,3), "t");
  Outlier_Model("General", T(5), U(0,4), "t");
  Curve("SHCal13","SHCal13.14c");
  Sequence("Te Niu")
  {
   After()
   {
    Prior("Start_Colonization","Start_Colonization.prior");
   };
   Boundary("Start TPQs");
   Phase("TPQ")
   {
    R_Date("AZ-23", 685, 50)
    {
     Outlier("Charcoal", 1);
    };
    R_Date("AZ-25", 650, 40)
    {
     Outlier("Charcoal", 1);
    };
    R_Date("Beta-95878", 700, 90)
    {
     Outlier("Charcoal", 1);
    };
    R_Date("Beta-106319", 570, 50)
```

```
  {
   Outlier("Charcoal", 1);
  };
  R_Date("AZ-28", 555, 40)
  {
   Outlier("General", 0.05);
  };
  R_Date("AZ-13", 535, 50)
  {
   Outlier("Charcoal", 1);
  };
 };
 Boundary("End TPQs");
 Date("Start Te Niu");
 Boundary("Start TAQs");
 Phase("TAQ")
 {
  R_Date("AZ-14", 230, 60)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("AZ-22", 325, 40)
  {
   Outlier("General", 0.05);
  };
  R_Date("Beta-95879", 230, 90)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("AZ-8", 375, 45)
  {
   Outlier("Charcoal", 1);
  };
```

```
    Curve("SHCal13","SHCal13.14c");
    Curve("Marine13","Marine13.14c");
    Delta_R("LocalMarine",-83,34);
    Mix_Curve("Mixed","SHCal13","LocalMarine",50,10);
    R_Date("AZ-20", 380, 45)
    {
     Outlier("General", 0.05);
    };
   };
   Boundary("End Te Niu");
   Before("Moai Fall")
   {
    Date(""Moai Fall"", U(1838, 1868));
   };
  };
 };
```

Ahu Motu Toremo Hiva

Ahu Motu Toremo Hiva v.1

```
Plot()
 {
  Outlier_Model("Charcoal", Exp(1,-10,0), U(0,3), "t");
  Outlier_Model("General", T(5), U(0,4), "t");
  Curve("SHCal13","SHCal13.14c");
  Sequence("Motu Toremo Hiva")
  {
   After()
   {
    Prior("Start_Colonization","Start_Colonization.prior");
   };
   Boundary("Start TPQs");
   Phase("TPQ")
   {
```

```
 R_Date("KIA-26464", 700, 25)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-26453", 675, 25)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-29812", 630, 25)
 {
  Outlier("Charcoal", 1);
 };
};
Boundary("Start Motu Toremo Hiva");
Phase("Targets")
{
 R_Date("KIA-26452", 675, 20)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-26461", 630, 25)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-29813", 610, 25)
 {
  Outlier("Charcoal", 1);
 };
};
Boundary("Start TAQs");
Phase("TAQ")
{
 R_Date("KIA-29814", 325, 25)
```

```
    {
     Outlier("Charcoal", 1);
    };
    R_Date("KIA-26487", 240, 20)
    {
     Outlier("Charcoal", 1);
    };
    Curve("SHCal13","SHCal13.14c");
    Curve("Marine13","Marine13.14c");
    Delta_R("LocalMarine",-83,34);
    Mix_Curve("Mixed","SHCal13","LocalMarine",50,10);
    R_Date("KIA-26483", 150, 20)
    {
     Outlier("General", 0.05);
    };
   };
   Boundary("End Motu Toremo Hiva");
   Before("Moai Fall")
   {
    Date(""Moai Fall"", U(1838, 1868));
   };
  };
 };
```

Ahu Motu Toremo Hiva v.2

```
Plot()
 {
  Outlier_Model("Charcoal", Exp(1,-10,0), U(0,3), "t");
  Curve("SHCal13","SHCal13.14c");
  Sequence("Motu Toremo Hiva")
  {
   After()
   {
    Prior("Start_Colonization","Start_Colonization.prior");
```

```
};
Boundary("Start TPQs");
Phase("TPQ")
{
 R_Date("KIA-26464", 700, 25)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-26453", 675, 25)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-29812", 630, 25)
 {
  Outlier("Charcoal", 1);
 };
};
Boundary("Start Motu Toremo Hiva");
Phase("Targets")
{
 R_Date("KIA-26452", 675, 20)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-26461", 630, 25)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-29813", 610, 25)
 {
  Outlier("Charcoal", 1);
 };
};
```

```
   Boundary("Start TAQs");
   Phase("TAQ")
   {
    R_Date("KIA-29814", 325, 25)
    {
     Outlier("Charcoal", 1);
    };
    R_Date("KIA-26487", 240, 20)
    {
     Outlier("Charcoal", 1);
    };
   };
   Boundary("End Motu Toremo Hiva");
   Before("Moai Fall")
   {
    Date(""Moai Fall"", U(1838, 1868));
   };
  };
 };
```

Ahu Tautira

```
Plot()
 {
  Outlier_Model("Charcoal", Exp(1,-10,0), U(0,3), "t");
  Curve("SHCal13","SHCal13.14c");
  Sequence("Tautira")
  {
   After()
   {
    Prior("Start_Colonization","Start_Colonization.prior");
   };
   Boundary("Start TPQs");
   Phase("TPQ")
   {
```

```
    R_Date("Ua-13284", 475, 60)
    {
     Outlier("Charcoal", 1);
    };
   };
   Boundary("End TPQs");
   Date("Start Tautira");
   Boundary("Start TAQs");
   Phase("TAQ")
   {
    R_Date("Ua-13162", 720, 50)
    {
     Outlier("Charcoal", 1);
    };
    R_Date("Ua-13161", 220, 50)
    {
     Outlier("Charcoal", 1);
    };
   };
   Boundary("End Tautira");
   Before("Moai Fall")
   {
    Date(""Moai Fall"", U(1838, 1868));
   };
  };
 };
```

Ahu Vai Teka

```
Plot()
 {
  Outlier_Model("Charcoal", Exp(1,-10,0), U(0,3), "t");
  Curve("SHCal13","SHCal13.14c");
  Sequence("Vai Teka")
  {
```

```
   After()
   {
    Prior("Start_Colonization","Start_Colonization.prior");
   };
   Boundary("Start TPQs");
   Phase("TPQ")
   {
    R_Date("I-455", 340, 75)
    {
     Outlier("Charcoal", 1);
    };
   };
   Boundary("Start Vai Teka");
   Phase("Targets")
   {
    R_Date("TBN-348-2", 399, 76)
    {
     Outlier("Charcoal", 1);
    };
   };
   Boundary("End Vai Teka");
   Before("Moai Fall")
   {
    Date(""Moai Fall"", U(1838, 1868));
   };
  };
 };
```

Ahu Akivi

```
Plot()
 {
  Outlier_Model("Charcoal", Exp(1,-10,0), U(0,3), "t");
  Curve("SHCal13","SHCal13.14c");
  Sequence("Akivi")
```

```
   {
    After()
    {
     Prior("Start_Colonization","Start_Colonization.prior");
    };
    Boundary("Start TPQs");
    Phase("TPQ")
    {
     R_Date("I-456", 460, 75)
     {
      Outlier("Charcoal", 1);
     };
    };
    Boundary("End TPQs");
    Date("Start Akivi");
    Boundary("Start TAQs");
    Phase("TAQ")
    {
     R_Date("M-1370", 425, 100)
     {
      Outlier("Charcoal", 1);
     };
    };
    Boundary("End Akivi");
    Before("Moai Fall")
    {
     Date(""Moai Fall"", U(1838, 1868));
    };
   };
  };
```

Ahu Ature Huki

```
Plot()
 {
```

```
 Outlier_Model("Charcoal", Exp(1,-10,0), U(0,3), "t");
 Curve("SHCal13","SHCal13.14c");
 Sequence("Ature Huki")
 {
  After()
  {
   Prior("Start_Colonization","Start_Colonization.prior");
  };
  Boundary("Start TPQs");
  Phase("TPQ")
  {
   R_Date("T-7979", 510, 80)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End TPQs");
  Date("Start Ature Huki");
  Boundary("Start TAQs");
  Phase("TAQ")
  {
   R_Date("Ua-1144", 580, 85)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End Ature Huki");
  Before("Moai Fall")
  {
   Date(""Moai Fall"", U(1838, 1868));
  };
 };
};
```

Ahu Heki'i 1

```
Plot()
 {
  Outlier_Model("General", T(5), U(0,4), "t");
  Curve("SHCal13","SHCal13.14c");
  Sequence("Hekii 1")
  {
   After()
   {
    Prior("Start_Colonization","Start_Colonization.prior");
   };
   Boundary("Start TPQs");
   Phase("TPQ")
   {
    R_Date("Ua-11700", 705, 45)
    {
     Outlier("General", 0.05);
    };
   };
   Boundary("End TPQs");
   Date("Start Hekii");
   Boundary("Start TAQs");
   Phase("TAQ")
   {
    R_Date("Ua-11702", 465, 45)
    {
     Outlier("General", 0.05);
    };
    R_Date("Ua-11703", 555, 50)
    {
     Outlier("General", 0.05);
    };
   };
```

```
  Boundary("End Hekii");
  Before()
  {
   Date(""Moai Fall"", U(1838, 1868));
  };
 };
};
```

Ahu Nau Nau and Nau Nau IV

Ahu Nau Nau v1

```
Plot()
{
 Outlier_Model("Charcoal", Exp(1,-10,0), U(0,3), "t");
 Outlier_Model("General", T(5), U(0,4), "t");
 Sequence("Nau Nau")
 {
  After()
  {
   Prior("Start_Colonization","Start_Colonization.prior");
  };
  Boundary("Start TPQs");
  Phase("TPQ")
  {
   Curve("SHCal13","SHCal13.14c");
   Curve("Marine13","Marine13.14c");
   Delta_R("LocalMarine",-83,34);
   Mix_Curve("Mixed","SHCal13","LocalMarine",50,10);
   R_Date("Ua-4626", 710, 75)
   {
    Outlier("General", 0.05);
   };
   R_Date("Ua-34187", 915, 60)
   {
```

```
 Outlier("General", 0.05);
};
R_Date("Ua-3007", 1015, 65)
{
 Outlier("General", 0.05);
};
Curve("SHCal13","SHCal13.14c");
R_Date("Ua-34186", 555, 35)
{
 Outlier("Charcoal", 1);
};
R_Date("Ua-34188", 655, 30)
{
 Outlier("Charcoal", 1);
};
R_Date("Ua-34190", 665, 35)
{
 Outlier("Charcoal", 1);
};
R_Date("T-6679", 1170, 140)
{
 Outlier("Charcoal", 1);
};
R_Date("T-7341", 900, 120)
{
 Outlier("Charcoal", 1);
};
R_Date("T-7959", 510, 40)
{
 Outlier("Charcoal", 1);
};
R_Date("T-7975", 710, 40)
{
```

```
   Outlier("Charcoal", 1);
  };
  R_Date("T-7343", 750, 100)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("T-7349", 550, 150)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("T-7350", 710, 80)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("Ua-34189", 565, 35)
  {
   Outlier("General", 0.05);
  };
  R_Date("Ua-34191", 565, 35)
  {
   Outlier("General", 0.05);
  };
 };
 Boundary("End TPQs");
 Date("Start Nau Nau");
 Boundary("Start TAQs");
 Phase("TAQ")
 {
  Curve("SHCal13","SHCal13.14c");
  Curve("Marine13","Marine13.14c");
  Delta_R("LocalMarine",-83,34);
  Mix_Curve("Mixed","SHCal13","LocalMarine",50,10);
  R_Date("Ua-34184", 640, 65)
```

```
  {
   Outlier("General", 0.05);
  };
  R_Date("Ua-34185", 610, 50)
  {
   Outlier("General", 0.05);
  };
  Curve("SHCal13","SHCal13.14c");
  R_Date("Ua-34183", 535, 35)
  {
   Outlier("General", 0.05);
  };
  R_Date("T-6678", 860, 130)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("T-7342", 710, 70)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("T-7347", 720, 120)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("Ua-617", 610, 85)
  {
   Outlier("Charcoal", 1);
  };
 };
 Boundary("End Nau Nau");
 Boundary("Start Nau Nau IV");
 Phase("Nau Nau IV target")
 {
```

```
   R_Date("T-7958", 340, 100)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("Start Nau Nau IV TAQ");
  Phase("Nau Nau IV TAQ")
  {
   R_Date("T-7976", 220, 80)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End Nau Nau IV");
  Before("Moai Fall")
  {
   Date(""Moai Fall"", U(1838, 1868));
  };
 };
};
```

Ahu Nau Nau v2

```
Plot()
{
 Outlier_Model("Charcoal", Exp(1,-10,0), U(0,3), "t");
 Outlier_Model("General", T(5), U(0,4), "t");
 Sequence("Nau Nau")
 {
  After()
  {
   Prior("Start_Colonization","Start_Colonization.prior");
  };
  Boundary("Start TPQs");
  Phase("TPQ")
```

```
{
 Curve("SHCal13","SHCal13.14c");
 Curve("Marine13","Marine13.14c");
 Delta_R("LocalMarine",-83,34);
 Mix_Curve("Mixed","SHCal13","LocalMarine",50,10);
 R_Date("Ua-4626", 710, 75)
 {
  Outlier("General", 0.05);
 };
 Curve("SHCal13","SHCal13.14c");
 R_Date("Ua-34186", 555, 35)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("Ua-34188", 655, 30)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("Ua-34190", 665, 35)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("T-6679", 1170, 140)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("T-7341", 900, 120)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("T-7959", 510, 40)
 {
  Outlier("Charcoal", 1);
```

```
  };
  R_Date("T-7975", 710, 40)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("T-7343", 750, 100)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("T-7349", 550, 150)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("T-7350", 710, 80)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("Ua-34189", 565, 35)
  {
   Outlier("General", 0.05);
  };
  R_Date("Ua-34191", 565, 35)
  {
   Outlier("General", 0.05);
  };
 };
 Boundary("End TPQs");
 Date("Start Nau Nau");
 Boundary("Start TAQs");
 Phase("TAQ")
 {
  Curve("SHCal13","SHCal13.14c");
  Curve("Marine13","Marine13.14c");
```

```
 Delta_R("LocalMarine",-83,34);
 Mix_Curve("Mixed","SHCal13","LocalMarine",50,10);
 R_Date("Ua-34184", 640, 65)
 {
  Outlier("General", 0.05);
 };
 R_Date("Ua-34185", 610, 50)
 {
  Outlier("General", 0.05);
 };
 Curve("SHCal13","SHCal13.14c");
 R_Date("Ua-34183", 535, 35)
 {
  Outlier("General", 0.05);
 };
 R_Date("T-6678", 860, 130)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("T-7342", 710, 70)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("T-7347", 720, 120)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("Ua-617", 610, 85)
 {
  Outlier("Charcoal", 1);
 };
};
Boundary("End Nau Nau");
```

```
   Boundary("Start Nau Nau IV");
   Phase("Nau Nau IV target")
   {
    R_Date("T-7958", 340, 100)
    {
     Outlier("Charcoal", 1);
    };
   };
   Boundary("Start Nau Nau IV TAQ");
   Phase("Nau Nau IV TAQ")
   {
    R_Date("T-7976", 220, 80)
    {
     Outlier("Charcoal", 1);
    };
   };
   Boundary("End Nau Nau IV");
   Before("Moai Fall")
   {
    Date(""Moai Fall"", U(1838, 1868));
   };
  };
 };
```

OxCal code using Difference query to estimate time-lag between colonization and ahu construction

```
Plot()
 {
  Prior("Start_Colonization","Start_Colonization.prior");
  Prior("Start_Akivi","Start_Akivi.prior");
  Prior("Start_Ature_Huki","Start_Ature_Huki.prior");
  Prior("Start_Hekii","Start_Hekii.prior");
  Prior("Start_Motu_Toremo_Hiva","Start_Motu_Toremo_Hiva.prior");
  Prior("Start_Nau_Nau","Start_Nau_Nau.prior");
```

```
 Prior("Start_Nau_Nau_IV","Start_Nau_Nau_IV.prior");
 Prior("Start_Ra_ai","Start_Ra_ai.prior");
 Prior("Start_Rongo_1","Start_Rongo_1.prior");
 Prior("Start_Tautira","Start_Tautira.prior");
 Prior("Start_Te_Niu","Start_Te_Niu.prior");
 Prior("Start_Vai_Teka","Start_Vai_Teka.prior");
 Difference("Akivi", "Start_Akivi", "Start_Colonization", );
 Difference("Ature Huki", "Start_Ature_Huki", "Start_Colonization");
 Difference("Hekii", "Start_Hekii", "Start_Colonization");
 Difference("Motu Toremo Hiva", "Start_Motu_Toremo_Hiva", "Start_Colonization", );
 Difference("Nau Nau", "Start_Nau_Nau", "Start_Colonization", );
 Difference("Nau Nau IV", "Start_Nau_Nau_IV", "Start_Colonization");
 Difference("Ra'ai", "Start_Ra_ai", "Start_Colonization", );
 Difference("Rongo 1", "Start_Rongo_1", "Start_Colonization", );
 Difference("Tautira", "Start_Tautira", "Start_Colonization", );
 Difference("Te Niu", "Start_Te_Niu", "Start_Colonization", );
 Difference("Vai Teka", "Start_Vai_Teka", "Start_Colonization", );
};
```

OxCal code for tempo plot with an AD 1838-1868 cutoff point

```
Plot()
{
 MCMC_Sample("ahu-construction-100k_1838-1868", 25, 100000);
 Outlier_Model("Charcoal", Exp(1,-10,0), U(0,3), "t");
 Outlier_Model("General", T(5), U(0,4), "t");
 Curve("SHCal13","SHCal13.14c");
 Phase()
 {
  Sequence("Akivi")
  {
   After()
   {
    Prior("Start_Colonization","Start_Colonization.prior");
   };
   Boundary("Start Akivi TPQs");
   Phase("Akivi TPQ")
```

```
  {
   R_Date("I-456", 460, 75)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End Akivi TPQs");
  Date("Start Akivi");
  Boundary("Start Akivi TAQs");
  Phase("Akivi TAQ")
  {
   R_Date("M-1370", 425, 100)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End Akivi");
  Before()
  {
   Date("Moai Fall", U(1838, 1868));
  };
 };
 Sequence("Ature Huki")
 {
  After()
  {
   Prior("Start_Colonization","Start_Colonization.prior");
  };
  Boundary("Start Ature Huki TPQs");
  Phase("Ature Huki TPQ")
  {
   R_Date("T-7979", 510, 80)
   {
```

```
   Outlier("Charcoal", 1);
  };
 };
 Boundary("End Ature Huki TPQs");
 Date("Start Ature Huki");
 Boundary("Start Ature Huki TAQs");
 Phase("Ature Huki TAQ")
 {
  R_Date("Ua-1144", 580, 85)
  {
   Outlier("Charcoal", 1);
  };
 };
 Boundary("End Ature Huki");
 Before()
 {
  Date("Moai Fall", U(1838, 1868));
 };
};
Sequence("Hekii 1")
{
 After()
 {
  Prior("Start_Colonization","Start_Colonization.prior");
 };
 Boundary("Start Hekii TPQs");
 Phase("Hekii TPQ")
 {
  R_Date("Ua-11700", 705, 45)
  {
   Outlier("General", 0.05);
  };
 };
```

```
 Boundary("End Hekii TPQs");
 Date("Start Hekii");
 Boundary("Start Hekii TAQs");
 Phase("Hekii TAQ")
 {
  R_Date("Ua-11702", 465, 45)
  {
   Outlier("General", 0.05);
  };
  R_Date("Ua-11703", 555, 50)
  {
   Outlier("General", 0.05);
  };
 };
 Boundary("End Hekii");
 Before()
 {
  Date("Moai Fall", U(1838, 1868));
 };
};
Sequence("Motu Toremo Hiva")
{
 After()
 {
  Prior("Start_Colonization","Start_Colonization.prior");
 };
 Boundary("Start Motu Toremo Hiva TPQs");
 Phase("Motu Toremo Hiva TPQ")
 {
  R_Date("KIA-26464", 700, 25)
  {
   Outlier("Charcoal", 1);
  };
```

```
 R_Date("KIA-26453", 675, 25)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-29812", 630, 25)
 {
  Outlier("Charcoal", 1);
 };
};
Boundary("Start Motu Toremo Hiva");
Phase("Motu Toremo Hiva Targets")
{
 R_Date("KIA-26452", 675, 20)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-26461", 630, 25)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-29813", 610, 25)
 {
  Outlier("Charcoal", 1);
 };
};
Boundary("Start Motu Toremo Hiva TAQs");
Phase("Motu Toremo Hiva TAQ")
{
 R_Date("KIA-29814", 325, 25)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-26487", 240, 20)
```

```
  {
   Outlier("Charcoal", 1);
  };
 };
 Boundary("End Motu Toremo Hiva");
 Before()
 {
  Date("Moai Fall", U(1838, 1868));
 };
};
Sequence("Nau Nau")
{
 After()
 {
  Prior("Start_Colonization","Start_Colonization.prior");
 };
 Boundary("Start Nau Nau TPQs");
 Phase("Nau Nau TPQ")
 {
  Curve("SHCal13","SHCal13.14c");
  Curve("Marine13","Marine13.14c");
  Delta_R("LocalMarine",-83,34);
  Mix_Curve("Mixed","SHCal13","LocalMarine",50,10);
  R_Date("Ua-4626", 710, 75)
  {
   Outlier("General", 0.05);
  };
  Curve("SHCal13","SHCal13.14c");
  R_Date("Ua-34186", 555, 35)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("Ua-34188", 655, 30)
```

```
{
 Outlier("Charcoal", 1);
};
R_Date("Ua-34190", 665, 35)
{
 Outlier("Charcoal", 1);
};
R_Date("T-6679", 1170, 140)
{
 Outlier("Charcoal", 1);
};
R_Date("T-7341", 900, 120)
{
 Outlier("Charcoal", 1);
};
R_Date("T-7959", 510, 40)
{
 Outlier("Charcoal", 1);
};
R_Date("T-7975", 710, 40)
{
 Outlier("Charcoal", 1);
};
R_Date("T-7343", 750, 100)
{
 Outlier("Charcoal", 1);
};
R_Date("T-7349", 550, 150)
{
 Outlier("Charcoal", 1);
};
R_Date("T-7350", 710, 80)
{
```

```
  Outlier("Charcoal", 1);
 };
 R_Date("Ua-34189", 565, 35)
 {
  Outlier("General", 0.05);
 };
 R_Date("Ua-34191", 565, 35)
 {
  Outlier("General", 0.05);
 };
};
Boundary("End Nau Nau TPQs");
Date("Start Nau Nau");
Boundary("Start Nau Nau TAQs");
Phase("Nau Nau TAQ")
{
 Curve("SHCal13","SHCal13.14c");
 Curve("Marine13","Marine13.14c");
 Delta_R("LocalMarine",-83,34);
 Mix_Curve("Mixed","SHCal13","LocalMarine",50,10);
 R_Date("Ua-34184", 640, 65)
 {
  Outlier("General", 0.05);
 };
 R_Date("Ua-34185", 610, 50)
 {
  Outlier("General", 0.05);
 };
 Curve("SHCal13","SHCal13.14c");
 R_Date("Ua-34183", 535, 35)
 {
  Outlier("General", 0.05);
 };
```

```
 R_Date("T-6678", 860, 130)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("T-7342", 710, 70)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("T-7347", 720, 120)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("Ua-617", 610, 85)
 {
  Outlier("Charcoal", 1);
 };
};
Boundary("End Nau Nau");
Boundary("Start Nau Nau IV");
Phase("Nau Nau IV target")
{
 R_Date("T-7958", 340, 100)
 {
  Outlier("Charcoal", 1);
 };
};
Boundary("Start Nau Nau IV TAQ");
Phase("Nau Nau IV TAQ")
{
 R_Date("T-7976", 220, 80)
 {
  Outlier("Charcoal", 1);
 };
```

```
  };
  Boundary("End Nau Nau IV");
  Before()
  {
   Date("Moai Fall", U(1838, 1868));
  };
 };
 Sequence("Raai")
 {
  Curve("SHCal13","SHCal13.14c");
  After()
  {
   Prior("Start_Colonization","Start_Colonization.prior");
  };
  Boundary("Start Raai TPQs");
  Phase("Raai TPQ")
  {
   R_Date("Ua-13167", 645, 50)
   {
    Outlier("Charcoal", 1);
   };
   R_Date("Ua-13166", 635, 50)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("Start Raai");
  Phase("Raai Targets")
  {
   R_Date("Ua-13165", 570, 50)
   {
    Outlier("Charcoal", 1);
   };
```

```
  };
  Boundary("Start Raai TAQs");
  Phase("TAQ")
  {
   R_Date("Ua-13164", 515, 60)
   {
    Outlier("Charcoal", 1);
   };
   R_Date("Ua-13163", 135, 60)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End Raai");
  Before()
  {
   Date("Moai Fall", U(1838, 1868));
  };
 };
 Sequence("Rongo 1")
 {
  After()
  {
   Prior("Start_Colonization","Start_Colonization.prior");
  };
  Boundary("Start Rongo 1 TPQs");
  Phase("Rongo 1 TPQ")
  {
   R_Date("GrA-18380", 655, 30)
   {
    Outlier("Charcoal", 1);
   };
   R_Date("GrA-18378", 655, 30)
```

```
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End Rongo 1 TPQs");
  Date("Start Rongo 1");
  Boundary("Start Rongo 1 TAQs");
  Phase("Rongo 1 TAQ")
  {
   R_Date("GrN-26318", 715, 35)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End Rongo 1");
  Before()
  {
   Date("Moai Fall", U(1838, 1868));
  };
 };
 Sequence("Tautira")
 {
  After()
  {
   Prior("Start_Colonization","Start_Colonization.prior");
  };
  Boundary("Start Tautira TPQs");
  Phase("Tautira TPQ")
  {
   R_Date("Ua-13284", 475, 60)
   {
    Outlier("Charcoal", 1);
   };
```

```
 };
 Boundary("End Tautira TPQs");
 Date("Start Tautira");
 Boundary("Start Tautira TAQs");
 Phase("Tautira TAQ")
 {
  R_Date("Ua-13162", 720, 50)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("Ua-13161", 220, 50)
  {
   Outlier("Charcoal", 1);
  };
 };
 Boundary("End Tautira");
 Before()
 {
  Date("Moai Fall", U(1838, 1868));
 };
};
Sequence("Te Niu")
{
 After()
 {
  Prior("Start_Colonization","Start_Colonization.prior");
 };
 Boundary("Start Te Niu TPQs");
 Phase("Te Niu TPQ")
 {
  R_Date("AZ-23", 685, 50)
  {
   Outlier("Charcoal", 1);
```

```
  };
  R_Date("AZ-25", 650, 40)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("Beta-95878", 700, 90)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("Beta-106319", 570, 50)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("AZ-28", 555, 40)
  {
   Outlier("General", 0.05);
  };
  R_Date("AZ-13", 535, 50)
  {
   Outlier("Charcoal", 1);
  };
 };
 Boundary("End Te Niu TPQs");
 Date("Start Te Niu");
 Boundary("Start Te Niu TAQs");
 Phase("Te Niu TAQ")
 {
  R_Date("AZ-14", 230, 60)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("AZ-22", 325, 40)
  {
```

```
    Outlier("General", 0.05);
   };
   R_Date("Beta-95879", 230, 90)
   {
    Outlier("Charcoal", 1);
   };
   R_Date("AZ-8", 375, 45)
   {
    Outlier("Charcoal", 1);
   };
   Curve("SHCal13","SHCal13.14c");
   Curve("Marine13","Marine13.14c");
   Delta_R("LocalMarine",-83,34);
   Mix_Curve("Mixed","SHCal13","LocalMarine",50,10);
   R_Date("AZ-20", 380, 45)
   {
    Outlier("General", 0.05);
   };
  };
  Boundary("End Te Niu");
  Before()
  {
   Date("Moai Fall", U(1838, 1868));
  };
 };
 Sequence("Vai Teka")
 {
  Curve("SHCal13","SHCal13.14c");
  After()
  {
   Prior("Start_Colonization","Start_Colonization.prior");
  };
  Boundary("Start Vai Teka TPQs");
```

```
   Phase("Vai Teka TPQ")
   {
    R_Date("I-455", 340, 75)
    {
     Outlier("Charcoal", 1);
    };
   };
   Boundary("Start Vai Teka");
   Phase("Vai Teka Targets")
   {
    R_Date("TBN-348-2", 399, 76)
    {
     Outlier("Charcoal", 1);
    };
   };
   Boundary("End Vai Teka");
   Before()
   {
    Date("Moai Fall", U(1838, 1868));
   };
  };
 };
};
```

OxCal code for tempo plot with an AD 1771 cutoff point

```
 Plot()
{
 MCMC_Sample("ahu-construction-100k-1771", 25, 100000);
 Outlier_Model("Charcoal", Exp(1,-10,0), U(0,3), "t");
 Outlier_Model("General", T(5), U(0,4), "t");
 Curve("SHCal13","SHCal13.14c");
 Phase()
```

```
{
 Sequence("Akivi")
 {
  After()
  {
   Prior("Start_Colonization","Start_Colonization.prior");
  };
  Boundary("Start Akivi TPQs");
  Phase("Akivi TPQ")
  {
   R_Date("I-456", 460, 75)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End Akivi TPQs");
  Date("Start Akivi");
  Boundary("Start Akivi TAQs");
  Phase("Akivi TAQ")
  {
   R_Date("M-1370", 425, 100)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End Akivi");
  Before()
  {
   C_Date("Spanish", AD(1771), 0.01);
  };
 };
 Sequence("Ature Huki")
 {
```

```
 After()
 {
  Prior("Start_Colonization","Start_Colonization.prior");
 };
 Boundary("Start Ature Huki TPQs");
 Phase("Ature Huki TPQ")
 {
  R_Date("T-7979", 510, 80)
  {
   Outlier("Charcoal", 1);
  };
 };
 Boundary("End Ature Huki TPQs");
 Date("Start Ature Huki");
 Boundary("Start Ature Huki TAQs");
 Phase("Ature Huki TAQ")
 {
  R_Date("Ua-1144", 580, 85)
  {
   Outlier("Charcoal", 1);
  };
 };
 Boundary("End Ature Huki");
 Before()
 {
  C_Date("Spanish", AD(1771), 0.01);
 };
};
Sequence("Hekii 1")
{
 After()
 {
  Prior("Start_Colonization","Start_Colonization.prior");
```

```
 };
 Boundary("Start Hekii TPQs");
 Phase("Hekii TPQ")
 {
  R_Date("Ua-11700", 705, 45)
  {
   Outlier("General", 0.05);
  };
 };
 Boundary("End Hekii TPQs");
 Date("Start Hekii");
 Boundary("Start Hekii TAQs");
 Phase("Hekii TAQ")
 {
  R_Date("Ua-11702", 465, 45)
  {
   Outlier("General", 0.05);
  };
  R_Date("Ua-11703", 555, 50)
  {
   Outlier("General", 0.05);
  };
 };
 Boundary("End Hekii");
 Before()
 {
  C_Date("Spanish", AD(1771), 0.01);
 };
};
Sequence("Motu Toremo Hiva")
{
 After()
 {
```

```
 Prior("Start_Colonization","Start_Colonization.prior");
};
Boundary("Start Motu Toremo Hiva TPQs");
Phase("Motu Toremo Hiva TPQ")
{
 R_Date("KIA-26464", 700, 25)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-26453", 675, 25)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-29812", 630, 25)
 {
  Outlier("Charcoal", 1);
 };
};
Boundary("Start Motu Toremo Hiva");
Phase("Motu Toremo Hiva Targets")
{
 R_Date("KIA-26452", 675, 20)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-26461", 630, 25)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("KIA-29813", 610, 25)
 {
  Outlier("Charcoal", 1);
 };
```

```
 };
 Boundary("Start Motu Toremo Hiva TAQs");
 Phase("Motu Toremo Hiva TAQ")
 {
  R_Date("KIA-29814", 325, 25)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("KIA-26487", 240, 20)
  {
   Outlier("Charcoal", 1);
  };
 };
 Boundary("End Motu Toremo Hiva");
 Before()
 {
  C_Date("Spanish", AD(1771), 0.01);
 };
};
Sequence("Nau Nau")
{
 After()
 {
  Prior("Start_Colonization","Start_Colonization.prior");
 };
 Boundary("Start Nau Nau TPQs");
 Phase("Nau Nau TPQ")
 {
  Curve("SHCal13","SHCal13.14c");
  Curve("Marine13","Marine13.14c");
  Delta_R("LocalMarine",-83,34);
  Mix_Curve("Mixed","SHCal13","LocalMarine",50,10);
  R_Date("Ua-4626", 710, 75)
```

```
{
 Outlier("General", 0.05);
};
Curve("SHCal13","SHCal13.14c");
R_Date("Ua-34186", 555, 35)
{
 Outlier("Charcoal", 1);
};
R_Date("Ua-34188", 655, 30)
{
 Outlier("Charcoal", 1);
};
R_Date("Ua-34190", 665, 35)
{
 Outlier("Charcoal", 1);
};
R_Date("T-6679", 1170, 140)
{
 Outlier("Charcoal", 1);
};
R_Date("T-7341", 900, 120)
{
 Outlier("Charcoal", 1);
};
R_Date("T-7959", 510, 40)
{
 Outlier("Charcoal", 1);
};
R_Date("T-7975", 710, 40)
{
 Outlier("Charcoal", 1);
};
R_Date("T-7343", 750, 100)
```

```
  {
   Outlier("Charcoal", 1);
  };
  R_Date("T-7349", 550, 150)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("T-7350", 710, 80)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("Ua-34189", 565, 35)
  {
   Outlier("General", 0.05);
  };
  R_Date("Ua-34191", 565, 35)
  {
   Outlier("General", 0.05);
  };
 };
 Boundary("End Nau Nau TPQs");
 Date("Start Nau Nau");
 Boundary("Start Nau Nau TAQs");
 Phase("Nau Nau TAQ")
 {
  Curve("SHCal13","SHCal13.14c");
  Curve("Marine13","Marine13.14c");
  Delta_R("LocalMarine",-83,34);
  Mix_Curve("Mixed","SHCal13","LocalMarine",50,10);
  R_Date("Ua-34184", 640, 65)
  {
   Outlier("General", 0.05);
  };
```

```
  R_Date("Ua-34185", 610, 50)
  {
   Outlier("General", 0.05);
  };
  Curve("SHCal13","SHCal13.14c");
  R_Date("Ua-34183", 535, 35)
  {
   Outlier("General", 0.05);
  };
  R_Date("T-6678", 860, 130)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("T-7342", 710, 70)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("T-7347", 720, 120)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("Ua-617", 610, 85)
  {
   Outlier("Charcoal", 1);
  };
 };
 Boundary("End Nau Nau");
 Boundary("Start Nau Nau IV");
 Phase("Nau Nau IV target")
 {
  R_Date("T-7958", 340, 100)
  {
   Outlier("Charcoal", 1);
```

```
   };
  };
  Boundary("Start Nau Nau IV TAQ");
  Phase("Nau Nau IV TAQ")
  {
   R_Date("T-7976", 220, 80)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End Nau Nau IV");
  Before()
  {
   C_Date("Spanish", AD(1771), 0.01);
  };
 };
 Sequence("Raai")
 {
  Curve("SHCal13","SHCal13.14c");
  After()
  {
   Prior("Start_Colonization","Start_Colonization.prior");
  };
  Boundary("Start Raai TPQs");
  Phase("Raai TPQ")
  {
   R_Date("Ua-13167", 645, 50)
   {
    Outlier("Charcoal", 1);
   };
   R_Date("Ua-13166", 635, 50)
   {
    Outlier("Charcoal", 1);
```

```
   };
  };
  Boundary("Start Raai");
  Phase("Raai Targets")
  {
   R_Date("Ua-13165", 570, 50)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("Start Raai TAQs");
  Phase("TAQ")
  {
   R_Date("Ua-13164", 515, 60)
   {
    Outlier("Charcoal", 1);
   };
   R_Date("Ua-13163", 135, 60)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End Raai");
  Before()
  {
   C_Date("Spanish", AD(1771), 0.01);
  };
 };
 Sequence("Rongo 1")
 {
  After()
  {
   Prior("Start_Colonization","Start_Colonization.prior");
```

```
  };
  Boundary("Start Rongo 1 TPQs");
  Phase("Rongo 1 TPQ")
  {
   R_Date("GrA-18380", 655, 30)
   {
    Outlier("Charcoal", 1);
   };
   R_Date("GrA-18378", 655, 30)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End Rongo 1 TPQs");
  Date("Start Rongo 1");
  Boundary("Start Rongo 1 TAQs");
  Phase("Rongo 1 TAQ")
  {
   R_Date("GrN-26318", 715, 35)
   {
    Outlier("Charcoal", 1);
   };
  };
  Boundary("End Rongo 1");
  Before()
  {
   C_Date("Spanish", AD(1771), 0.01);
  };
 };
 Sequence("Tautira")
 {
  After()
  {
```

```
  Prior("Start_Colonization","Start_Colonization.prior");
 };
 Boundary("Start Tautira TPQs");
 Phase("Tautira TPQ")
 {
  R_Date("Ua-13284", 475, 60)
  {
   Outlier("Charcoal", 1);
  };
 };
 Boundary("End Tautira TPQs");
 Date("Start Tautira");
 Boundary("Start Tautira TAQs");
 Phase("Tautira TAQ")
 {
  R_Date("Ua-13162", 720, 50)
  {
   Outlier("Charcoal", 1);
  };
  R_Date("Ua-13161", 220, 50)
  {
   Outlier("Charcoal", 1);
  };
 };
 Boundary("End Tautira");
 Before()
 {
  C_Date("Spanish", AD(1771), 0.01);
 };
};
Sequence("Te Niu")
{
 After()
```

```
{
 Prior("Start_Colonization","Start_Colonization.prior");
};
Boundary("Start Te Niu TPQs");
Phase("Te Niu TPQ")
{
 R_Date("AZ-23", 685, 50)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("AZ-25", 650, 40)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("Beta-95878", 700, 90)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("Beta-106319", 570, 50)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("AZ-28", 555, 40)
 {
  Outlier("General", 0.05);
 };
 R_Date("AZ-13", 535, 50)
 {
  Outlier("Charcoal", 1);
 };
};
Boundary("End Te Niu TPQs");
Date("Start Te Niu");
```

```
Boundary("Start Te Niu TAQs");
Phase("Te Niu TAQ")
{
 R_Date("AZ-14", 230, 60)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("AZ-22", 325, 40)
 {
  Outlier("General", 0.05);
 };
 R_Date("Beta-95879", 230, 90)
 {
  Outlier("Charcoal", 1);
 };
 R_Date("AZ-8", 375, 45)
 {
  Outlier("Charcoal", 1);
 };
 Curve("SHCal13","SHCal13.14c");
 Curve("Marine13","Marine13.14c");
 Delta_R("LocalMarine",-83,34);
 Mix_Curve("Mixed","SHCal13","LocalMarine",50,10);
 R_Date("AZ-20", 380, 45)
 {
  Outlier("General", 0.05);
 };
};
Boundary("End Te Niu");
Before()
{
 C_Date("Spanish", AD(1771), 0.01);
};
```

```
  };
  Sequence("Vai Teka")
  {
   Curve("SHCal13","SHCal13.14c");
   After()
   {
    Prior("Start_Colonization","Start_Colonization.prior");
   };
   Boundary("Start Vai Teka TPQs");
   Phase("Vai Teka TPQ")
   {
    R_Date("I-455", 340, 75)
    {
     Outlier("Charcoal", 1);
    };
   };
   Boundary("Start Vai Teka");
   Phase("Vai Teka Targets")
   {
    R_Date("TBN-348-2", 399, 76)
    {
     Outlier("Charcoal", 1);
    };
   };
   Boundary("End Vai Teka");
   Before()
   {
    C_Date("Spanish", AD(1771), 0.01);
   };
  };
 };
};
```

REFERENCES CITED

Abbott, D.N., 1972. The Utility of the Concept of Phase in the Archaeology of the Southern Northwest Coast. Syesis 5, 267–278.

Abrams, E.M., 1994. How the Maya built their world: energetics and ancient architecture. University of Texas Press, Austin.

Abrams, E.M., 1989. Architecture and energy: An evolutionary perspective. Archaeological method and theory 1, 47–87.

Abrams, E.M., Bolland, T.W., 1999. Architectural energetics, ancient monuments, and operations management. Journal of Archaeological Method and Theory 6, 263–291.

Akaike, H., 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control 19, 716–723. https://doi.org/10.1109/TAC.1974.1100705

Akhavan, N., Yorke, J.A., 2019. Population collapse in Elite-dominated societies: A differential equations model without differential equations. arXiv:1908.02870 [physics, q-bio].

Allen, M.S., 2017. Spatial variability and human eco-dynamics in central East Polynesian fisheries, in: Albarella, U., Rizzeto, M., Russ, H., Vickers, K., Viner-Daniels, S. (Eds.), The Oxford Handbook of Zooarchaeology. Oxford University Press, Oxford, pp. 737–756.

Allen, M.S., 2014. Variability is in the Mesh-size of the Sorter: Harataonga Beach and Spatio-temporal Patterning in Northern Māori Fisheries. Journal of Pacific Archaeology 5, 21–38.

Allen, M.S., 2010. Oscillating climate and socio-political process: the case of the Marquesan Chiefdom, Polynesia. Antiquity 84, 86–102.

Allen, M.S., Huebert, J.M., 2014. Short-lived plant materials, long-lived trees, and Polynesian 14 C dating: Considerations for 14 C sample selection and documentation. Radiocarbon 56, 257–276.

Allen, M.S., Kahn, J.G., 2010. Central East Polynesia: an introduction. Archaeology in Oceania 45, 49–53.

Anderies, J.M., 2000. On modeling human behavior and institutions in simple ecological economic systems. Ecological Economics 35, 393–412. https://doi.org/10.1016/S0921-8009(00)00221-4

Anderson, A., 2014. Monumentality and Ritual Behaviour in South Polynesia, in: Martinsson-Wallin, H., Thomas, T. (Eds.), Monuments and People in the Pacific. Uppsala University, Uppsala, pp. 273–296.

Anderson, A., 2012a. “Dwelling carelessly, quiet and secure”: A brief ethnohistory of Rapa Island, French Polynesia, AD 1791-1840, in: Anderson, A., Kennett, D.J. (Eds.), Taking the High Ground: The Archaeology of Rapa, a Fortified Island in Remote East Polynesia, Terra Australis 37. ANU Press, Canberra, pp. 25–45.

Anderson, A., 2012b. Archaeology of the coastal sites on Rapa Island, in: Anderson, A., Kennett, D.J. (Eds.), Taking the High Ground: The Archaeology of Rapa, a Fortified Island in Remote East Polynesia, Terra Australis 37. ANU Press, Canberra, pp. 47–76.

Anderson, A., 2001. No meat on that beautiful shore: the prehistoric abandonment of subtropical Polynesian islands. International Journal of Osteoarchaeology 11, 14–23.

Anderson, A., Green, R., 2001. Domestic and religious structures in the Emily Bay settlement site, Norfolk Island. RECORDS-AUSTRALIAN MUSEUM 53, 43–52.

Anderson, A., Kennett, D.J., Conte, E., 2012a. The prehistory of Rapa Island, in: Anderson, A., Kennett, D.J. (Eds.), Taking the High Ground: The Archaeology of Rapa, a Fortified Island in Remote East Polynesia, Terra Australis 37. ANU Press, Canberra, pp. 247–256.

Anderson, A., Kennett, D.J., Conte, E., 2012b. Archaeological research on Rapa Island, French Polynesia, in: Anderson, A., Kennett, D.J. (Eds.), Taking the High Ground: The Archaeology of Rapa, a Fortified Island in Remote East Polynesia, Terra Australis 37. ANU Press, Canberra, pp. 7–23.

Andrushko, V.A., Torres, E.C., 2011. Skeletal evidence for Inca warfare from the Cuzco region of Peru. American Journal of Physical Anthropology 146, 361–372. https://doi.org/10.1002/ajpa.21574

Anovitz, L.M., Elam, J.M., Riciputi, L.R., Cole, D.R., 1999. The Failure of Obsidian Hydration Dating: Sources, Implications, and New Directions. Journal of Archaeological Science 26, 735–752.

Arana, P.M., 2014. Ancient fishing activities developed in Easter Island. Latin American Journal of Aquatic Research 42, 673–689.

Aranyosi, E.F., 1999. Wasteful advertising and variance reduction: Darwinian models for the significance of nonutilitarian architecture. Journal of Anthropological Archaeology 18, 356–375.

Arkush, E., Stanish, C., 2005. Interpreting Conflict in the Ancient Andes: Implications for the Archaeology of Warfare. Current Anthropology 46, 3–28. https://doi.org/10.1086/425660

Arkush, E., Tung, T.A., 2013. Patterns of War in the Andes from the Archaic to the Late Horizon: Insights from Settlement Patterns and Cranial Trauma. J Archaeol Res 21, 307–369. https://doi.org/10.1007/s10814-013-9065-1

Artursson, M., Earle, T., Brown, J., 2016. The construction of monumental landscapes in low-density societies: New evidence from the Early Neolithic of Southern Scandinavia (4000–3300BC) in comparative perspective (November 5, 2015). Journal of Anthropological Archaeology 41, 1–18.

Atran, S., Henrich, J., 2010. The Evolution of Religion: How Cognitive By-Products, Adaptive Learning Heuristics, Ritual Displays, and Group Competition Generate Deep Commitments to Prosocial Religions. Biol Theory 5, 18–30. https://doi.org/10.1162/BIOT_a_00018

Ayala-Bradford, I., Lipo, C.P., Hunt, T.L., 2005. An application of high-resolution satellite imagery for the mapping of habitation and subsistence features on Rapa Nui (Easter Island), in: Stevenson, C.M., Ramirez, J.M., Morin, F.J., Barbacci, N. (Eds.), The Reñaca Papers: VI International Conference on Rapa Nui and the Pacific. Easter Island Foundation and University of Valparaiso, Los Osos, pp. 113–123.

Ayres, W., 1985. Easter Island Subsistence. Journal de la Société des Océanistes 41, 103–124. https://doi.org/10.3406/jso.1985.2805

Ayres, W.S., 1979. Easter Island Fishing. Asian Perspectives 22, 61–92.

Ayres, W.S., 1974. Easter Island :Investigations in Prehistoric Cultural Dynamics. Report to the National Science Foundation.

Ayres, W.S., 1971. Radiocarbon dates from Easter Island. The Journal of the Polynesian Society 80, 497–504.

Ayres, W.S., Saleeby, B., Levy, C., B., 2000a. Late prehistoric-early historic Easter Island subsistence patterns, in: Stevenson, C.M., Ayres, W. (Eds.), Easter Island Archaeology: Research on Early Rapanui Culture. Bearsville Press, Los Osos, pp. 191–203.

Ayres, W.S., Spear, R.L., Beardsley, F.R., 2000b. Easter Island Obsidian Artifacts: Typology and Use-Wear, in: Stevenson, C.M., Ayres, W.S. (Eds.), Easter Island Archaeology: Research on Early Rapanui Culture. Bearsville Press, Los Osos, pp. 173–190.

Baddeley, A., Diggle, P.J., Hardegen, A., Lawrence, T., Milne, R.K., Nair, G., 2014. On tests of spatial pattern based on simulation envelopes. Ecological Monographs 84, 477–489. https://doi.org/10.1890/13-2042.1

Baddeley, A., Rubak, E., Turner, R., 2015. Spatial Point Patterns: Methodology and Applications with R. Chapman and Hall/CRC Press, New York.

Baddeley, A.J., Møller, J., Waagepetersen, R., 2000. Non- and semi-parametric estimation of interaction in inhomogeneous point patterns. Statistica Neerlandica 54, 329–350. https://doi.org/10.1111/1467-9574.00144

Baer, A., 2016. Ceremonial architecture and the spatial proscription of community: Location versus form and function in Kaupo, Maui, Hawaiian islands. Journal of the Polynesian Society, The 125, 289.

Bahn, P., 1997. Easter Island or (Man-) Eaters Island? Rapa Nui Journal 11, 123–125.

Bahn, P., 1993. The History of Human Settlement on Rapanui, in: Fischer, S.R. (Ed.), Easter Island Studies: Contributions to the History of Rapanui in Memory of William T. Mulloy. Oxbow Books, Oxford, pp. 53–55.

Bahn, P., Flenley, J., 2017. Easter Island, Earth Island: The Enigmas of Rapa Nui, Fourth Edition. ed. Rowman & Littlefield, Lanham, MD.

Bahn, P., Flenley, J., 1992. Easter Island, Earth Island. Thames, London.

Banks, W.E., Bertran, P., Ducasse, S., Klaric, L., Lanos, P., Renard, C., Mesa, M., 2019. An application of hierarchical Bayesian modeling to better constrain the chronologies of Upper Paleolithic archaeological cultures in France between ca. 32,000–21,000 calibrated years before present. Quaternary Science Reviews 220, 188–214. https://doi.org/10.1016/j.quascirev.2019.07.025

Banning, E.B., 2011. So Fair a House: Göbekli Tepe and the Identification of Temples in the Pre-Pottery Neolithic of the Near East. Current Anthropology 52, 619–660. https://doi.org/10.1086/661207

Barber, I.G., 1996. Loss, change, and monumental landscaping: Towards a new interpretation of the" Classic" Maaori emergence. Current Anthropology 37, 868–880.

Bar-Oz, G., Weissbrod, L., Erickson-Gini, T., Tepper, Y., Malkinson, D., Benzaquen, M., Langgut, D., Dunseth, Z.C., Butler, D.H., Shahack-Gross, R., Roskin, J., Fuks, D., Weiss, E., Marom, N., Ktalav, I., Blevis, R., Zohar, I., Farhi, Y., Filatova, A., Gorin-Rosen, Y., Yan, X., Boaretto, E., 2019. Ancient trash mounds unravel urban collapse a century before the end of Byzantine hegemony in the southern Levant. PNAS 116, 8239–8248. https://doi.org/10.1073/pnas.1900233116

Bartoń, K., 2018. MuMIn: multi-model inference.

Bartruff, J., Kennett, D.J., Winterhalder, B., 2012. Rapan agroecology and population estimates, in: Anderson, A., Kennett, D.J. (Eds.), Taking the High Ground: The Archaeology of Rapa, a Fortified Island in Remote East Polynesia, Terra Australis 37. ANU Press, Canberra, pp. 235–246.

Basener, B., Ross, D., 2004. Booming and Crashing Populations and Easter Island. SIAM J. Appl. Math. 65, 684–701. https://doi.org/10.1137/S0036139903426952

Basener, W.F., Basener, W.J., 2019. Ecological collapse of Easter Island and the role of price fixing. European Journal of Mathematics 5, 646–655. https://doi.org/10.1007/s40879-019-00352-5

Baustian, K.M., Harrod, R.P., Osterholtz, A.J., Martin, D.L., 2012. Battered and abused: Analysis of trauma at Grasshopper Pueblo (AD 1275–1400). International Journal of Paleopathology, Body parts and parts of bodies: Traces of violence in past cultures 2, 102–111. https://doi.org/10.1016/j.ijpp.2012.09.006

Bayliss, A., Ramsey, C.B., Plicht, J. van der, Whittle, A., 2007. Bradshaw and Bayes: Towards a Timetable for the Neolithic. Cambridge Archaeological Journal 17, 1–28. https://doi.org/10.1017/S0959774307000145

Beale, C.M., Lennon, J.J., Yearsley, J.M., Brewer, M.J., Elston, D.A., 2010. Regression analysis of spatial data. Ecology Letters 13, 246–264. https://doi.org/10.1111/j.1461-0248.2009.01422.x

Beardsley, F.R., 1996. Stylistic and spatial affinities of Easter Island ahu. Bulletin of the Indo-Pacific Prehistory Association 15, 23–36.

Beck, J.W., Hewitt, L., Burr, G.S., Loret, J., Hochstetter, F.T., 2003. Mata Ki Te Rangi: Eyes Towards the Heavens, in: Loret, John, Tanacredi, J., T. (Eds.), Easter Island: Scientific Exploration into the World's Environmental Problems in Microcosm. Kluwer Academic/Plenum Publishers, New York, pp. 93–112.

Beheim, B.A., Bell, A.V., 2011. Inheritance, ecology and the evolution of the canoes of east Oceania. Proceedings of the Royal Society B: Biological Sciences 278, 3089–3095.

Bell, A.V., Currie, T.E., Irwin, G., Bradbury, C., 2015. Driving Factors in the Colonization of Oceania: Developing Island-Level Statistical Models to Test Competing Hypotheses. American Antiquity 80, 397–407. https://doi.org/10.7183/0002-7316.80.2.397

Berman, M., 1986. Testing for Spatial Association Between a Point Process and Another Stochastic Process. Journal of the Royal Statistical Society. Series C (Applied Statistics) 35, 54–62. https://doi.org/10.2307/2347865

Bernardini, W., 2004. Hopewell geometric earthworks: a case study in the referential and experiential meaning of monuments. Journal of Anthropological Archaeology 23, 331–356.

Besag, J., 1977. Discussion of Dr. Ripley's paper. Journal of the Royal Statistical Society, Series B 39, 193–195.

Best, E., 1927. The Pa Maori (Dominion Museum Bulletin No. 6). Wellington, New Zealand.

Best, S., 1993. At the Halls of the Mountain Kings. Fijian and Samoan fortifications: comparison and analysis. The Journal of the Polynesian Society 102, 385–447.

Bevan, A., Crema, E., Li, X., Palmisano, A., 2013. Intensities, interactions and uncertainties: some new approaches to archaeological distributions, in: Bevan, A., Lake, M. (Eds.), Computational Approaches to Archaeological Spaces. Left Coast Press, Walnut Creek, pp. 27–52.

Bevan, A., Wilson, A., 2013. Models of settlement hierarchy based on partial evidence. Journal of Archaeological Science 40, 2415–2427. https://doi.org/10.1016/j.jas.2012.12.025

Bird, D.W., O'Connell, J.F., 2006. Behavioral ecology and archaeology. Journal of Archaeological Research 14, 143–188.

Bivand, R.S., Pebesma, E., Gomez-Rubio, V., 2013. Applied Spatial Data Analysis with R. Springer, New York.

Blakeslee, D.J., 1994. Reassessment of Some Radiocarbon Dates from the Central Plains. Plains Anthropologist 39, 103–210. https://doi.org/10.1080/2052546.1994.11931727

Bliege Bird, R., Power, E.A., 2015. Prosocial signaling and cooperation among Martu hunters. Evolution and Human Behavior 36, 389–397. https://doi.org/10.1016/j.evolhumbehav.2015.02.003

Bliege Bird, R., Smith, E.A., 2005. Signaling Theory, Strategic Interaction, and Symbolic Capital. Current Anthropology 46, 221–248.

Boersema, J.J., 2018. An earthly paradise? Easter Island (Rapa Nui) as seen by the eighteenth-century European explorers, in: Haoa-Cardinali, S., Ingersoll, K.B., Ingersoll Jr, D.W., Stevenson, C.M. (Eds.), Cultural and Environmental Change on Rapa Nui. Routledge, New York, pp. 156–178.

Boersema, J.J., 2015. The Survival of Easter Island. Cambridge University Press.

Boldsen, J.L., Milner, G.R., Weise, S., 2015. Cranial vault trauma and selective mortality in medieval to early modern Denmark. PNAS 112, 1721–1726. https://doi.org/10.1073/pnas.1412511112

Bologna, M., Flores, J.C., 2008. A simple mathematical model of society collapse applied to Easter Island. EPL 81, 48006. https://doi.org/10.1209/0295-5075/81/48006

Boone, J.L., 2000. Status signaling, social power, and lineage survival, in: Diehl, M.W. (Ed.), Hierarchies in Action: Cui Bono. Center for Archaeological Investigations, Occasional Paper No. 27, Carbondale, pp. 267–290.

Boone, J.L., 1998. The evolution of magnanimity: When is it better to give than to receive? Human Nature 9, 1–21.

Boone, J.L., 1992. Competition, conflict, and the development of social hierarchies, in: Smith, E.A., Winterhalder, B. (Eds.), Evolutionary Ecology and Human Behavior. pp. 301–337.

Bork, H.-R., Mieth, A., Tschochner, B., 2004. Nothing But Stones? A review fo the extent and technical efforts of prehistoric stone mulching on Rapa Nui. Rapa Nui Journal 18, 10–14.

Bowles, S., 2009. Did Warfare Among Ancestral Hunter-Gatherers Affect the Evolution of Human Social Behaviors? Science 324, 1293–1298. https://doi.org/10.1126/science.1168112

Bradley, R., 2012. The significance of monuments: on the shaping of human experience in Neolithic and Bronze Age Europe. Routledge.

Brain, J.P., 1978. The Archaeological Phase: Ethnographic Fact or Fancy?, in: Dunnell, R.C., Hall, E.S. (Eds.), Archaeological Essays in Honor of Irving B. Rouse. De Gruyter Mouton, New York, pp. 311–318.

Brander, J.A., Taylor, M.S., 1998. The Simple Economics of Easter Island: A Ricardo-Malthus Model of Renewable Resource Use. The American Economic Review 88, 119–138.

Brandt, G., Merico, A., 2015. The slow demise of Easter Island: insights from a modeling investigation. Front. Ecol. Evol. 3. https://doi.org/10.3389/fevo.2015.00013

Bronk Ramsey, C., 2017a. OxCal Project, Version 4.3.

Bronk Ramsey, C., 2017b. Methods for Summarizing Radiocarbon Datasets. Radiocarbon 59, 1809–1833. https://doi.org/10.1017/RDC.2017.108

Bronk Ramsey, C., 2009. Dealing with outliers and offsets in radiocarbon dating. Radiocarbon 51, 1023–1045.

Brosnan, T., Becker, M.W., Lipo, C.P., 2019. Coastal groundwater discharge and the ancient inhabitants of Rapa Nui (Easter Island), Chile. Hydrogeol J 27, 519–534. https://doi.org/10.1007/s10040-018-1870-7

Brosnan, T., Becker, M.W., Lipo, C.P., 2018. Coastal groundwater discharge and the ancient inhabitants of Rapa Nui (Easter Island, Chile). Hydrogeology Journal.

Broughton, J.M., Bayham, F.E., 2003. Showing off, Foraging Models, and the Ascendance of Large-Game Hunting in the California Middle Archaic. American Antiquity 68, 783–789. https://doi.org/10.2307/3557073

Brousse, R., Gelugne, P., 1986. Géologie et pétrologie de L’ile de Rapa, in: Service Mixte de Contrôle Biologique (Ed.), Rapa. Direction des Centres d’Expérimentation Nucléaires, Moisdon-la-Rivière, France, pp. 9–61.

Brown, J.L., 1964. The evolution of diversity in avian territorial systems. The Wilson Bulletin 160–169.

Buccellati, F., Hageneuer, S., van der Heyden, S., Levenson, F., 2019. Size matters: understanding monumentality across ancient civilizations. Transcript Verlag, Bielefeld.

Bulbulia, J., Sosis, R., 2011. Signalling theory and the evolution of religious cooperation. Religion 41, 363–388. https://doi.org/10.1080/0048721X.2011.604508

Burnham, K.P., Anderson, D.R., 2010. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. Springer, New York, NY.

Burnham, K.P., Anderson, D.R., 2004. Multimodel Inference: Understanding AIC and BIC in Model Selection. Sociological Methods & Research 33, 261–304. https://doi.org/10.1177/0049124104268644

Burnham, K.P., Anderson, D.R., Huyvaert, K.P., 2011. AIC model selection and multimodel inference in behavioral ecology: some background, observations, and comparisons. Behav Ecol Sociobiol 65, 23–35. https://doi.org/10.1007/s00265-010-1029-6

Butzer, K.W., Endfield, G.H., 2012. Critical perspectives on historical collapse. PNAS 109, 3628–3631. https://doi.org/10.1073/pnas.1114772109

Cañellas-Boltà, N., Rull, V., Sáez, A., Margalef, O., Bao, R., Pla-Rabes, S., Blaauw, M., Valero-Garcés, B., Giralt, S., 2013. Vegetation changes and human settlement of Easter Island during the last millennia: a multiproxy study of the Lake Raraku sediments. Quaternary Science Reviews 72, 36–48. https://doi.org/10.1016/j.quascirev.2013.04.004

Carneiro, R.L., 1970. A Theory of the Origin of the State: Science 169, 733–738. https://doi.org/10.1126/science.169.3947.733

Carrero-Pazos, M., Rodríguez-Casal, A.A., Forthcoming. General and Local Spatial Trends in Galician Megalithic Landscapes (NW Iberian Peninsula), in: Hinz, M., Müller, J. (Eds.), Megaliths, Societies and Landscapes: Early Monumentality and Social Differentiation in Neolithic Europe. Universität zu Kiel, Kiel, pp. 1–25.

Carson, M.T., 2012. An overview of latte period archaeology. Micronesica 42, 1–79.

Carter, A.K., Stark, M.T., Quintus, S., Zhuang, Y., Wang, H., Heng, P., Chhay, R., 2019. Temple occupation and the tempo of collapse at Angkor Wat, Cambodia. PNAS 116, 12226–12231. https://doi.org/10.1073/pnas.1821879116

Cashdan, E., 1992. Spatial organization and habitat use, in: Smith, E.A., Winterhalder, B. (Eds.), Evolutionary Ecology and Human Behavior, Foundations of Human Behavior. Aldine de Gruyter, Hawthorne, NY, US, pp. 237–266.

Cauwe, N., 2016. Ostentation, power and megaliths: the example of Easter Island, in: Laporte, L., Scarre, C. (Eds.), The Megalithic Architectures of Europe. Oxbow Books, Oxford, pp. 55–70.

Cauwe, N., 2014. Megaliths of Easter Island, in: Proceedings of the International Conference 'Autour Du Petit-Chasseur à Sion'(Valais, Switzerland, 27-30 October 2011). Oxford, Bar, International Series.

Cauwe, N., Huyge, D., Coupe, D., De Poorter, A., Lemaitre, S., Claes, W., De Dapper, M., Meulemeester, J.D., al-Shqour, R., 2010. Ahu Motu Toremo Hiva (Poike Peninsula, Easter Island): dynamic architecture of a series of ahu, in: Wallin, P., Martinsson Wallin, H. (Eds.), The Gotland Papers: Selected Papers from the VII International Conference on Easter Island and the Pacific. Gotland University Press, Gotland, pp. 47–56.

Cauwe, N., Huyge, D., De Meulemeester, J., De Dapper, M., Coupe, D., Claes, W., De Poorter, A., 2006. New data from Poike (Rapa Nui-Easter Island): dynamic architecture of a series of Ahu. Rapa Nui Journal 20, 31–36.

Cazalis, V., Loreau, M., Henderson, K., 2018. Do we have to choose between feeding the human population and conserving nature? Modelling the global dependence of people on ecosystem services. Science of The Total Environment 634, 1463–1474. https://doi.org/10.1016/j.scitotenv.2018.03.360

Cegielski, W.H., Rogers, J.D., 2016. Rethinking the role of Agent-Based Modeling in archaeology. Journal of Anthropological Archaeology 41, 283–298. https://doi.org/10.1016/j.jaa.2016.01.009

Chirikure, S., Pollard, M., Manyanga, M., Bandama, F., 2013. A Bayesian chronology for Great Zimbabwe: re-threading the sequence of a vandalised monument. Antiquity 87, 854–872. https://doi.org/10.1017/S0003598X00049516

Choi, J.-K., Bowles, S., 2007. The Coevolution of Parochial Altruism and War. Science 318, 636–640. https://doi.org/10.1126/science.1144237

Church, F., Ellis, J.G., 1996. A use-wear analysis of obsidian tools from an Ana Kionga. Rapa Nui Journal 10, 81–88.

Church, F., Rigney, J., 1994. A micro-wear analysis of tools from Site 10-241, Easter Island–an inland processing site. Rapa Nui Journal 8, 101–105.

Church, M., 2012. Florentine palaces, costly signaling, and lineage survival (Ph.D. Dissertation). University of New Mexico, Albuquerque, N.M.

Ciszewski, A., Ryn, Z.J., Szelerewicz, M., 2009. The Caves of Easter Island: Underground World of Rapa Nui. AGH University of Science and Technology, Poland.

Clark, G., Martinsson-Wallin, H., 2007. Monumental architecture in West Polynesia: origins, chiefs and archaeological approaches. Archaeology in Oceania 42, 1–30. https://doi.org/10.1002/j.1834-4453.2007.tb00006.x

Clark, G., Parton, P., Reepmeyer, C., Melekiola, N., Burley, D., 2018. Conflict and State Development in Ancient Tonga: The Lapaha Earth Fort. The Journal of Island and Coastal Archaeology 13, 405–419. https://doi.org/10.1080/15564894.2017.1337658

Cochrane, E.E., 2018. The Evolution of Migration: the Case of Lapita in the Southwest Pacific. J Archaeol Method Theory 25, 520–558. https://doi.org/10.1007/s10816-017-9345-z

Cochrane, E.E., 2015. Phylogenetic Analysis of Polynesian Ritual Architecture Suggests Extensive Cultural Sharing and Innovation. Journal of the Polynesian Society 124, 7–46.

Cochrane, E.E., 1998. Recent research and future advances in the analysis of Polynesian ceremonial architecture: a review essay. Asian Perspectives 37, 279–300.

Cochrane, E.E., Mills, J., 2018. LiDAR Imagery Confirms Extensive Interior Land-Use on Tutuila, American Sāmoa. Journal of Pacific Archaeology 9, 70–78.

Cocquyt, C., 1991. Diatoms from Easter Island. Biologisch Jaarboek [Dodonaea] 59, 109–124.

Codding, B.F., Bird, D.W., 2015. Behavioral ecology and the future of archaeological science. Journal of Archaeological Science, Scoping the Future of Archaeological Science: Papers in Honour of Richard Klein 56, 9–20. https://doi.org/10.1016/j.jas.2015.02.027

Codding, B.F., Jones, T.L., 2007. Man the Showoff? Or the Ascendance of a Just-so-Story: A Comment on Recent Applications of Costly Signaling Theory in American Archaeology. American Antiquity 72, 349–357. https://doi.org/10.2307/40035818

Codding, B.F., Parker, A.K., Jones, T.L., 2017. Territorial behavior among Western North American foragers: Allee effects, within group cooperation, and between group conflict. Quaternary International.

Cole, M., Lipo, C.P., Becker, M.W., 2015. Coastal groundwater seeps on Rapa Nui. Presented at the Paper Presented at The 80th Annual Meeting of the Society for American Archaeology, San Francisco, CA.

Commendador, A.S., Dudgeon, J.V., Finney, B.P., Fuller, B.T., Esh, K.S., 2013. A stable isotope (δ13C and δ15N) perspective on human diet on rapa nui (Easter Island) ca. AD 1400–1900. American Journal of Physical Anthropology 152, 173–185. https://doi.org/10.1002/ajpa.22339

Commendador, A.S., Dudgeon, J.V., Fuller, B.T., Finney, B.P., 2014. Radiocarbon dating human skeletal material on Rapa Nui: evaluating the effect of uncertainty in marine-derived carbon. Radiocarbon 56, 277–294.

Commendador, A.S., Finney, B.P., Fuller, B.T., Tromp, M., Dudgeon, J.V., 2019. Multiproxy isotopic analyses of human skeletal material from Rapa Nui: Evaluating the evidence from carbonates, bulk collagen, and amino acids. American Journal of Physical Anthropology 0, 1–16. https://doi.org/10.1002/ajpa.23851

Conolly, J., 2017. Costly signalling in archaeology: origins, relevance, challenges and prospects. World Archaeology 49, 435–445. https://doi.org/10.1080/00438243.2017.1401860

Contreras, D.A., Meadows, J., 2014. Summed radiocarbon calibrations as a population proxy: a critical evaluation using a realistic simulation approach. Journal of Archaeological Science 52, 591–608. https://doi.org/10.1016/j.jas.2014.05.030

Corney, B.G., González de Haedo, F., Roggeveen, J., 1967. The voyage of Captain Don Felipe González : in the ship of the line San Lorenzo, with the frigate Santa Rosalia in company, to Easter Island in 1770-1. Preceded by an extract from Mynheer Jacob Roggeveen's official log of his discovery of and visit to Easter Island in 1722. Kraus Reprint, Nendeln, Liechtenstein.

Crane, H.R., Griffin, J.B., 1965. University of Michigan Radiocarbon Dates X. Radiocarbon 7, 123–152.

Crema, E.R., Habu, J., Kobayashi, K., Madella, M., 2016. Summed Probability Distribution of 14 C Dates Suggests Regional Divergences in the Population Dynamics of the Jomon Period in Eastern Japan. PLOS ONE 11, e0154809. https://doi.org/10.1371/journal.pone.0154809

Cressey, J., 1998. Making a splash in the Pacific: dolphin and whale myths and legends in Oceania. Rapa Nui Journal 12, 75–84.

Čučković, Z., 2017. Claiming the sea: Bronze Age fortified sites of the north-eastern Adriatic Sea (Cres and Lošinj islands, Croatia). World Archaeology 49, 526–546. https://doi.org/10.1080/00438243.2017.1341331

Culleton, B.J., Prufer, K.M., Kennett, D.J., 2012. A Bayesian AMS 14C chronology of the Classic Maya Center of Uxbenká, Belize. Journal of Archaeological Science 39, 1572–1586. https://doi.org/10.1016/j.jas.2011.12.015

D'Alessandro, S., 2007. Non-linear dynamics of population and natural resources: The emergence of different patterns of development. Ecological Economics 62, 473–481. https://doi.org/10.1016/j.ecolecon.2006.07.008

Dalton, T.R., Coats, R.M., 2000. Could institutional reform have saved Easter Island? Journal of Evolutionary Economics 10, 489–505.

Dalton, T.R., Coats, R.M., Asrabadi, B.R., 2005. Renewable resources, property-rights regimes and endogenous growth. Ecological Economics 52, 31–41. https://doi.org/10.1016/j.ecolecon.2004.03.033

Davies, N.B., Houston, A.I., 1984. Territory Economics, in: Krebs, J.R., Davies, N.B. (Eds.), Behavioural Ecology: An Evolutionary Approach, Second Edition. Sinauer Associates Inc, Sunderland, pp. 148–169.

de la Croix, D., Dottori, D., 2008. Easter Island's collapse: a tale of a population race. J Econ Growth 13, 27–55. https://doi.org/10.1007/s10887-007-9025-z

De Souza, J.G., Corteletti, R., Robinson, M., Iriarte, J., 2016. The genesis of monuments: Resisting outsiders in the contested landscapes of southern Brazil. Journal of Anthropological Archaeology 41, 196–212.

Dee, M.W., Bronk Ramsey, C., 2014. High-Precision Bayesian Modeling of Samples Susceptible to Inbuilt Age. Radiocarbon 56, 83–94. https://doi.org/10.2458/56.16685

DeMarrais, E., Castillo, L.J., Earle, T., 1996. Ideology, Materialization, and Power Strategies. Current Anthropology 37, 15–31. https://doi.org/10.1086/204472

Diamond, J., 2007. Easter Island Revisited. Science 317, 1692–1694. https://doi.org/10.1126/science.1138442

Diamond, J., 2005. Collapse: how societies choose to fail or succeed. Viking, New York.

Diamond, J., 1995. Easter's end. Discover 9, 62–69.

DiNapoli, R.J., Leppard, T.P., 2018. Islands as Model Environments. The Journal of Island and Coastal Archaeology 13, 157–160. https://doi.org/10.1080/15564894.2017.1311285

DiNapoli, R.J., Lipo, C.P., Brosnan, T., Hunt, T.L., Hixon, S., Morrison, A.E., Becker, M., 2019. Rapa Nui (Easter Island) monument (ahu) locations explained by freshwater sources. PLOS ONE 14, e0210409. https://doi.org/10.1371/journal.pone.0210409

DiNapoli, R.J., Morrison, A.E., 2017. Human behavioural ecology and Pacific archaeology. Archaeology in Oceania 52, 1–12. https://doi.org/10.1002/arco.5124

DiNapoli, R.J., Morrison, A.E., Lipo, C.P., Hunt, T.L., Lane, B.G., 2018. East Polynesian Islands as Models of Cultural Divergence: The Case of Rapa Nui and Rapa Iti. The Journal of Island and Coastal Archaeology 13, 206–223. https://doi.org/10.1080/15564894.2016.1276490

DiNapoli, R.J., Rieth, T.M., Lipo, C.P., Hunt, T.L., 2020. A model-based approach to the tempo of "collapse": The case of Rapa Nui (Easter Island). Journal of Archaeological Science 116, 105094. https://doi.org/10.1016/j.jas.2020.105094

Dockstader, Z., Bauch, C.T., Anand, M., 2019. Interconnections Accelerate Collapse in a Socio-Ecological Metapopulation. Sustainability 11, 1852. https://doi.org/10.3390/su11071852

Dolfini, A., Crellin, R.J., Horn, C., Uckelmann, M., 2018. Prehistoric Warfare and Violence: Quantitative and Qualitative Approaches. Springer.

Dos Pasos, J., 1971. Easter Island: Island of Enigmas. Doubleday, Garden City, NY.

Downey, S.S., Haas, W.R., Shennan, S.J., 2016. European Neolithic societies showed early warning signals of population collapse. PNAS 113, 9751–9756. https://doi.org/10.1073/pnas.1602504113

Dudgeon, J.V., 2008. The genetic architecture of the late prehistoric and protohistoric Rapanui (PhD Dissertation). University of Hawaii, Manoa, Honolulu.

Dudgeon, J.V., Tromp, M., 2014. Diet, Geography and Drinking Water in Polynesia: Microfossil Research from Archaeological Human Dental Calculus, Rapa Nui (Easter Island). International Journal of Osteoarchaeology 24, 634–648. https://doi.org/10.1002/oa.2249

Dungan, K.A., Peeples, M.A., 2018. Public architecture as performance space in the prehispanic central southwest. Journal of Anthropological Archaeology 50, 12–26. https://doi.org/10.1016/j.jaa.2018.02.001

Dungan, K.A., White, D., Déderix, S., Mills, B.J., Safi, K., 2018. A total viewshed approach to local visibility in the Chaco World. Antiquity 92, 905–921. https://doi.org/10.15184/aqy.2018.135

Dunnell, R.C., 1999. The Concept of Waste in an Evolutionary Archaeology. Journal of Anthropological Archaeology 18, 243–250.

Dunnell, R.C., 1989. Aspects of the application of evolutionary theory in archaeology, in: Lamberg-Karlovksy, C.C. (Ed.), Archaeological Thought in America. Cambridge University Press, Cambridge, pp. 35–49.

Dunnell, R.C., 1982. Science, Social Science, and Common Sense: The Agonizing Dilemma of Modern Archaeology. Journal of Anthropological Research 38, 1–25.

Dunnell, R.C., 1980. Evolutionary Theory and Archaeology, in: Schiffer, M.B. (Ed.), Advances in Archaeological Method and Theory, Vol. 3. Academic Press, New York, pp. 35–99.

Dunnell, R.C., 1971. Systematics in Prehistory. The Free Press, New York.

Dunnell, R.C., Greenlee, D.M., 1999. Late Woodland Period "Waste" Reduction in the Ohio River Valley. Journal of Anthropological Archaeology 18, 376–395.

Dye, T.S., 2016. Long-term rhythms in the development of Hawaiian social stratification. Journal of Archaeological Science 71, 1–9.

Dye, T.S., 2012. Hawaiian temples and Bayesian chronology. Antiquity 86, 1202–1206.

Dye, T.S., 2010. Traditional Hawaiian surface architecture: absolute and relative dating, in: Dye, T.S. (Ed.), Research Designs for Hawaiian Archaeology: Agriculture, Architecture, Methodology. Society for Hawaiian Archaeology, Honolulu, pp. 93–155.

Dyson-Hudson, R., Smith, E.A., 1978. Human Territoriality: An Ecological Reassessment. American Anthropologist 80, 21–41.

Earle, T., 1997. How Chiefs Come to Power: The Political Economy in Prehistory. Stanford University Press, Stanford.

Earle, T., Spriggs, M., 2015. Political Economy in Prehistory: A Marxist Approach to Pacific Sequences. Current Anthropology 56, 515–544.

Earle, T.K., 1993. Chiefdoms: Power, Economy, and Ideology. Cambridge University Press, Cambridge.

Ebert, C.E., Culleton, B.J., Awe, J.J., Kennett, D.J., 2016. AMS 14C Dating of Preclassic to Classic Period Household Construction in the Ancient Maya Community of Cahal Pech, Belize. Radiocarbon 58, 69–87. https://doi.org/10.1017/RDC.2015.7

Ebert, C.E., Peniche May, N., Culleton, B.J., Awe, J.J., Kennett, D.J., 2017. Regional response to drought during the formation and decline of Preclassic Maya societies. Quaternary Science Reviews 173, 211–235. https://doi.org/10.1016/j.quascirev.2017.08.020

Edwards, E., Marchetti, R., Dominichetti, L., Gonzáles-Ferrán, O., 1996. When the Earth trembled, the statues fell. Rapa Nui Journal 10, 1–16.

Englert, S., 1970. Island at the Center of the World: New Light on Easter island. Scribner, New York.

Englert, S., 1948. La Tierra de Hotu Matu'a: Historia, Etnologia, y Lengua de Isla de Pascua. San Francisco.

Erickson, J.D., Gowdy, J.M., 2000. Resource Use, Institutions, and Sustainability: A Tale of Two Pacific Island Cultures. Land Economics 76, 345–354. https://doi.org/10.2307/3147033

Esen-Baur, H.-M., 1983. Untersuchungen über den Vogelmann-Kult auf der Osterinsel. Wiesbaden, Frankfurt.

Eve, S.J., Crema, E.R., 2014. A house with a view? Multi-model inference, visibility fields, and point process analysis of a Bronze Age settlement on Leskernick Hill (Cornwall, UK). Journal of Archaeological Science 43, 267–277. https://doi.org/10.1016/j.jas.2013.12.019

Fehren-Schmitz, L., Jarman, C.L., Harkins, K.M., Kayser, M., Popp, B.N., Skoglund, P., 2017. Genetic Ancestry of Rapanui before and after European Contact. Current Biology 27, 3209–3215.

Ferdon, E.N., 1961. The ceremonial site of Orongo, in: Heyerdahl, T., Ferdon, E.N. (Eds.), Reports of the Norwegian Archaeological Expedition to Easter Island and the East Pacific Volume 1: Archaeology of Easter Island. Forum Publishing House, Stockholm, pp. 221–255.

Fessler, D.M.T., Holbrook, C., 2016. Synchronized behavior increases assessments of the formidability and cohesion of coalitions. Evolution and Human Behavior 37, 502–509. https://doi.org/10.1016/j.evolhumbehav.2016.05.003

Field, J.S., 2008. Explaining Fortifications in Indo-Pacific Prehistory. Archaeology in Oceania 43, 1–10. https://doi.org/10.1002/j.1834-4453.2008.tb00025.x

Field, J.S., 2004. Environmental and climatic considerations: a hypothesis for conflict and the emergence of social complexity in Fijian prehistory. Journal of Anthropological Archaeology 23, 79–99. https://doi.org/10.1016/j.jaa.2003.12.004

Field, J.S., Kirch, P.V., Kawelu, K., Ladefoged, T.N., 2010. Households and Hierarchy: Domestic Modes of Production in Leeward Kohala, Hawai'i Island. The Journal of Island and Coastal Archaeology 5, 52–85. https://doi.org/10.1080/15564890903178663

Field, J.S., Ladefoged, T.N., Sharp, W.D., Kirch, P.V., 2011. Residential Chronology, Household Subsistence, and the Emergence of Socioeconomic Territories in Leeward Kohala, Hawai'i Island. Radiocarbon 53, 605–627.

Field, J.S., Lape, P.V., 2010. Paleoclimates and the emergence of fortifications in the tropical Pacific islands. Journal of Anthropological Archaeology 29, 113–124.

Finlayson, B., Mithen, S.J., Najjar, M., Smith, S., Maričević, D., Pankhurst, N., Yeomans, L., 2011. Architecture, sedentism, and social complexity at Pre-Pottery Neolithic A WF16, Southern Jordan. PNAS 108, 8183–8188. https://doi.org/10.1073/pnas.1017642108

Fischer, S.R., 2005. Island at the End of the World: The Turbulent History of Easter Island. Reaktion Books Ltd, London.

Fischer, S.R., 1992. At the Teeth of Savages. Rapa Nui Journal 6, 72–73.

Fitzpatrick, S.M., 2001. Archaeological investigation of Omis Cave: a Yapese stone money quarry in Palau. Archaeology in Oceania 36, 153–162. https://doi.org/10.1002/j.1834-4453.2001.tb00489.x

Flenley, J., Bahn, P., 2003. The enigmas of Easter Island: island on the edge. Oxford University Press, New York.

Flenley, J.R., 1998. New Data and New Thoughts on Rapa Nui, in: Stevenson, C.M., Lee, G., Morin, F.J. (Eds.), Easter Island in Pacific Context: South Seas Symposium: Proceedings of the Fourth International Conference on Easter Island and East Polynesia. Easter Island Foundation, Los Osos, pp. 125–128.

Flenley, J.R., 1996. Further evidence of vegetational change on Easter Island. South Pacific Study 16, 135–141.

Flenley, J.R., 1979. Stratigraphic evidence of environmental change on Easter Island. Asian Perspectives 22, 33–40.

Flenley, J.R., King, A.S.M., Jackson, J., Chew, C., Teller, J.T., Prentice, M.E., 1991. The Late Quaternary vegetational and climatic history of Easter Island. Journal of Quaternary Science 6, 85–115.

Flenley, J.R., King, S.M., 1984. Late quaternary pollen records from Easter Island. Nature 307, 47–50.

Fogelin, L., 2003. Ritual and Presentation in Early Buddhist Religious Architecture. Asian Perspectives 42, 129–154.

Forster, G., Kahn, R.L., 1968. Georg Forsters Werke. Akad.-Verl., Berlin.

Friedlander, A.M., Ballesteros, E., Beets, J., Berkenpas, E., Gaymer, C.F., Gorny, M., Sala, E., 2013. Effects of isolation and fishing on the marine ecosystems of Easter Island and Salas y Gómez, Chile. Aquatic Conserv: Mar. Freshw. Ecosyst. 23, 515–531. https://doi.org/10.1002/aqc.2333

Fry, D.P., Söderberg, P., 2013. Lethal Aggression in Mobile Forager Bands and Implications for the Origins of War. Science 341, 270–273. https://doi.org/10.1126/science.1235675

Genz, J., Hunt, T.L., 2003. El Nino/Southern Oscillation and Rapa Nui Prehistory. Rapa Nui Journal 17, 7–14.

Geyer, C.J., Møller, J., 1994. Simulation Procedures and Likelihood Inference for Spatial Point Processes. Scandinavian Journal of Statistics 21, 359–373.

Gill, G.W., Owsley, D.W., 1993. Human osteology of Rapanui, in: Fischer, S.R. (Ed.), Contributions to the History of Rapanui in Memory of William T. Mulloy (Oxbow Monograph, 32). Oxbow Books, Oxford, pp. 56–62.

Gill, G.W., Owsley, D.W., Baker, S.J., 1983. Craniometric evaluation of prehistoric Easter Island populations. American Journal of Physical Anthropology 110, 407–419.

Gill, G.W., Stefan, V.H., 2016. Rapanui origins, relationships, and warfare: A summary in theoretical context, in: Stefan, V.H., Gill, G.W. (Eds.), Skeletal Biology of the Ancient Rapanui (Easter Islanders). Cambridge University Press, Cambridge, pp. 286–302.

Gillings, M., 2017. Mapping liminality: Critical frameworks for the GIS-based modelling of visibility. Journal of Archaeological Science, Archaeological GIS Today: Persistent Challenges, Pushing Old Boundaries, and Exploring New Horizons 84, 121–128. https://doi.org/10.1016/j.jas.2017.05.004

Gintis, H., Smith, E.A., Bowles, S., 2001. Costly Signaling and Cooperation. Journal of Theoretical Biology 213, 103–119.

Giovas, C.M., Fitzpatrick, S.M., 2014. Prehistoric migration in the Caribbean: past perspectives, new models and the ideal free distribution of West Indian colonization. World Archaeology 46, 569–589. https://doi.org/10.1080/00438243.2014.933123

Gittins, R., Pettitt, P., 2017. Is Palaeolithic cave art consistent with costly signalling theory? Lascaux as a test case. World Archaeology 49, 466–490. https://doi.org/10.1080/00438243.2017.1386590

Glatz, C., Plourde, A.M., 2011. Landscape Monuments and Political Competition in Late Bronze Age Anatolia: An Investigation of Costly Signaling Theory. Bulletin of the American Schools of Oriental Research 361, 33–66.

Glowacki, L., Wilson, M.L., Wrangham, R.W., 2017. The evolutionary anthropology of war. Journal of Economic Behavior & Organization.

Goldman, I., 1970. Ancient Polynesian society. University of Chicago Press, Chicago.

Gómez, J.M., Verdú, M., González-Megías, A., Méndez, M., 2016. The phylogenetic roots of human lethal violence. Nature 538, 233–237. https://doi.org/10.1038/nature19758

Grafen, A., 1990. Biological signals as handicaps. Journal of Theoretical Biology 144, 517–546.

Graves, M.W., Ladefoged, T.N., 1995. The evolutionary significance of ceremonial architecture in Polynesia, in: Teltser, P.A. (Ed.), Evolutionary Archaeology: Methodological Issues. University of Arizona Press, Tucson, pp. 149–174.

Graves, M.W., Sweeney, M., 1993. Ritual behaviour and ceremonial structures in eastern Polynesia: changing perspectives on archaeological variability, in: Graves, M.W., Green, R.C. (Eds.), The Evolution and Organisation of Prehistoric Society in Polynesia. New Zealand Archaeological Association, Auckland, pp. 106–125.

Green, R.C., 2000. Origins for the Rapanui of Easter Island Before European Contact: Solutions from Holistic Anthropology to an Issue no Longer Much of a Mystery. Rapa Nui Journal 14, 71–76.

Green, S., Bevan, A., Shapland, M., 2014. A comparative assessment of structure from motion methods for archaeological research. Journal of Archaeological Science 46, 173–181. https://doi.org/10.1016/j.jas.2014.02.030

Grimstead, D.N., 2010. Ethnographic and Modeled Costs of Long-Distance, Big-Game Hunting. American Antiquity 75, 61–80. https://doi.org/10.7183/0002-7316.75.1.61

Guilaine, J., Zammit, J., 2008. The Origins of War: Violence in Prehistory. John Wiley & Sons.

Guilford, T., Dawkins, M.S., 1993. Receiver psychology and the design of animal signals. Trends in Neurosciences 16, 430–436. https://doi.org/10.1016/0166-2236(93)90068-W

Hamilton, S., Nahoe Arellano, S., Richards, C., Torres H., F., 2008. Quarried away: thinking about landscapes of megalithic construction on Rapa Nui (Easter Island), in: David, B., Thomas, J. (Eds.), Handbook of Landscape Archaeology. World Archaeological Congress, pp. 176–186.

Hawkes, K., Bliege Bird, R., 2002. Showing off, handicap signaling, and the evolution of men’s work. Evol. Anthropol. 11, 58–67. https://doi.org/10.1002/evan.20005

Hem, J.D., 1985. Study and interpretation of the chemical characteristics of natural water. Department of the Interior, US Geological Survey.

Henrich, J., 2009. The evolution of costly displays, cooperation and religion: credibility enhancing displays and their implications for cultural evolution. Evolution and Human Behavior 30, 244–260. https://doi.org/10.1016/j.evolhumbehav.2009.03.005

Herrera, C., Custodio, E., 2008. Conceptual hydrogeological model of volcanic Easter Island (Chile) after chemical and isotopic surveys. Hydrogeology Journal 16, 1329–1348.

Heyerdahl, T., Ferdon, E.N., 1961. Archaeology of Easter Island. Forum Publishing House, Stockholm.

Hildebrand, E.A., 2013. Is monumentality in the eye of the beholder? Lessons from constructed spaces in Africa. Azania: Archaeological Research in Africa 48, 155–172.

Hixon, S.W., DiNapoli, R.J., Lipo, C.P., Hunt, T.L., 2019. The Ethnohistory of Freshwater Use on Rapa Nui (Easter Island, Chile). The Journal of the Polynesian Society 128, 163–190.

Hixon, S.W., Lipo, C.P., Hunt, T.L., Lee, C., 2017. Using Structure from Motion Mapping to Record and Analyze Details of the Colossal Hats (Pukao) of Monumental Statues on Rapa Nui (Easter Island). Advances in Archaeological Practice 6, 42–57. https://doi.org/10.1017/aap.2017.28

Hixon, S.W., Lipo, C.P., McMorran, B., Hunt, T.L., 2018. The colossal hats (pukao) of monumental statues on Rapa Nui (Easter Island, Chile): Analyses of pukao variability, transport, and emplacement. Journal of Archaeological Science. https://doi.org/10.1016/j.jas.2018.04.011

Hochstetter, F.T., Haoa, S.R., Lipo, C.P., Hunt, T.L., 2011. A PUBLIC DATABASE OF ARCHAEOLOGICAL RESOURCES ON EASTER ISLAND (RAPA NUI) USING GOOGLE EARTH. Latin American Antiquity 22, 385–397.

Hoggarth, J.A., Breitenbach, S.F.M., Culleton, B.J., Ebert, C.E., Masson, M.A., Kennett, D.J., 2016. The political collapse of Chichén Itzá in climatic and cultural context. Global and Planetary Change, Climate Change and Archaeology in Mesoamerica: A Mirror for the Anthropocene 138, 25–42. https://doi.org/10.1016/j.gloplacha.2015.12.007

Holton, G.E.L., 2004. Heyerdahl’s Kon Tiki Theory and the Denial of the Indigenous Past. Anthropological Forum 14, 163–181.

Horrocks, M., Baisden, T., Flenley, J., Feek, D., Love, C., Haoa-Cardinali, S., González Nualart, L., Edmunds Gorman, T., 2017. Pollen, phytolith and starch analyses of dryland soils from Easter Island (Rapa Nui) show widespread vegetation clearance and Polynesian-introduced crops. Palynology 41, 339–350.

Horrocks, M., Wozniak, J.A., 2008. Plant microfossil analysis reveals disturbed forest and a mixed-crop, dryland production system at Te Niu, Easter Island. Journal of Archaeological Science 35, 126–142.

Howey, M.C., Clark, M., 2017. Analyzing landform patterns in the monumental landscape of the northern Great Lakes, 1200–1600CE. Journal of Archaeological Science: Reports. https://doi.org/10.1016/j.jasrep.2017.05.033

Howey, M.C.L., Palace, M.W., McMichael, C.H., 2016. Geospatial modeling approach to monument construction using Michigan from A.D. 1000–1600 as a case study. PNAS 113, 7443–7448. https://doi.org/10.1073/pnas.1603450113

Hubbard, D.K., Garcia, M., 2003. The Corals and Coral Reefs of Easter Island — A Preliminary Look, in: Loret, J., Tanacredi, J., T. (Eds.), Easter Island: Scientific Exploration into the World's Environmental Problems in Microcosm. Springer, Boston, pp. 53–77. https://doi.org/10.1007/978-1-4615-0183-1_5

Hunt, T.L., 2007. Rethinking Easter Island's ecological catastrophe. Journal of Archaeological Science 34, 485–502.

Hunt, T.L., 2006. Rethinking the fall of Easter Island. American Scientist 94, 412.

Hunt, T.L., Lipo, C., 2018. The Archaeology of Rapa Nui (Easter Island), in: Cochrane, E.E., Hunt, T.L. (Eds.), The Oxford Handbook of Prehistoric Oceania. Oxford University Press, New York, pp. 416–449.

Hunt, T.L., Lipo, C.P., 2013. The Human Transformation of Rapa Nui (Easter Island, Pacific Ocean), in: Larrue, S. (Ed.), Biodiversity and Societies in the Pacific Islands. Pressed Universitaires de Provence, pp. 167–184.

Hunt, T.L., Lipo, C.P., 2011. The Statues That Walked: Unraveling the Mystery of Easter Island. Free Press, New York.

Hunt, T.L., Lipo, C.P., 2009. Revisiting Rapa Nui (Easter Island) '"Ecocide."' Pacific Science 63, 601–616.

Hunt, T.L., Lipo, C.P., 2008. Evidence for a Shorter Chronology on Rapa Nui (Easter Island). The Journal of Island and Coastal Archaeology 3, 140–148. https://doi.org/10.1080/15564890801990797

Hunt, T.L., Lipo, C.P., 2007. Chronology, deforestation, and "collapse:" Evidence vs. faith in Rapa Nui prehistory. Rapa Nui Journal 21, 85–97.

Hunt, T.L., Lipo, C.P., 2006. Late colonization of Easter island. Science 311, 1603–1606. https://doi.org/10.1126/science.1121879

Hunt, T.L., Lipo, C.P., 2001. Cultural Elaboration and Environmental Uncertainty in Polynesia, in: Stevenson, C.M., Lee, G., Morin, F.J. (Eds.), Pacific 2000. Proceedings of the Fifth International Conference on Easter Island and the Pacific. Easter Island Foundation, Los Osos, pp. 103–115.

Hunt, T.L., Lipo, C.P., Sterling, S.L., 2001. Posing Questions for a Scientific Archaeology, in: Hunt, T.L., Lipo, C.P., Sterling, S.L. (Eds.), Posing Questions for a Scientific Archaeology. Bergin & Garvey, Westport, pp. 1–21.

Hunter-Anderson, R.L., 1998. Human vs climatic impacts at Rapa Nui: Did the people really cut down all those trees?, in: Stevenson, C.M., Lee, G., Morin, F.J. (Eds.), Easter Island in Pacific Context: South Seas Symposium. Proceedings of the Fourth International Conference on Easter Island and East Polynesia. Easter Island Foundation, Los Osos, pp. 85–99.

Huyge, D., Cauwe, N., 2005. Preliminary Report on the Discovery of an unknown ahu at Viri o Tuki (Ko Te Aheru), South Coast, Easter Island. Rapa Nui Journal 19, 7–9.

Huyge, D., Cauwe, N., 2002. The Ahu o Rongo project: archaeological research on Rapa Nui. Rapa Nui Journal 16, 11–16.

Inomata, T., 2006. Plazas, Performers, and Spectators: Political Theaters of the Classic Maya. Current Anthropology 47, 805–842. https://doi.org/10.1086/506279

Irons, W., 2001. Religion as a hard-to-fake sign of commitment, in: Nesse, R. (Ed.), Evolution and the Capacity for Commitment. Russell Sage Foundation, New York, pp. 292–309.

Jaklič, A., Erič, M., Mihajlović, I., Stopinšek, Ž., Solina, F., 2015. Volumetric models from 3D point clouds: The case study of sarcophagi cargo from a 2nd/3rd century AD Roman shipwreck near Sutivan on island Brač, Croatia. Journal of Archaeological Science 62, 143–152. https://doi.org/10.1016/j.jas.2015.08.007

Jakubowska, Z., 2014. Still More to Discover: Easter Island in an Unknown Manuscript by the Forsters from the 18th Century. Muzeum Historii Polskiego Ruchu Ludowego, Warsaw.

Jarman, C.L., Larsen, T., Hunt, T., Lipo, C., Solsvik, R., Wallsgrove, N., Ka'apu-Lyons, C., Close, H.G., Popp, B.N., 2017. Diet of the prehistoric population of Rapa Nui (Easter Island, Chile) shows environmental adaptation and resilience. American journal of physical anthropology 164, 343–361.

Jiménez, G.A., 2018. Untangling Bronze Age Warfare: The Case of Argaric Society, in: Dolfini, A., Crellin, R.J., Horn, C., Uckelmann, M. (Eds.), Prehistoric Warfare and Violence: Quantitative and Qualitative Approaches, Quantitative Methods in the Humanities and Social Sciences. Springer International Publishing, Cham, pp. 327–343. https://doi.org/10.1007/978-3-319-78828-9_15

Johansen, P.G., 2004. Landscape, monumental architecture, and ritual: a reconsideration of the South Indian ashmounds. Journal of Anthropological Archaeology 23, 309–330. https://doi.org/10.1016/j.jaa.2004.05.003

Johnstone, R.A., 1997. The Evolution of Animal Signals, in: Krebs, J.R., Davies, N.B. (Eds.), Behavioural Ecology: An Evolutionary Approach. Blackwell Publishing Ltd, Malden, pp. 155–178.

Joye, Y., Dewitte, S., 2016. Up speeds you down. Awe-evoking monumental buildings trigger behavioral and perceived freezing. Journal of Environmental Psychology 47, 112–125.

Joye, Y., Verpooten, J., 2013. An exploration of the functions of religious monumental architecture from a Darwinian perspective. Review of General Psychology 17, 53–68. https://doi.org/10.1037/a0029920

Kahn, J.G., Kirch, P.V., 2014. Monumentality and Ritual Materialization in the Society Islands: The Archaeology of a Major Ceremonial Complex in the'Opunohu Valley, Mo'orea. Bishop Museum Press, Honolulu.

Kahn, J.G., Kirch, P.V., 2011. Monumentality and the materialization of ideology in Central Eastern Polynesia. Archaeology in Oceania 46, 93–104.

Kantner, J., Vaughn, K.J., 2012. Pilgrimage as costly signal: Religiously motivated cooperation in Chaco and Nasca. Journal of Anthropological Archaeology 31, 66–82. https://doi.org/10.1016/j.jaa.2011.10.003

Kaplan, H., Hill, K., 1992. The Evolutionary Ecology of Food Acquisition, in: Smith, E.A., Winterhalder, B. (Eds.), Evolutionary Ecology and Human Behavior. Aldine Transaction, New York, pp. 167–202.

Kayser, M., 2010. The human genetic history of Oceania: near and remote views of dispersal. Current Biology 20, R194–R201.

Keeley, L.H., 1996. War Before Civilization: The Myth of the Peaceful Savage. Oxford University Press, New York.

Keeley, L.H., Fontana, M., Quick, R., 2007. Baffles and bastions: The universal features of fortifications. Journal of Archaeological Research 15, 55–95.

Kelly, R.L., 2013. From peaceful to the warlike: ethnographic and archaeological insights into hunter-gatherer warfare and homicide, in: Fry, D.P. (Ed.), War, Peace, and Hunam Nature: The Convergence of Evolutionary and Cultural Views. Oxford University Press, Oxford, pp. 151–167.

Kennett, D., Anderson, A., Prebble, M., Conte, E., Southon, J., 2006. Prehistoric human impacts on Rapa, French Polynesia. antiquity 80, 340–354.

Kennett, D.J., Culleton, B.J., Anderson, A., Southon, J., 2012. A Bayesian AMS 14C chronology for the colonisation and fortification of Rapa Island, in: Anderson, A., Kennett, D.J. (Eds.), Taking the High Ground: The Archaeology of Rapa, a Fortified Island in Remote East Polynesia. ANU Press, Canberra, pp. 203–234.

Kennett, D.J., McClure, S.B., 2012. The archaeology of Rapan fortifications, in: Anderson, A., Kennett, D.J. (Eds.), Taking the High Ground: The Archaeology of Rapa, a Fortified Island in Remote East Polynesia, Terra Australis 37. ANU Press, Canberra, pp. 203–234.

Kennett, D.J., Winterhalder, B. (Eds.), 2006. Behavioral Ecology and the Transition to Agriculture, 1st ed. University of California Press.

Kintigh, K.W., Altschul, J.H., Beaudry, M.C., Drennan, R.D., Kinzig, A.P., Kohler, T.A., Limp, W.F., Maschner, H.D.G., Michener, W.K., Pauketat, T.R., Peregrine, P., Sabloff, J.A., Wilkinson, T.J., Wright, H.T., Zeder, M.A., 2014a. Grand Challenges for Archaeology. American Antiquity 79, 5–24. https://doi.org/10.7183/0002-7316.79.1.5

Kintigh, K.W., Altschul, J.H., Beaudry, M.C., Drennan, R.D., Kinzig, A.P., Kohler, T.A., Limp, W.F., Maschner, H.D.G., Michener, W.K., Pauketat, T.R., Peregrine, P., Sabloff, J.A., Wilkinson, T.J., Wright, H.T., Zeder, M.A., 2014b. Grand challenges for archaeology. PNAS 111, 879–880. https://doi.org/10.1073/pnas.1324000111

Kirch, P.V., 2017. On the road of the winds: an archaeological history of the Pacific Islands before European contact. University of California Press, Oakland.

Kirch, P.V., 2010. How chiefs became kings: Divine kingship and the rise of archaic states in ancient Hawai'i. Univ of California Press.

Kirch, P.V., 2007a. Hawaii as a Model System for Human Ecodynamics. American Anthropologist 109, 8–26.

Kirch, P.V., 2007b. Three islands and an archipelago: reciprocal interactions between humans and island ecosystems in Polynesia. Earth and Environmental Science Transactions of the Royal Society of Edinburgh 98, 85–99. https://doi.org/10.1017/S1755691007000011

Kirch, P.V., 2000. On the Road of the Winds: An Archaeological History of the Pacific Islands before European Contact. University of California Press, Berkeley, Calif.

Kirch, P.V., 1997. Microcosmic Histories: Island Perspectives on "Global" Change. American Anthropologist 99, 30–42.

Kirch, P.V., 1994. The Wet and The Dry: Irrigation and Agricultural Intensification in Polynesia. The University of Chicago Press, Chicago.

Kirch, P.V., 1990a. Monumental architecture and power in Polynesian chiefdoms: A comparison of Tonga and Hawaii. World Archaeology 22, 206–222.

Kirch, P.V., 1990b. The evolution of sociopolitical complexity in prehistoric Hawaii: an assessment of the archaeological evidence. Journal of World Prehistory 4, 311–345.

Kirch, P.V., 1986. Introduction: the archaeology of island societies, in: Kirch, P.V. (Ed.), Island Societies: Archaeological Approaches to Evolution and Transformation. Cambridge University Press, Cambridge, pp. 1–5.

Kirch, P.V., 1984a. The Polynesian outliers: Continuity, change, and replacement. The Journal of Pacific History 19, 224–238.

Kirch, P.V., 1984b. The Evolution of the Polynesian Chiefdoms. Cambridge University Press, Cambridge.

Kirch, P.V., Green, R.C., 2001. Hawaiki, Ancestral Polynesia: An Essay in Historical Anthropology, 1st ed. Cambridge University Press.

Kirch, P.V., Rallu, J.-L. (Eds.), 2007. The Growth and Collapse of Pacific Island Societies: Archaeological and Demographic Perspectives. University of Hawai’i Press, Honolulu.

Knapp, B., 2009. Monumental architecture, identity and memory, in: Proceedings of the Symposium: Bronze Age Architectural Traditions in the East Mediterranean: Diffusion and Diversity. pp. 47–59.

Kohler, T.A., Ortman, S.G., Grundtisch, K.E., Fitzpatrick, C.M., Cole, S.M., 2014. The Better Angels of their Nature: Declining Violence through Time Among Prehispanic Farmers of the Pueblo Southwest. American Antiquity 79, 444–464. https://doi.org/10.7183/0002-7316.79.3.444

Kolb, M.J., 2020. Making sense of monuments: narratives of time, movement, and scale. Routledge, Oxon.

Kolb, M.J., 2012. The genesis of monuments in island societies, in: Smith, M.E. (Ed.), The Comparative Archaeology of Complex Societies. Cambridge University Press, Cambridge, pp. 138–164.

Kolb, M.J., 1999. Monumental grandeur and political florescence in pre-contact Hawai’i: Excavations at Pi’ilanihale Heiau, Maui. Archaeology in Oceania 34, 71–82.

Kolb, M.J., 1992. Diachronic design changes in heiau temple architecture on the island of Maui, Hawai’i. Asian Perspectives 9–37.

Kolb, M.J., 1991. Social power, chiefly authority, and ceremonial architecture, in an island polity, Maui, Hawaii (Unpublished Ph.D. Dissertation). University of California Los Angeles, Los Angeles, CA.

Kolb, M.J., Cordy, R., Earle, T., Feinman, G., Graves, M.W., Hastorf, C.A., Hodder, I., Miksic, J.N., Price, B.J., Trigger, B.G., 1994. Monumentality and the Rise of Religious Authority in Precontact Hawai'i [and Comments and Reply]. Current Anthropology 35, 521–547.

Krebs, John R., McCleery, R., 1984. Optimization in Behavioural Ecology, in: Krebs, J. R., Davies, N.B. (Eds.), Behavioural Ecology: An Evolutionary Approach, Second Edition. Sinauer Associates Inc, Sunderland, pp. 91–121.

Kuha, J., 2004. AIC and BIC: Comparisons of Assumptions and Performance. Sociological Methods & Research 33, 188–229. https://doi.org/10.1177/0049124103262065

Kuhn, S.L., 2014. Signaling Theory and Technologies of Communication in the Paleolithic. Biological Theory 9, 42–50.

Ladefoged, T.N., Flaws, A., Stevenson, C.M., 2013. The distribution of rock gardens on Rapa Nui (Easter Island) as determined from satellite imagery. Journal of Archaeological Science 40, 1203–1212.

Ladefoged, T.N., Stevenson, C.M., Haoa, S., Mulrooney, M., Puleston, C., Vitousek, P.M., Chadwick, O.A., 2010. Soil nutrient analysis of Rapa Nui gardening. Archaeology in Oceania 45, 80–85. https://doi.org/10.1002/j.1834-4453.2010.tb00082.x

Lambert, P.M., 2002. The archaeology of war: a North American perspective. Journal of Archaeological Research 10, 207–241.

Lambrides, A.B.J., Weisler, M.I., 2016. Pacific Islands Ichthyoarchaeology: Implications for the Development of Prehistoric Fishing Studies and Global Sustainability. J Archaeol Res 24, 275–324. https://doi.org/10.1007/s10814-016-9090-y

Lane, B.G., 2017. Geospatial modelling for predicting the ideal free settlement of Rapa. Archaeology in Oceania 52, 13–21. https://doi.org/10.1002/arco.5123

Larsen, A., Simpson, D.F.J., 2014. Comment to Rull et al. (2013)—Challenging Easter Island's Collapse: the need for interdisciplinary synergies. Front. Ecol. Evol. 2. https://doi.org/10.3389/fevo.2014.00056

Lawrence, D.L., Low, S.M., 1990. The Built Environment and Spatial Form. Annual Review of Anthropology 19, 453–505. https://doi.org/10.1146/annurev.an.19.100190.002321

Lee, G., 1992. Rock Art of Easter Island: Symbols of Power, Prayers to the Gods. Regents of the University of California, Los Angeles.

Lee, G., 1986. Easter Island rock art: ideological symbols as evidence of socio-political change. (Unpublished Ph.D. Dissertation). University of California, Los Angeles, Los Angeles, CA.

Lee, G., Altman, A.M., Morin, F., 2004. Early Visitors to Easter Island 1864-1877: The Reports of Eugène Eyraud, Hippolyte Roussel, Pierre Loti and Alphonse Pinart. Bearsville Press, Los Osos.

Levenson, F., 2019. Monuments and monumentality - different perspectives, in: Buccellati, F., Hageneuer, S., van der Heyden, S., Levenson, F. (Eds.), Size Matters: Understanding Monumentality across Ancient Civilizations. Transcript Verlag, Bielefeld, pp. 17–39.

Lewontin, R.C., 1974. The genetic basis of evolutionary change. Columbia University Press, New York.

Lipo, C., 2001. Science, Style and the Study of Community Structure: An Example from the Central Mississippi River Valley. British Archaeological Reports, International Series, no. 918, Oxford.

Lipo, C., DiNapoli, R.J., Hunt, T.L., 2019. Commentary: Response: Commentary: Rain, Sun, Soil, and Sweat: A Consideration of Population Limits on Rapa Nui (Easter Island) before European Contact (preprint). SocArXiv. https://doi.org/10.31235/osf.io/6dqeg

Lipo, C.P., DiNapoli, R.J., Hunt, T.L., 2018. Commentary: Rain, Sun, Soil, and Sweat: A Consideration of Population Limits on Rapa Nui (Easter Island) before European Contact. Front. Ecol. Evol. 6. https://doi.org/10.3389/fevo.2018.00025

Lipo, C.P., Hunt, T.L., 2016. Chronology and Easter Island prehistory, in: Stefan, V.H., Gill, G.W. (Eds.), Skeletal Biology of the Ancient Rapanui (Easter Islanders). Cambridge University Press, Cambridge, pp. 39–65.

Lipo, C.P., Hunt, T.L., 2009. AD 1680 and Rapa Nui prehistory. Asian Perspectives 48, 309–317.

Lipo, C.P., Hunt, T.L., 2005. Mapping prehistoric statue roads on Easter Island. Antiquity 79, 158–168. https://doi.org/10.1017/S0003598X00113778

Lipo, C.P., Hunt, T.L., Haoa, S.R., 2013. The ‘walking’ megalithic statues (moai) of Easter Island. Journal of Archaeological Science 40, 2859–2866. https://doi.org/10.1016/j.jas.2012.09.029

Lipo, C.P., Hunt, T.L., Horneman, R., Bonhomme, V., 2016. Weapons of war? Rapa Nui mata’a morphometric analyses. Antiquity 90, 172–187.

Lipo, C.P., Hunt, T.L., Hundtoft, B., 2015. An Analysis of Stylistic Variability of Stemmed Obsidian Tools (Mata'a) on Rapa Nui (Easter Island), in: Goodale, N., Andrefsky, W. (Eds.), Lithic Technological Systems and Evolutionary Theory. Cambridge University Press, Cambridge, pp. 225–238.

Lipo, C.P., Hunt, T.L., Hundtoft, B., 2010. Stylistic variability of stemmed obsidian tools (mata'a), frequency seriation, and the scale of social interaction on Rapa Nui (Easter Island). Journal of Archaeological Science 37, 2551–2561.

Liston, J., 2009. Cultural chronology of earthworks in Palau, western Micronesia. Archaeology in Oceania 44, 56–73.

Llobera, M., 2003. Extending GIS-based visual analysis: the concept of visualscapes. International Journal of Geographical Information Science 17, 25–48. https://doi.org/10.1080/713811741

Llobera, M., Wheatley, D., Steele, J., Cox, S., Parchment, O., 2010. Calculating the inherent visual structure of a landscape (inherent viewshed) using high-throughput computing, in: Niccolucci, F., Hermon, S. (Eds.), Beyond the Artefact: Digital Interpretation of the Past: Proceedings of CAA2004, Prato, 13-17 April 2004. Archaeolingua, Budapest, pp. 146–151.

López, J.A.B., Jiménez, G.A., Romero, M.S., García, E.A., Martín, S.F., Medina, A.L., Guerrero, J.A.E., 2016. 3D modelling in archaeology: The application of Structure from Motion methods to the study of the megalithic necropolis of Panoria (Granada, Spain). Journal of Archaeological Science: Reports 10, 495–506. https://doi.org/10.1016/j.jasrep.2016.11.022

Louwagie, G., Stevenson, C.M., Langohr, R., 2006. The impact of moderate to marginal land suitability on prehistoric agricultural production and models of adaptive strategies for Easter Island (Rapa Nui, Chile). Journal of Anthropological Archaeology 25, 290–317.

Lyman, R.L., O'Brien, M.J., Dunnell, R.C., 1997. The Rise and Fall of Culture History, 1st ed. Springer.

Mann, D., Edwards, J., Chase, J., Beck, W., Reanier, R., Mass, M., Finney, B., Loret, J., 2008. Drought, vegetation change, and human history on Rapa Nui (Isla de Pascua, Easter Island). Quaternary Research 69, 16–28. https://doi.org/10.1016/j.yqres.2007.10.009

Marcus, J., Flannery, K.V., 2004. The coevolution of ritual and society: New 14C dates from ancient Mexico. PNAS 101, 18257–18261. https://doi.org/10.1073/pnas.0408551102

Marsh, E.J., Kidd, R., Ogburn, D., Durán, V., 2017. Dating the Expansion of the Inca Empire: Bayesian Models from Ecuador and Argentina. Radiocarbon 59, 117–140. https://doi.org/10.1017/RDC.2016.118

Martin, D.L., Harrod, R.P., 2015. Bioarchaeological contributions to the study of violence. American journal of physical anthropology 156, 116–145.

Martinsson Wallin, H., 2004. Archaeological excavation at Vinapu (Rapa Nui). Rapa Nui Journal 18, 7–9.

Martinsson-Wallin, H., 2014. Monuments and people - an introduction, in: Martinsson-Wallin, H., Thomas, T. (Eds.), Monuments and People in the Pacific. Uppsala University, Uppsala, pp. 9–44.

Martinsson-Wallin, H., 2004. A historical perspective of restoration and reconstruction of ceremonial sites on Rapa Nui (Easter Island) - a discussion of the recycling of stones with “mana.” Bulletin of the Indo-Pacific Prehistory Association 24, 159–167.

Martinsson-Wallin, H., 2000. “No Stone Unturned”.... a reflection on the recycling of worked stones on Rapa Nui, in: Wallin, P., Martinsson-Wallin, H. (Eds.), Essays in Honour of Arne Skjølsvold: 75 Years, The Kon-Tiki Museum Occasional Papers. The Kon-Tiki Museum, Olso, pp. 44–60.

Martinsson-Wallin, H., 1998. Excavations at Ahu Heki’i, La Perouse, Easter Island, in: Stevenson, C.M., Lee, G., Morin, F.J. (Eds.), Easter Island in Pacific Context: South Seas Symposium. Bearsville Press, Los Osos, pp. 171–177.

Martinsson-Wallin, H., 1994. Ahu - The Ceremonial Stone Structures of Easter Island. Societas Archaeologica Upsaliensis, Uppsala.

Martinsson-Wallin, H., Crockford, S.J., 2002. Early Settlement of Rapa Nui (Easter Island). Asian Perspectives 40, 243–278.

Martinsson-Wallin, H., Wallin, P., 2014. Spatial Perspectives on Ceremonial Complexes: Testing Traditional Land Divisions on Rapa Nui.

Martinsson-Wallin, H., Wallin, P., 2000. Ahu and settlement: archaeological excavations at ’Anakena and La Perouse, in: Stevenson, C.M., Ayres, W.S. (Eds.), Easter Island Archaeology: Research on Early Rapanui Culture. Bearsville Press, Los Osos, pp. 27–43.

Martinsson-Wallin, H., Wallin, P., 1998. Dating of ahu structures within the La Perouse Area. Rapa Nui Journal 12, 85.

Martinsson-Wallin, H., Wallin, P., Anderson, A., Solsvik, R., 2013a. Chronogeographic Variation in Initial East Polynesian Construction of Monumental Ceremonial Sites. The Journal of Island and Coastal Archaeology 8, 405–421. https://doi.org/10.1080/15564894.2013.834009

Martinsson-Wallin, H., Wallin, P., Anderson, A., Solsvik, R., 2013b. Chronogeographic variation in initial East Polynesian construction of monumental ceremonial sites. The Journal of Island and Coastal Archaeology 8, 405–421.

Maschner, H.D.G., Reedy-Maschner, K.L., 1998. Raid, Retreat, Defend (Repeat): The Archaeology and Ethnohistory of Warfare on the North Pacific Rim. Journal of Anthropological Archaeology 17, 19–51. https://doi.org/10.1006/jaar.1997.0315

Matisoo-Smith, E., 2015. Ancient DNA and the human settlement of the Pacific: A review. Journal of Human Evolution, Special Issue: Ancient DNA and Human Evolution 79, 93–104. https://doi.org/10.1016/j.jhevol.2014.10.017

Mattison, S.M., Smith, E.A., Shenk, M.K., Cochrane, E.E., 2016. The evolution of inequality. Evol. Anthropol. 25, 184–199. https://doi.org/10.1002/evan.21491

Maude, H.E., 1981. Slavers in Paradise: The Peruvian slave trade in Polynesia, 1862-1864. Stanford University Press, Stanford.

Maynard Smith, J., 1982. Evolution and the Theory of Games, 1St Edition. ed. Cambridge University Press.

Maynard Smith, J., 1978. Optimization Theory in Evolution. Annual Review of Ecology and Systematics 9, 31–56.

Maynard Smith, J., Harper, D., 2003. Animal Signals. Oxford University Press, New York.

Maynard Smith, J., Harper, D.G.C., 1995. Animal Signals: Models and Terminology. Journal of Theoretical Biology 177, 305–311. https://doi.org/10.1006/jtbi.1995.0248

McAnany, P.A., Yoffee, N., 2010. Questioning Collapse: Human Resilience, Ecological Vulnerability, and the Aftermath of Empire. Cambridge University Press, Cambridge.

McAndrew, F.T., 2002. New Evolutionary Perspectives on Altruism: Multilevel-Selection and Costly-Signaling Theories. Curr Dir Psychol Sci 11, 79–82. https://doi.org/10.1111/1467-8721.00173

McCoy, M., 2014. The Significance of Religious Ritual in Ancient Hawai‘i. Journal of Pacific Archaeology 5, 72–80.

McCoy, M.D., Ladefoged, T.N., 2019. In Pursuit of Māori Warfare: New archaeological research on conflict in pre-European contact New Zealand. Journal of Anthropological Archaeology 56, 101113. https://doi.org/10.1016/j.jaa.2019.101113

McCoy, M.D., Ladefoged, T.N., Bickler, S.H., Stephen, J.W., Graves, M.W., 2012. The value of an" eclectic and pragmatic" approach to chronology building. Antiquity 86, 1206.

McCoy, M.D., Ladefoged, T.N., Graves, M.W., Stephen, J.W., 2011. Strategies for constructing religious authority in ancient Hawai'i. Antiquity 85, 927–941.

McCoy, P.C., 2014. The dressed stone manufacturing technology of Rapa Nui: A preliminary model based on evidence from the Rano Kau, Maunga Tarareina, and Ko Ori quarries. Rapa Nui Journal 28, 5–23.

McCoy, P.C., 1976. Easter Island Settlement Patterns in the Late Prehistoric and Protohistoric Periods. Easter Island Committee, New York.

McCurdy, L., Abrams, E.M., 2019. Architectural energetics in archaeology: analytical expansions and global explorations. Routledge, Oxon.

McGuire, K.R., Hildebrandt, W.R., 2005. Re-Thinking Great Basin Foragers: Prestige Hunting and Costly Signaling during the Middle Archaic Period. American Antiquity 70, 695–712. https://doi.org/10.2307/40035870

McGuire, K.R., Hildebrandt, W.R., Carpenter, K.L., 2007. Costly Signaling and the Ascendance of No-Can-Do Archaeology: A Reply to Codding and Jones. American Antiquity 72, 358–365. https://doi.org/10.2307/40035819

McIvor, I.H., 2015. Monumental ideology: A GIS spatial analysis of interior features of Matakawau Pa, Ahuahu (Stingray Point Pa, Great Mercury Island), New Zealand. Journal of the Polynesian Society, The 124, 269–302.

McLaughlin, S., 2005. Cannibalism and Easter Island: evaluation, discussion of probabilities, and survey of the literature on the subject. Rapa Nui Journal 19, 30–50.

McLaughlin, T.R., 2019. On Applications of Space–Time Modelling with Open-Source 14C Age Calibration. J Archaeol Method Theory 26, 479–501. https://doi.org/10.1007/s10816-018-9381-3

McMichael, C.H., Palace, M.W., Golightly, M., 2014. Bamboo-dominated forests and pre-Columbian earthwork formations in south-western Amazonia. J. Biogeogr. 41, 1733–1745. https://doi.org/10.1111/jbi.12325

Métraux, A., 1957. Easter Island; a Stone-Age Civilization of the Pacific. Oxford University Press, New York.

Métraux, A., 1940. Ethnology of Easter Island. Bishop Museum Press, Honolulu.

Middleton, G., 2012. Nothing Lasts Forever: Environmental Discourses on the Collapse of Past Societies. Journal of Archaeological Research 20, 257–307. https://doi.org/10.1007/s10814-011-9054-1

Middleton, G.D., 2017. Understanding Collapse: Ancient History and Modern Myths. Cambridge University Press, New York.

Mieth, A., Bork, H.-R., 2018. A vanished landscape - phenomena and eco-cultural consequences of extensive deforestation in the prehistory of Rapa Nui, in: Haoa-Cardinali, S., Ingersoll, K.B., Ingersoll Jr, D.W., Stevenson, C.M. (Eds.), Cultural and Environmental Change on Rapa Nui. Routledge, New York, pp. 32–58.

Mieth, A., Bork, H.-R., 2010. Humans, climate or introduced rats – which is to blame for the woodland destruction on prehistoric Rapa Nui (Easter Island)? Journal of Archaeological Science 37, 417–426. https://doi.org/10.1016/j.jas.2009.10.006

Milner, G.R., 1999. Warfare in Prehistoric and Early Historic Eastern North America. J Archaeol Res 7, 105–151. https://doi.org/10.1007/s10814-005-0001-x

Montgomery & Associates, Inc., 2011. Condiciones Hidrogeologicas Isla de Pascua, Chile.

Moore, J.D., 1996. Architecture and Power in the Ancient Andes: The Archaeology of Public Buildings. Cambridge University Press.

Morrison, A., 2012. An archaeological analysis of Rapa Nui settlement structure: a multi-scalar approach (Unpublished PhD Dissertation). University of Hawaii, Manoa, Honolulu, Hi.

Mulloy, E.R., 1993. The long and short of it: Some thoughts on the meaning of the names Hanau Eepe and Hanau Momoko in Rapanui tradition. Rapa Nui Journal 7, 71–72.

Mulloy, W., 1965. The Fortified Village of Morongo Uta, in: Heyerdahl, T., Ferdon, E.N. (Eds.), Reports of the Norwegian Archaeological Expedition to Easter Island and the East Pacific, Volume 2, Miscellaneous Papers. Forum Publishing House, Stockholm, pp. 23–68.

Mulloy, W., 1961. The Ceremonial Center of Vinapu, in: Heyerdahl, T., Ferdon, E.N. (Eds.), Archaeology of Easter Island. Forum Publishing House, Stockholm, pp. 93–180.

Mulloy, W.T., 1974. Contemplate the Navel of the World. Americas 26, 25–33.

Mulloy, W.T., Figueroa, G., 1978. The A Kivi-Vai Teka complex and its relationship to Easter Island architectural prehistory. Social Science Research Institute, University of Hawaii.

Mulrooney, M., A., Ladefoged, T., N., 2005. Hawaiian Heiau and Agricultural Production in The Kohala Dryland Field System. The Journal of the Polynesian Society 114, 45–67.

Mulrooney, M.A., 2013a. An island-wide assessment of the chronology of settlement and land use on Rapa Nui (Easter Island) based on radiocarbon data. Journal of Archaeological Science 40, 4377–4399. https://doi.org/10.1016/j.jas.2013.06.020

Mulrooney, M.A., 2013b. An island-wide assessment of the chronology of settlement and land use on Rapa Nui (Easter Island) based on radiocarbon data. Journal of Archaeological Science 40, 4377–4399.

Mulrooney, M.A., Bickler, S.H., Allen, M.S., Ladefoged, T.N., 2011. High-precision dating of colonization and settlement in East Polynesia. Proceedings of the National Academy of Sciences 108, E192–E194.

Mulrooney, M.A., Ladefoged, T.N., Gibb, R., McCurdy, D., 2005. Eight million points per day: archaeological implications of laser scanning and three-dimensional modeling of Pu ‘ukohola Heiau, Hawai ‘i Island. Hawaiian Archaeology 10, 18–28.

Mulrooney, M.A., Ladefoged, T.N., Stevenson, C., Haoa, S., 2009. The Myth of AD 1680: New Evidence from Hanga Ho’onu, Rapa Nui (Easter Island). Rapa Nui Journal 23, 94–105.

Mulrooney, M.A., Ladefoged, T.N., Stevenson, C.M., 2010. Empirical assessment of a pre-European societal collapse on Rapa Nui (Easter Island), in: Wallin, P., Martinsson-Wallin, H. (Eds.), The Gotland Papers: Selected Papers from the VII International Conference on Easter Island and the Pacific. Gotland University Press, Gotland University, Sweden, pp. 141–153.

Mulrooney, M.A., McAlister, A., Stevenson, C.M., Morrison, A.E., Gendreau, L., 2014. Sourcing Rapa Nui mata’a from the collections of Bishop Museum using non-destructive pXRF. Journal of the Polynesian Society 123, 301–338.

Neff, H., 2014. Pots as signals: explaining the enigma of long-distance ceremaic exchange, in: Martinón-Torres, M. (Ed.), Craft and Science: International Perspectives on Archaeological Ceramics. Bloomsbury Qatar Foundation, Doha, pp. 1–11.

Neiman, F.D., 1997. Conspicuous Consumption as Wasteful Advertising: a Darwinian Perspective on Spatial Patterns in Classic Maya Terminal Monument Dates, in: Barton, C.M., Clark, G.A. (Eds.), Rediscovering Darwin: Evolutionary Theory and Archaeological Explanation, Archaeological Papers of the American Anthropological Association, No. 7. pp. 267–290.

Norenzayan, A., Shariff, A.F., 2008. The Origin and Evolution of Religious Prosociality. Science 322, 58–62. https://doi.org/10.1126/science.1158757

Norenzayan, A., Shariff, A.F., Gervais, W.M., Willard, A.K., McNamara, R.A., Slingerland, E., Henrich, J., 2016. The cultural evolution of prosocial religions. Behavioral and brain sciences 39, 1–65.

Notroff, J., Dietrich, O., Schmidt, K., 2014. Building monuments, creating communities: early monumental architecture at Pre-Pottery Neolithic Gobekli Tepe, in: Osborne, J.F. (Ed.), Approaching Monumentality in Archaeology. State University of New York Press, Albany, pp. 83–105.

Nunn, P.D., 2000. Environmental catastrophe in the Pacific Islands around A. D. 1300. Geoarchaeology 15, 715–740.

Nunn, P.D., 1998. Sea-Level Changes over the past 1,000 Years in the Pacific. Journal of Coastal Research 14, 23–30.

Nunn, P.D., 1997. Late Quaternary environmental changes on Pacific islands: controversy, certainty and conjecture. Journal of Quaternary Science 12, 443–450.

Nunn, P.D., Britton, J.M., 2001. Human-environment relationships in the Pacific Islands around AD 1300. Environment and History 7, 3–22.

Nunn, P.D., Hunter-Anderson, R., Carson, M.T., Thomas, F., Ulm, S., Rowland, M.J., 2007. Times of Plenty, Times of Less: Last-Millennium Societal Disruption in the Pacific Basin. Human Ecology 35, 385–401. https://doi.org/10.1007/s10745-006-9090-5

O'Connor, J.T., White, F.J., Hunt, T.L., 2017. Fishhook variability and cultural transmission in East Polynesia. Archaeology in Oceania 52, 32–44. https://doi.org/10.1002/arco.5120

O'Driscoll, J., 2017. Landscape prominence: Examining the topographical position of Irish hillforts using a cumulative viewshed approach. Journal of Archaeological Science: Reports 16, 73–89. https://doi.org/10.1016/j.jasrep.2017.09.033

Orliac, C., Orliac, M., 2008. Extinct flora of Easter Island, in: Di Piazza, A., Pearthree, E., Sand, C. (Eds.), At the Heart of Ancient Societies: French Contributions to Pacific Archaeology. Département Archéologie, Nouméa, New Caledonia, pp. 197–209.

Osborne, J.F., 2014. Approaching monumentality in archaeology. SUNY Press, Albany.

O'Shea, J.M., Parditka, G., Nicodemus, A., Kristiansen, K., Sjögren, K.-G., Paja, L., Pálfi, G., Milašinović, L., 2019. Social formation and collapse in the Tisza-Maros region: dating the Maros Group and its Late Bronze Age successors. Antiquity 93, 604–623. https://doi.org/10.15184/aqy.2019.40

O'Sullivan, D., Perry, G.L.W., 2013. Spatial Simulation: Exploring Pattern and Process, 1 edition. ed. Wiley-Blackwell, Chichester, West Sussex, UK.

Owsley, D.W., Barca, K.G., Simon, V.E., Gill, G.W., 2016. Evidence for injuries and violent death, in: Stefan, V.H., Gill, G.W. (Eds.), Skeletal Biology of the Ancient Rapanui (Easter Islanders). Cambridge University Press, Cambridge, pp. 222–252.

Owsley, D.W., Gill, G.W., Ousley, S.D., 1994. Biological Effects of European Contact on Easter Island, in: Larsen, C.S., Milner, G.R. (Eds.), The Wake of Contact: Biological Responses to Conquest. Wiley-Liss, New York, pp. 161–177.

Palmer, J.L., 1870. A Visit to Easter Island, or Rapa Nui, in 1868. The Journal of the Royal Geographical Society of London 40, 167–181. https://doi.org/10.2307/1798641

Palmer, M.A., Graves, M., Ladefoged, T.N., Chadwick, O.A., Duarte, T.K., Porder, S., Vitousek, P.M., 2009. Sources of Nutrients to Windward Agricultural Systems in Pre-Contact Hawai'i. Ecological Applications 19, 1444–1453.

Parkinson, W.A., Duffy, P.R., 2007. Fortifications and enclosures in European prehistory: a cross-cultural perspective. Journal of Archaeological Research 15, 97–141.

Parton, P.A., Clark, G., Reepmeyer, C., Burley, D., 2018. The Field of War: LiDAR Identification of Earthwork Defences on Tongatapu Island, Kingdom of Tonga. Journal of Pacific Archaeology 9, 11–24.

Peiser, B., 2005. From Genocide to Ecocide: The Rape of Rapa Nui. Energy & Environment 16, 513–539. https://doi.org/10.1260/0958305054672385

Pezzey, J.C.V., Anderies, J.M., 2003. The effect of subsistence on collapse and institutional adaptation in population–resource societies. Journal of Development Economics 72, 299–320. https://doi.org/10.1016/S0304-3878(03)00078-6

Philippe, A., Vibet, M.-A., Dye, T.S., 2019. ArchaeoPhases: post-processing of the Markov Chain simulated by “ChronoModel”, “Oxcal” or “BCal”.

Phillips, N., Ladefoged, T.N., McPhee, B.W., Asner, G.P., 2015. Location, location, location: A viewshed analysis of heiau spatial and temporal relationships in leeward Kohala, Hawaiʻi. Journal of Pacific Archaeology 6, 21–40.

Phillips, P., Willey, G.R., 1953. Method and Theory in American Archaeology: An Operational Basis for Culture-Historical Integration. American Anthropologist 55, 615–633.

Pierce, D.E., 2017. Finding class in the glass: Obsidian source as a costly signal. Journal of Anthropological Archaeology 48, 217–232. https://doi.org/10.1016/j.jaa.2017.05.001

Plourde, A., 2008. The Origins of Prestige Goods as Honest Signals of Skill and Knowledge. Human Nature 19, 374–388. https://doi.org/10.1007/s12110-008-9050-4

Pluckhahn, T.J., Thompson, V.D., Rink, J., 2016. Evidence for Stepped Pyramids of Shell in the Woodland Period of Eastern North America. American Antiquity 81, 345–363.

Polet, C., Bocherens, H., 2016. New insights into the marine contribution to ancient Easter Islanders' diet. Journal of Archaeological Science: Reports 6, 709–719. https://doi.org/10.1016/j.jasrep.2015.09.013

Pollard, J., Paterson, A., Welham, K., 2010. Te Miro o'one: the archaeology of contact on Rapa Nui (Easter Island). World Archaeology 42, 562–580. https://doi.org/10.1080/00438243.2010.517670

Power, E.A., 2017. Discerning devotion: Testing the signaling theory of religion. Evolution and Human Behavior 38, 82–91. https://doi.org/10.1016/j.evolhumbehav.2016.07.003

Prebble, M., Anderson, A., 2012. Palaeobotany and the early development of agriculture on Rapa Island, in: Anderson, A., Kennett, D.J. (Eds.), Taking the High Ground: The Archaeology of Rapa, a Fortified Island in Remote East Polynesia, Terra Australis 37. ANU Press, Canberra, pp. 167–187.

Prebble, M., Anderson, A., Kennett, D.J., 2013. Forest clearance and agricultural expansion on Rapa, Austral Archipelago, French Polynesia. The Holocene 23, 179–196. https://doi.org/10.1177/0959683612455551

Prebble, M., Dowe, J.L., 2008. The late Quaternary decline and extinction of palms on oceanic Pacific islands. Quaternary Science Reviews 27, 2546–2567.

Premo, L.S., 2006. Agent-based models as behavioral laboratories for evolutionary anthropological research. Arizona Anthropologist 17, 91–117.

Puleston, C.O., Ladefoged, T.N., Haoa, S., Chadwick, O.A., Vitousek, P.M., Stevenson, C.M., 2018. Commentary: Commentary: Rain, Sun, Soil, and Sweat: A Consideration of Population Limits on Rapa Nui (Easter Island) before European Contact. Front. Ecol. Evol. 6. https://doi.org/10.3389/fevo.2018.00072

Puleston, C.O., Ladefoged, T.N., Haoa, S., Chadwick, O.A., Vitousek, P.M., Stevenson, C.M., 2017. Rain, Sun, Soil, and Sweat: A Consideration of Population Limits on Rapa Nui (Easter Island) before European Contact. Front. Ecol. Evol. 5, 1–14. https://doi.org/10.3389/fevo.2017.00069

Quinn, C.P., 2019. Costly signaling theory in archaeology, in: Prentiss, A.M. (Ed.), Handbook of Evolutionary Research in Archaeology. Springer Nature Switzerland, Cham, pp. 275–294.

Quinn, C.P., 2015. Signals in stone: exploring the role of social information exchange, conspicuous consumption, and costly signaling theory in lithic analysis, in: Goodale, N., Andrefsky, W. (Eds.), Lithic Technological Systems and Evolutionary Theory. Cambridge University Press, New York, pp. 198–222.

Quintus, S., Huebert, J., Kirch, P.V., Lincoln, N.K., Maxwell, J., 2019. Qualities and Contributions of Agroforestry Practices and Novel Forests in Pre-European Polynesia and the Polynesian Outliers. Hum Ecol. https://doi.org/10.1007/s10745-019-00110-x

R Core Team, 2019. R: a language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria.

Rainbird, P., 2006. The archaeology of the conical clan in Micronesia, in: Lilley, I. (Ed.), Archaeology of Oceania: Australia and the Pacific Islands. Blackwell Publishing Ltd, Malden, pp. 302–317.

Rainbird, P., 2002. A message for our future? The Rapa Nui (Easter Island) ecodisaster and Pacific island environments. World Archaeology 33, 436–451. https://doi.org/10.1080/00438240120107468

Reanier, R.E., Ryan, D.P., 2003. Mapping the Poike Ditch, in: Loret, J., Tanacredi, J.T. (Eds.), Easter Island: Scientific Exploration into the World’s Environmental Problems in Microcosm. Kluwer Academic/Plenum Publishers, New York, pp. 207–221.

Reeder-Myers, L.A., 2014. Multi-scalar foraging decisions in the Santa Barbara Channel, southern California. Journal of Anthropological Archaeology 35, 202–219. https://doi.org/10.1016/j.jaa.2014.06.002

Renfrew, A.C., 1976. Megaliths, territories, and populations, in: De Laet, S.J. (Ed.), Acculturation and Continuity in Atlantic Europe. De Tempel, Brugge, pp. 198–220.

Reuveny, R., 2012. Taking Stock of Malthus: Modeling the Collapse of Historical Civilizations. Annual Review of Resource Economics 4, 303–329. https://doi.org/10.1146/annurev-resource-110811-114537

Reuveny, R., Decker, C.S., 2000. Easter Island: historical anecdote or warning for the future? Ecological Economics 35, 271–287. https://doi.org/10.1016/S0921-8009(00)00202-0

Richards, C., Croucher, K., Paoa, T., Parish, T., Tucki, E., Welham, K., 2011. Road my body goes: re-creating ancestors from stone at the great moai quarry of Rano Raraku, Rapa Nui (Easter Island). World Archaeology 43, 191–210. https://doi.org/10.1080/00438243.2011.579483

Richards, R., 2008. Easter Island 1793 to 1861: Observations by Early Visitors before the Slave Raids. Easter Island Foundation, Los Osos.

Riesenfeld, A., 1950. The Megalithic Culture of Melanesia. E. J. Brill, Leiden.

Rieth, T.M., Athens, J.S., 2013. Suggested best practices for the application of radiocarbon dating to Hawaiian archaeology. Hawaiian Archaeology 13, 3–29.

Robinson, T., Stevenson, C.M., 2017. The Cult of the Birdman: Religious Change at ‘Orongo, Rapa Nui (Easter Island). 1 8, 88–102.

Rolett, B., Diamond, J., 2004. Environmental predictors of pre-European deforestation on Pacific islands. Nature 431, 443–446. https://doi.org/10.1038/nature02801

Roman, S., Bullock, S., Brede, M., 2017. Coupled Societies are More Robust Against Collapse: A Hypothetical Look at Easter Island. Ecological Economics 132, 264–278. https://doi.org/10.1016/j.ecolecon.2016.11.003

Roman, S., Palmer, E., Brede, M., 2018. The Dynamics of Human–Environment Interactions in the Collapse of the Classic Maya. Ecological Economics 146, 312–324. https://doi.org/10.1016/j.ecolecon.2017.11.007

Rorrer, K., 1998. Subsistence evidence from inland and coastal cave sites on Easter Island, in: Stevenson, C.M., Lee, G., Morin, F.J. (Eds.), Easter Island in Pacific Context, South Seas Symposium: Proceedings of the Fourth International Conference on Easter Island and East Polynesia. Bearsville Press, Los Osos, pp. 193–198.

Roscoe, P., 2009. Social signaling and the organization of small-scale society: the case of contact-era New Guinea. Journal of Archaeological Method and Theory 16, 69–116.

Rouse, I., 1955. On the Correlation of Phases of Culture. American Anthropologist 57, 713–722.

Routledge, K., 1919. The Mystery of Easter Island. Cosimo, New York.

Ruiz-Tagle, E., 2007. Easter Island: The First Three Expeditions. Rapa Nui Press, Los Osos.

Rull, V., 2020a. The deforestation of Easter Island. Biological Reviews 95, 124–141. https://doi.org/10.1111/brv.12556

Rull, V., 2020b. Drought, freshwater availability and cultural resilience on Easter Island (SE Pacific) during the Little Ice Age. The Holocene 0959683619895587. https://doi.org/10.1177/0959683619895587

Rull, V., 2018. Strong Fuzzy EHLFS: A General Conceptual Framework to Address Past Records of Environmental, Ecological and Cultural Change. Quaternary 1, 10. https://doi.org/10.3390/quat1020010

Rull, V., 2016. Natural and anthropogenic drivers of cultural change on Easter Island: Review and new insights. Quaternary Science Reviews 150, 31–41. https://doi.org/10.1016/j.quascirev.2016.08.015

Rull, V., Cañellas-Boltà, N., Sáez, A., Giralt, S., Pla, S., Margalef, O., 2010. Paleoecology of Easter Island: Evidence and uncertainties. Earth-Science Reviews 99, 50–60. https://doi.org/10.1016/j.earscirev.2010.02.003

Rull, V., Cañellas-Boltà, N., Saez, A., Margalef, O., Bao, R., Pla-Rabes, S., Valero-Garcés, B., Giralt, S., 2013. Challenging Easter Island's collapse: the need for interdisciplinary synergies. Front. Ecol. Evol. 1. https://doi.org/10.3389/fevo.2013.00003

Rull, V., Montoya, E., Seco, I., Cañellas-Boltà, N., Giralt, S., Margalef, O., Pla-Rabes, S., D'Andrea, W., Bradley, R., Sáez, A., 2018. CLAFS, a Holistic Climatic-Ecological-Anthropogenic Hypothesis on Easter Island's Deforestation and Cultural Change: Proposals and Testing Prospects. Front. Ecol. Evol. 6. https://doi.org/10.3389/fevo.2018.00032

Safi, K.N., 2015. Costly signaling among great houses on the Chaco periphery (Ph.D.). Washington State University, United States -- Washington.

Sahlins, M., 1958. Social Stratification in Polynesia, First Edition. ed. University of Washington Press.

Sahlins, M.D., 1955. Esoteric efflorescence in Easter Island. American Anthropologist 57, 1045–1052.

Sand, C., 1996a. Recent developments in the study of New Caledonia's prehistory. Archaeology in Oceania 31, 45–71.

Sand, C., 1996b. Structural remains as markers of complex societies in southern Melanesia during prehistory: the case of the monumental forts of Mare Island, New Caledonia. Bulletin of the Indo-Pacific Prehistory Association 15, 37–44.

Sand, C., 1996c. Archaeological structures, socio-political complexity and population density: new insight into the prehistory of the new Caledonian archipelago, in: Davidson, J., Irwin, G., Leach, F., Pawley, A., Brown, D. (Eds.), Oceanic Culture History: Essays in Honour of Roger Green. New Zealand Journal of Archaeology Special Publication, Dunedin, pp. 287–295.

Scarre, C., 2011. Monumentality. The Oxford Handbook of the Archaeology of Ritual and Religion. https://doi.org/10.1093/oxfordhb/9780199232444.013.0002

Schavelzon, D., 2014. From Ethnographical Subjects to Archaeological Objects: Pierre Loti on Easter Island (Rapa Nui). Bulletin of the History of Archaeology 24, Art. 19. https://doi.org/10.5334/bha.2419

Schávelzon, D., Igareta, A., 2017. Historical Archaeology and Easter Island: cultural destruction and the aborted formation of national identity, in: Brooks, A., Mehler, N. (Eds.), The Country Where My Heart Is: Historical Archaeologies of Nationalism and National Identity. University Press of Florida, Gainesville, pp. 312–332.

Scheffer, M., 2016. Anticipating societal collapse; Hints from the Stone Age. PNAS 113, 10733–10735. https://doi.org/10.1073/pnas.1612728113

Scheffer, M., Carpenter, S.R., Lenton, T.M., Bascompte, J., Brock, W., Dakos, V., Koppel, J. van de, Leemput, I.A. van de, Levin, S.A., Nes, E.H. van, Pascual, M., Vandermeer, J., 2012. Anticipating Critical Transitions. Science 338, 344–348. https://doi.org/10.1126/science.1225244

Schmid, M.M.E., Dugmore, A.J., Foresta, L., Newton, A.J., Vésteinsson, O., Wood, R., 2018. How 14C dates on wood charcoal increase precision when dating colonization: The examples of Iceland and Polynesia. Quaternary Geochronology 48, 64–71. https://doi.org/10.1016/j.quageo.2018.07.015

Schulz Paulsson, B., 2019. Radiocarbon dates and Bayesian modeling support maritime diffusion model for megaliths in Europe. PNAS 201813268. https://doi.org/10.1073/pnas.1813268116

Schwartz, G.M., Nichols, J.J., 2006. After Collapse: The Regeneration of Complex Societies. University of Arizona Press, Tucson.

Schwarz, G., 1978. Estimating the Dimension of a Model. Ann. Statist. 6, 461–464. https://doi.org/10.1214/aos/1176344136

Seager Thomas, M., 2014. Stone use and avoidance on Easter Island: Red scoria from the topknot quarry at Puna Pau and other sources. Archaeology in Oceania 49, 95–109.

Sear, D.A., Allen, M.S., Hassall, J.D., Maloney, A.E., Langdon, P.G., Morrison, A.E., Henderson, A.C.G., Mackay, H., Croudace, I.W., Clarke, C., Sachs, J.P., Macdonald, G., Chiverrell, R.C., Leng, M.J., Cisneros-Dozal, L.M., Fonville, T., 2020. Human settlement of East Polynesia earlier, incremental, and coincident with prolonged South Pacific drought. PNAS. https://doi.org/10.1073/pnas.1920975117

Shaw, L.C., 2000a. The Investigation of a Ahu Poepoe and Two Avanga on Easter Island, in: Stevenson, C.M., Ayres, W.S. (Eds.), Easter Island Archaeology: Research on Early Rapanui Culture. Easter Island Foundation, Los Osos, pp. 13–26.

Shaw, L.C., 2000b. Human Burials: The Coastal Caves of Easter Island, in: Stevenson, C.M., Ayres, W.S. (Eds.), Easter Island Archaeology: Research on Early Rapanui Culture. Easter Island Foundation, Los Osos, pp. 59–80.

Shennan, S., Downey, S.S., Timpson, A., Edinborough, K., Colledge, S., Kerig, T., Manning, K., Thomas, M.G., 2013. Regional population collapse followed initial agriculture booms in mid-Holocene Europe. Nat Commun 4, 1–8. https://doi.org/10.1038/ncomms3486

Shepardson, B.L., 2013. Moai: A New Look at Old Faces. Rapa Nui Press, Santiago.

Shepardson, B.L., 2006. Explaining spatial and temporal patterns of energy investment in the prehistoric statuary of Rapa Nui (Easter Island) (PhD Thesis). University of Hawaii at Manoa.

Shepardson, B.L., 2005. The role of Rapa Nui (Easter Island) statuary as territorial boundary markers. Antiquity 79, 169–178.

Sherwood, S.C., Van Tilburg, J.A., Barrier, C.R., Horrocks, M., Dunn, R.K., Ramírez-Aliaga, J.M., 2019. New excavations in Easter Island's statue quarry: Soil fertility, site formation and chronology. Journal of Archaeological Science 111, 104994. https://doi.org/10.1016/j.jas.2019.104994

Silvestri, L., Achino, K.F., Gatta, M., Rolfo, M.F., 2017. Bioarchaeological remains as indicators of costly signalling: two case studies from the Middle Bronze Age of Central Italy. World Archaeology 49, 491–505. https://doi.org/10.1080/00438243.2017.1311803

Simpson, D.F., 2009. Rapa Nui's Political Economy and the Visibility of Its Monumental Architecture. Rapa Nui Journal 23, 131–48.

Simpson, D.F., Dussubieux, L., 2018a. A collapsed narrative? Geochemistry and spatial distribution of basalt quarries and fine–grained artifacts reveal communal use of stone on Rapa Nui (Easter Island). Journal of Archaeological Science: Reports 18, 370–385. https://doi.org/10.1016/j.jasrep.2018.01.038

Simpson, D.F., Dussubieux, L., 2018b. A collapsed narrative? geochemistry and spatial distribution of basalt quarries and fine-grained artifacts reveal communal use of sstone on Rapa Nui (Easter Island). J. Archaeol. Sci. Rep 18, 370–385.

Simpson, D.F., Van Tilburg, J., Dussubieux, L., 2018a. Geochemical and radiometric analyses of archaeological remains from Easter Island's moai (statue) quarry reveal prehistoric timing, provenance, and use of fine–grain basaltic resources. 1 9, 12–34.

Simpson, D.F., Weisler, M.I., Pierre, E.J.S., Feng, Y., Bolhar, R., 2018b. The archaeological documentation and geochemistry of the Rua Tokitoki adze quarry and the Poike fine-grain basalt source on Rapa Nui (Easter Island). Archaeology in Oceania 53, 15–27. https://doi.org/10.1002/arco.5132

Skjølsvold, A., 1994. Archaeological investigations at Anakena, Easter Island. Kon Tiki Museum Occasional Papers, Olso.

Smith, C., Cochrane, E.E., 2011. How is visibility important for defence? A GIS analysis of sites in the western Fijian Islands. Archaeology in Oceania 46, 76–84. https://doi.org/10.1002/j.1834-4453.2011.tb00101.x

Smith, C.S., 1965. The Burial Complex on the Island of Rapa Iti, in: Heyerdahl, T., Ferdon, E.N. (Eds.), Reports of the Norwegian Archaeological Expedition to Easter Island and the East Pacific, Volume 2, Miscellaneous Papers. Forum Publishing House, Stockholm, pp. 89–95.

Smith, C.S., 1961a. A Temporal Sequence Derived from Certain AHU, in: Heyerdahl, T., Ferdon, E.N. (Eds.), Archaeology of Easter Island. Forum Publishing House, Stockholm, pp. 181–219.

Smith, C.S., 1961b. Radio carbon dates from Easter Island, in: Heyerdahl, T., Ferdon, E.N. (Eds.), Archaeology of Easter Island. Forum Publishing House, Stockholm, pp. 393–396.

Smith, C.S., 1961c. The Poike Ditch, in: Heyerdahl, T., Ferdon, E.N. (Eds.), Archaeology of Easter Island. Forum Publishing House, Stockholm, pp. 385–391.

Smith, E.A., 2004. Why do good hunters have higher reproductive success? Hum Nat 15, 343–364. https://doi.org/10.1007/s12110-004-1013-9

Smith, E.A., Bird, R.B., Bird, D.W., 2003. The benefits of costly signaling: Meriam turtle hunters. Behavioral Ecology 14, 116–126.

Smith, E.A., Bird, R.L.B., 2000. Turtle hunting and tombstone opening: public generosity as costly signaling. Evolution and Human Behavior 21, 245–261. https://doi.org/10.1016/S1090-5138(00)00031-3

Smith, E.A., Bliege Bird, R., 2005. Costly Signaling and Cooperative Behavior, in: Gintis, H., Bowles, S., Boyd, R., Fehr, E. (Eds.), Moral Sentiments and Material Interests: The Foundations of Cooperation in Economic Life. The MIT Press, Cambridge, pp. 115–148.

Smith, E.A., Winterhalder, B. (Eds.), 1992. Evolutionary Ecology and Human Behavior. Aldine Transaction, New York.

Smith, M.E., 2011. Empirical Urban Theory for Archaeologists. J Archaeol Method Theory 18, 167–192. https://doi.org/10.1007/s10816-010-9097-5

Smith-Guzmán, N.E., Cooke, R.G., 2018. Interpersonal Violence at Playa Venado, Panama (550–850 AD): A Reevaluation of the Evidence. Latin American Antiquity 1–18. https://doi.org/10.1017/laq.2018.48

Soler, M., Batiste, F., Cronk, L., 2014. In the eye (and ears) of the beholder: Receiver psychology and human signal design. Evol. Anthropol. 23, 136–145. https://doi.org/10.1002/evan.21413

Sosis, R., 2003. Why aren't we all hutterites? Hum Nat 14, 91–127. https://doi.org/10.1007/s12110-003-1000-6

Sosis, R., Alcorta, C., 2003. Signaling, solidarity, and the sacred: The evolution of religious behavior. Evol. Anthropol. 12, 264–274. https://doi.org/10.1002/evan.10120

Spencer, C., Bevan, A., 2018. Settlement location models, archaeological survey data and social change in Bronze Age Crete. Journal of Anthropological Archaeology 52, 71–86. https://doi.org/10.1016/j.jaa.2018.09.001

Spriggs, M., 2008. Ethnographic parallels and the denial of history. World Archaeology 40, 538–552. https://doi.org/10.1080/00438240802453161

Spriggs, M., 1989. The dating of the Island Southeast Asian Neolithic: an attempt at chronometric hygiene and linguistic correlation. Antiquity 63, 587–613.

Spriggs, M., Anderson, A., 1993. Late colonization of East Polynesia. Antiquity 67, 200–217.

Steadman, D.W., Casanova, P.V., Ferrando, C.C., 1994. Stratigraphy, chronology, and cultural context of an early faunal assemblage from Easter Island. Asian Perspectives 33, 79–96.

Stefan, V.H., 1999. Craniometric Variation and Homogeneity in Prehistoric/Protohistoric Rapa Nui (Easter Island) Regional Populations. American Journal of Physical Anthropology 110, 407–419.

Sterelny, K., 2019. Religion: costs, signals, and the Neolithic transition. Religion, Brain & Behavior 0, 1–18. https://doi.org/10.1080/2153599X.2019.1678513

Stevenson, C.M., 2002. Territorial divisions on Easter Island in the 16th century: evidence from the distribution of ceremonial architecture, in: Ladefoged, T.N., Graves, M.W. (Eds.), Pacific Landscapes: Archaeological Approaches. Bearsville Press, Los Osos, pp. 211–229.

Stevenson, C.M., 1997. Archaeological Investigations on Easter Island: Maunga Tari: an Upland Agricultural Complex. Easter Island Foundation, Los Osos.

Stevenson, C.M., 1986. The socio-political structure of the southern coastal area of Easter Island: AD 1300-1864, in: Kirch, P.V. (Ed.), Island Societies: Archaeological Approaches to Evolution and Transformation. Cambridge University Press, Cambridge, pp. 69–77.

Stevenson, C.M., 1984. Corporate Descent Group Structure in Easter Island Prehistory (Ph.D. Dissertation). Pennsylvania State University, State College, PA.

Stevenson, C.M., Haoa, S. (Eds.), 2008. Prehistoric Rapa Nui: Landscape and Settlement Archaeology at Hanga Hoʻonu. Bearsville Press, Los Osos.

Stevenson, C.M., Haoa-Cardinali, S., 1998. Prehistoric Gardening Systems and Agricultural Intensification in the La Perouse Area of Easter Island, in: Stevenson, C.M., Lee, G., Morin, F.J. (Eds.), Easter Island in Pacific Context: South Seas Symposium: Proceedings of the Fourth International Conference on Easter Island and East Polynesia. Easter Island Foundation, Los Osos, pp. 205–213.

Stevenson, C.M., Jackson, T.L., Mieth, A., Bork, H.-R., Ladefoged, T.N., 2006. Prehistoric and early historic agriculture at Maunga Orito, Easter Island (Rapa Nui), Chile. Antiquity 80, 919–936.

Stevenson, C.M., Ladefoged, T.N., Haoa, S., 2002. Productive stratgies in an uncertain environment: prehistoric agriculture on Easter Island. Rapa Nui Journal 16, 17–22.

Stevenson, C.M., Ladefoged, T.N., Haoa, S., Chadwick, O., Puleston, C., 2013. Prehistoric Obsidian Exchange on Rapa Nui. The Journal of Island and Coastal Archaeology 8, 108–121. https://doi.org/10.1080/15564894.2012.745457

Stevenson, C.M., Puleston, C.O., Vitousek, P.M., Chadwick, O.A., Haoa, S., Ladefoged, T.N., 2015. Variation in Rapa Nui (Easter Island) land use indicates production and population peaks prior to European contact. PNAS 112, 1025–1030. https://doi.org/10.1073/pnas.1420712112

Stevenson, C.M., Williams, C., 2018. The temporal occurrence and possible uses of obsidian mata’a on Rapa Nui (Easter Island, Chile). Archaeology in Oceania 53, 92–102. https://doi.org/10.1002/arco.5145

Stevenson, C.M., Williams, C., Carpenter, E., Hunt, C.S., Novak, S.W., 2019. Architecturally Modified Caves on Rapa Nui: Post-European Contact Ritual Spaces? Rapa Nui Journal. https://doi.org/10.1353/rnj.0.0003

Stevenson, C.M., Wozniak, J., Haoa, S., 1999. Prehistoric agricultural production on Easter Island (Rapa Nui), Chile. Antiquity 73, 801–812. https://doi.org/10.1017/S0003598X00065546

Stokes, J.F., 1991. Heiau of the Island of Hawaii: A Historic Survey of Native Hawaiian Temple Sites, Edited and Introduced by Tom Dye. Bishop Museum Press, Honolulu.

Stokes, J.F.G., n.d. Ethnology of Rapa Island. Unpublished draft of B.P. Bishop Museum Bulletin of the Bayard Dominick Expedition., Honolulu.

Strunz, S., Marselle, M., Schröter, M., 2019. Leaving the "sustainability or collapse" narrative behind. Sustain Sci 14, 1717–1728. https://doi.org/10.1007/s11625-019-00673-0

Sutton, D.G., Furey, L., Marshall, Y.M., 2003. The archaeology of Pouerua. Auckland University Press, Auckland.

Szabó, K., Vogel, Y., Anderson, A., 2012. Marine resource exploitation on Rapa Island: Archaeology, material culture and ethnography, in: Anderson, A., Kennett, D.J. (Eds.), Taking the High Ground: The Archaeology of Rapa, a Fortified Island in Remote East Polynesia, Terra Australis 37. ANU Press, Canberra, pp. 145–166.

Számadó, S., 2011. The cost of honesty and the fallacy of the handicap principle. Animal Behaviour 81, 3–10. https://doi.org/10.1016/j.anbehav.2010.08.022

Tainter, J., 1988. The Collapse of Complex Societies. Cambridge University Press, Cambridge.

Tainter, J.A., 2006. Archaeology of Overshoot and Collapse. Annu. Rev. Anthropol. 35, 59–74. https://doi.org/10.1146/annurev.anthro.35.081705.123136

Takács, B., Horváth, R., Faragó, I., 2019. The effect of tree diffusion in a two-dimensional continuous model for Easter Island. European Journal of Mathematics 5, 845–857. https://doi.org/10.1007/s40879-018-0276-3

Tefft, S.K., Reinhardt, D., 1974. Warfare Regulation: A Cross-Cultural Test of Hypotheses Among Trlbal Peoples. Behavior Science Research 9, 151–172. https://doi.org/10.1177/106939717400900203

Thomas, J., 1990. Monuments from the inside: The case of the Irish megalithic tombs. World Archaeology 22, 168–178. https://doi.org/10.1080/00438243.1990.9980138

Thomson, W.J., 1891. Te Pito Te Henua; Or, Easter Island. Smithsonian Institution Press, Washington, D.C.

Thorpe, I.J., 2003. Anthropology, archaeology, and the origin of warfare. World Archaeology 35, 145–165.

Timpson, A., Colledge, S., Crema, E., Edinborough, K., Kerig, T., Manning, K., Thomas, M.G., Shennan, S., 2014. Reconstructing regional population fluctuations in the European Neolithic using radiocarbon dates: a new case-study using an improved method. Journal of Archaeological Science 52, 549–557.

Torrence, R., Kononenko, N., White, P., 2018. Revisiting Rapa Nui Mata'a. Rapa Nui Journal 13, 1–20. https://doi.org/10.1353/rnj.0.0000

Tremayne, A.H., Winterhalder, B., 2017. Large mammal biomass predicts the changing distribution of hunter-gatherer settlements in mid-late Holocene Alaska. Journal of Anthropological Archaeology 45, 81–97. https://doi.org/10.1016/j.jaa.2016.11.006

Trigger, B.G., 1990. Monumental architecture: a thermodynamic explanation of symbolic behaviour. World Archaeology 22, 119–132.

Tromp, M., Dudgeon, J.V., 2015. Differentiating dietary and non-dietary microfossils extracted from human dental calculus: the importance of sweet potato to ancient diet on Rapa Nui. Journal of Archaeological Science 54, 54–63. https://doi.org/10.1016/j.jas.2014.11.024

Tung, T.A., 2007. Trauma and violence in the Wari empire of the Peruvian Andes: Warfare, raids, and ritual fights. American Journal of Physical Anthropology 133. https://doi.org/10.1002/ajpa.20565

Turchin, P., 2007. War and peace and war: The rise and fall of empires. Penguin.

Turchin, P., Currie, T.E., Turner, E.A.L., Gavrilets, S., 2013. War, space, and the evolution of Old World complex societies. PNAS 110, 16384–16389. https://doi.org/10.1073/pnas.1308825110

Turner, B.L., Sabloff, J.A., 2012. Classic Period collapse of the Central Maya Lowlands: Insights about human–environment relationships for sustainability. PNAS 109, 13908–13914. https://doi.org/10.1073/pnas.1210106109

Uehara, T., Nagase, Y., Wakeland, W., 2010. System Dynamics Implementation of an Extended Brander and Taylor-like Easter Island Model. Systems Science Faculty Publications and Presentations.

Van Tilburg, J.A., 1996. Easter Island (Rapa Nui) Archaeology Since 1955, in: Davidson, J., Irwin, G., Leach, F., Pawley, A.K., Brown, D. (Eds.), Oceanic Culture History: Essays in Honour of Roger Green, New Zealandd Journal of Archaeology Special Publication. New Zealand Archaeological Association, Dunedin, pp. 55–577.

Van Tilburg, J.A., 1994. Easter Island: Archaeology, Ecology, and Culture. Smithsonian Institution Press, Washington, D.C.

Van Tilburg, J.A., 1986. Power and Symbol: the Stylistic Analysis of Easter Island Monolithic Sculpture (Unpublished Ph.D. Dissertation). University of California, Los Angeles, Los Angeles, CA.

Vargas, V.C., Ferrando, C.C., Izaurieta, R., 2006. 1000 años en Rapa Nui: Arqueología del asentamiento. Editorial Universitaria.

Verpooten, J., Joye, Y., 2014. Evolutionary interactions between human biology and architecture: insights from signaling theory and a cross-species comparative approach, in: Csibra, G., Richerson, P., Pléh, C. (Eds.), Naturalistic Approaches to Culture. Akadémiai Kiadó, Budapest, pp. 201–221.

Vezzoli, L., Acocella, V., 2009. Easter Island, SE Pacific: An end-member type of hotspot volcanism. Geological Society of America Bulletin 121, 869–886. https://doi.org/10.1130/B26470.1

Vitousek, P.M., 2002. Oceanic islands as model systems for ecological studies. Journal of Biogeography 29, 573–582. https://doi.org/10.1046/j.1365-2699.2002.00707.x

Vitousek, P.M., Chadwick, O.A., Hotchkiss, S.C., Ladefoged, T.N., Stevenson, C.M., 2014. Farming the Rock: A biogeochemical perspective on intensive agriculture in Polynesia. Journal of Pacific Archaeology 5, 51–61.

Vogt, B., Kühlem, A., 2018. By the Quebrada of Ava Ranga Uka A Toroke Hau - about landscape transformation and the significance of water and trees, in: Haoa-Cardinali, S., Ingersoll, K.B., Ingersoll Jr, D.W., Stevenson, C.M. (Eds.), Cultural and Environmental Change on Rapa Nui. Routledge, New York, pp. 113–132.

Vogt, B., Moser, J., 2010. Ancient Rapanui water management–German archaeological investigations in Ava Ranga Uka A Toroke Hau, 2008-2010. Rapa Nui Journal 24, 18–26.

von Saher, H., 1994. The complete journal of Captain Cornelis Bouman, master of the ship Theinhoven, forming part of the fleet of Jacob Roggeveen from 31 March to 13 April 1722 during their stay around Easter Island. Rapa Nui Journal 8, 95–100.

Voss, R.S., Helgen, K.M., Jansa, S.A., 2014. Extraordinary claims require extraordinary evidence: a comment on Cozzuol et al. (2013). mamm 95, 893–898. https://doi.org/10.1644/14-MAMM-A-054

Walczak, J., 2003. Presentation des Données Actuelles sur la Préhistoire de Rapa Iti (archiple des Australes-Polynésie Française), in: Orliac, C. (Ed.), Archeologie En Oceanie Insulaire: Peuplement, Societes et Paysages. Editions Artcom, Paris, pp. 28–45.

Walker, P.L., 2001. A bioarchaeological perspective on the history of violence. Annual review of Anthropology 30, 573–596.

Wallin, P., 1993. Ceremonial stone structures : the archaeology and ethnohistory of the Marae Complex in the Society Islands, French Polynesia, Aun, 18. Societas Archaeologica Upsaliensis : Distributed by Dept. of Archaeology Uppsala University, Uppsala.

Wallin, P., Martinsson Wallin, H., Possnert, G., 2010. Re-dating Ahu Nau Nau and the Settlement at'Anakena, Rapa Nui, in: The Gotland Papers: Selected Papers from the VII International Conference on Easter Island and the Pacific: Migration, Identity, and Cultural Heritage. pp. 37–46.

Wallin, P., Martinsson-Wallin, H., 2011. Monumental structures and the Spirit of chiefly actions. Time and Mind 4, 43–58.

Wallin, P., Martinsson-Wallin, H., 2008. Religious structures in the Hanga Ho'onu region, in: Stevenson, C.M., Haoa-Cardinali, S. (Eds.), Prehistoric Rapa Nui: Landscape and Settlement Archaeology at Hanga Ho'onu. Easter Island Foundation, Los Osos, pp. 127–161.

Wallin, Paul, Martinsson-Wallin, H., Possnert, G., 2010. Re-dating Ahu Nau Nau and the Settlement at 'Anakena, Rapa Nui, in: Wallin, P., Martinsson-Wallin, H. (Eds.), The Gotland Papers: Selected Papers from the VII International Conference on Easter Island and the Pacific : Migration, Identity, and Cultural Heritage. Gotland University Press, Visby, pp. 37–46.

Wallin, P., Stevenson, C.M., Ladefoged, T.N., 2005. Sweet Potato Production on Rapa Nui, in: Ballard, C., Brown, P., Bourke, R.M., Harwood, T. (Eds.), The Sweet Potato in Oceania: A Reappraisal, Ethnology Monographs 19. University of Pittsburgh and University of Sydney, pp. 85–88.

Walter, R., Smith, I., Jacomb, C., 2006. Sedentism, subsistence and socio-political organization in prehistoric New Zealand. World Archaeology 38, 274–290. https://doi.org/10.1080/00438240600693992

Walworth, M., 2014. Eastern Polynesian: The linguistic evidence revisited. Oceanic Linguistics 53, 256–272.

Wandsnider, L., 2015. "Fighting over a shadow?": Hellenistic Greek cities and Greco-Roman cities as fora and media for multi-level social signaling, in: Kemezis, A.M. (Ed.), Urban Dreams and Realities in Antiquity: Remains and Representations of the Ancient City. Brill, Boston, pp. 69–98.

Wandsnider, L., 2013. Public buildings and civic benefactions in Western Rough Cilicia: insights from signaling theory, in: Hoff, M., Townsend, R. (Eds.), Rough Cilicia: New Archaeological and Historical Approaches. Oxbow Books, Oxford, pp. 170–181.

Watling, J., Iriarte, J., Mayle, F.E., Schaan, D., Pessenda, L.C., Loader, N.J., Street-Perrott, F.A., Dickau, R.E., Damasceno, A., Ranzi, A., 2017. Impact of pre-

Columbian “geoglyph” builders on Amazonian forests. Proceedings of the National Academy of Sciences 201614359. https://doi.org/10.1073/pnas.1614359114

Watson, J.T., Phelps, D.O., 2016. Violence and Perimortem Signaling among Early Irrigation Communities in the Sonoran Desert. Current Anthropology 57, 586–609. https://doi.org/10.1086/688256

Watson-Jones, R.E., Legare, C.H., 2016. The Social Functions of Group Rituals. Curr Dir Psychol Sci 25, 42–46. https://doi.org/10.1177/0963721415618486

Weisler, M., Walter, R., 2017. East Polynesian connectivity, in: Hodos, T. (Ed.), The Routledge Handbook of Archaeology and Globalization. Routledge, New York, pp. 369–386.

Weitzel, E.M., Codding, B.F., Carmody, S.B., Zeanah, D.W., 2020. Food Production and Domestication Produced Both Cooperative and Competitive Social Dynamics in Eastern North America. Environmental Archaeology.

Westoby, M.J., Brasington, J., Glasser, N.F., Hambrey, M.J., Reynolds, J.M., 2012. ‘Structure-from-Motion’ photogrammetry: A low-cost, effective tool for geoscience applications. Geomorphology 179, 300–314. https://doi.org/10.1016/j.geomorph.2012.08.021

Willer, D., Willer, J., 1973. Systematic Empiricism: Critique of a Pseudoscience. Prentice-Hall, Inc., Englewood Cliffs.

Willey, G.R., Phillips, P., 1958. Method and Theory in American Archaeology. University of Chicago Press, Chicago.

Wilmshurst, J.M., Hunt, T.L., Lipo, C.P., Anderson, A.J., 2011. High-precision radiocarbon dating shows recent and rapid initial human colonization of East Polynesia. PNAS 108, 1815–1820. https://doi.org/10.1073/pnas.1015876108

Winterhalder, B., 2002. Models, in: Hart, J.P., Terrell, J.E. (Eds.), Darwin and Archaeology: A Handbook of Key Concepts. Bergin & Garvey, Westport, pp. 201–223.

Winterhalder, B., Smith, E.A., 1992. Evolutionary Ecology and the Social Sciences, in: Smith, E.A., Winterhalder, B. (Eds.), Evolutionary Ecology and Human Behavior. Aldine Transaction, New York, pp. 3–24.

Wozniak, J.A., 2018. Subsistence strategies on Rapa Nui (Easter Island): prehistoric gardening practices on Rapa Nui and how they relate to current farming practices, in: Haoa-Cardinali, S., Ingersoll, K.B., Ingersoll Jr, D.W., Stevenson, C.M. (Eds.), Cultural and Environmental Change on Rapa Nui. Routledge, New York, pp. 87–112.

Wozniak, J.A., 2003. Exploring Landscapes on Easter Island (Rapanui) with Geoarchaeological Studies: Settlement, Subsistence, and Environmental Changes (Ph.D. Dissertation). University of Oregon, Eugene, OR.

Wozniak, J.A., 1999. Prehistoric Horticultural Practices on Easter Island: Lithic Mulched Gardens and Field Systems. Rapa Nui Journal 13, 95–99.

Wright, J., 2017. The honest labour of stone mounds: monuments of Bronze and Iron Age Mongolia as costly signals. World Archaeology 49, 547–567. https://doi.org/10.1080/00438243.2017.1360791

Yoffee, N., 1993. Too many chiefs? (or, Safe texts for the '90s), in: Yoffee, N., Sherratt, A. (Eds.), Archaeological Theory: Who Sets the Agenda? Cambridge University Press, Cambridge, pp. 60–78.

Yoffee, N., Cowgill, G.L., 1988. The Collapse of Ancient States and Civilizations. University of Arizona Press, Tucson.

Younger, S., 2011. Leadership, Violence, and Warfare in Small Societies. Journal of Artificial Societies and Social Simulation 14, 1–20.

Younger, S.M., 2009. Violence and warfare in the pre-contact Caroline Islands. The Journal of the Polynesian Society 118, 135–164.

Younger, S.M., 2008. Conditions and Mechanisms for Peace in Precontact Polynesia. Current Anthropology 49, 927–934. https://doi.org/10.1086/591276

Zahavi, A., 1975. Mate selection—a selection for a handicap. Journal of theoretical Biology 53, 205–214.

Zahavi, Amotz, Zahavi, Avishag, 1999. The Handicap Principle: A Missing Piece of Darwin's Puzzle. Oxford University Press, USA.

Zeferjahn, T., L., 2016. Submarine groundwater discharge as a freshwater resource for the ancient inhabitants of Rapa Nui (M.S. Thesis). California State University, Long Beach, Long Beach.

Zefferman, M.R., Mathew, S., 2015. An evolutionary theory of large-scale human warfare: Group-structured cultural selection. Evol. Anthropol. 24, 50–61. https://doi.org/10.1002/evan.21439