GEOGRAPHIC AND SPATIAL EVALUATION OF GROUP AND TERRITORIAL DECISION ON RAPA, AUSTRAL ISLANDS

by

BRIAN G. LANE

A DISSERTATION

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

June 2022

DISSERTATION APPROVAL PAGE

Student: Brian G. Lane

Title: Geographic and Spatial Evaluation of Group and Territorial Decisions on Rapa, Austral Islands

This dissertation has been accepted and approved in partial fulfillment of the requirements for the Doctor of Philosophy degree in the Department of Anthropology by:

Scott M. Fitzpatrick	Chair
Jon M. Erlandson	Core Member
Gyoung-Ah Lee	Core Member
Patrick J. Bartlein	Institutional Representative

and

Krista Chronister	Vice Provost of the Graduate School

Original approval signatures are on file with the University of Oregon Division of Graduate Studies

Degree awarded June 2022.

DISSERTATION ABSTRACT

Brian G. Lane

Doctor of Philosophy

Department of Anthropology

June 2022

Title: Geographic and Spatial Evaluation of Group Territoriality on Rapa, Austral Islands.

A myriad of local adaptations has been associated with the great human dispersal across the Pacific Ocean, occasionally expressing cultural change in dramatic ways. On the small and remote island of Rapa (Rapa Iti) in the South Pacific, a tradition of monumental ridgetop fortified settlements was established between AD 1300-1400, only a century after colonization. In the 300 years that followed, fortified settlements became entrenched as a visible extension of endemic intergroup competition on the island. However, the underlying reasons for the construction and specific role these constructions played in the associated territorial conflict is still not well understood. The striking nature of the forts has dominated the island's archaeology for over a century, and although often used as an example of the endpoint of intense intergroup competition in Polynesia, Rapa's history and explanations concerning the emergence of territorial strategies have only been partially explored. This dissertation explicitly applies a human behavioral ecology framework to provide hypotheses and explanations regarding the endemic competition through analysis of the island's resource base and placement of fortified settlements. This is accomplished through a series of geospatial analyses and spatial statistical models that explore agricultural productivity and cost reductive strategies related to territorial defense. The results of this body of work point to the changing nature of competition in the past and the dynamic roles that the fortified settlements played within society. The human behavioral

ecology models of the ideal free distribution and economic defendability provide the theoretical framework for a more nuanced explanation of past intergroup competition and its most visible features, the *pare*.

This dissertation contains previously published material and unpublished co-authored material.

CURRICULUM VITAE

NAME OF AUTHOR: Brian G. Lane

GRADUATE AND UNDERGRADUATE SCHOOLS ATTENDED

University of Oregon, Eugene
University of Hawai'i at Mānoa, Honolulu
University of Cincinnati, Cincinnati
Aquinas College, Grand Rapids

DEGREES AWARDED

Doctor of Philosophy, Anthropology, 2022, University of Oregon
Master of Arts, Anthropology, 2009, University of Cincinnati
Bachelor of Arts, Sociology, 2007, Aquinas College

AREAS OF SPECIAL INTEREST:

Islands and Coastal Archaeology
Human Behavioral Ecology
Evolutionary Theory
Pacific Archaeology
North American Archaeology

PROFESSIONAL EXPERIENCE:

Archaeologist, Museum of Natural and Cultural History, Research Division, 2021-present

Graduate Teaching Fellow, University of Oregon, Dept. of Anthropology, 2014-2021

Graduate Employee, University of Oregon Museum of Natural and Cultural History: Collections, 2017-2019

Field Technician, International Archaeological Research Institute Inc., 2012-2017

Instructor, Kaua'i Archaeological Field School, 2013

Teaching Assistant for the Department of Anthropology, University of Hawai'i, 2011-2014

Camp Manager & Field Tech, Ancient Maya Agroforestry and Water Management, Tikal, Guatemala, 2010

Graduate Research Assistant, University of Cincinnati, 2007-2009

GRANTS, AWARDS, AND HONORS:

Graduate Teaching Fellowship, University of Oregon, 2014-2021

Center for Asian and Pacific Studies Small Professional Grant for Graduate Students, 2016

Achievement Scholarship, Department of ANthropology, University of Hawai'i at Mānoa, 2010-2013

University Graduate Scholarship, University of Cincinnati, 2007-2008 and 2008-2009

PUBLICATIONS:

Lane, B. and DiNapoli, R.J. In prep. Empirical Measurements of the Effects of Visibility and Defense. Prepared for the *Journal of Island and Coastal Archaeology*.

Lane, B. In prep. Defensive influences on placement indicate multiple roles for fortified settlements on Rapa, Austral Islands. Prepared for *Archaeology in Oceania*.

Napolitano, M.F., DiNapoli, R.J., Stone, J.H., Levin, M.J., Jew, N.P., Lane, B.G., O'Connor, J.T., and Fitzpatrick, S.M., 2019. Reevaluating Human Colonization of the Caribbean Using Chronometric Hygiene and Bayesian Modeling. *Science Advances*. 5:12

DiNapoli, R.J., Hunt, T.L., Lane, B.G., Lipo, C.P., and Morrison, A.E., 2018. East Polynesian islands as models of cultural divergence: The case of Rapa Nui and Rapa Iti. *Journal of Island and Coastal Archaeology, 13*(2): 206–223.

Lane, B.G. 2017. Geospatial Modelling for Predicting the Ideal Free Settlement of Rapa. *Archaeology in Oceania, 52*(1): 13–21.

Lane, B. and Scarborough, V., 2015. At the Core of Tikal: Terrestrial Sediment Sampling and Water Management. Lentz, D, N. Dunning, and V. Scarborough (eds.) *Tikal* *and Maya Ecology: Water, Landscape, and Resilience.* Cambridge University Press.

Lentz, D.L., Lane, B., andThompson, K., 2014. Food, Farming, and Forest Management at Aguateca. In: *Life and Politics at the Royal Court of Aguateca: Artifacts, Analytical Data, and Synthesis*. T. Inomata and D. Triadan eds. The University of Utah Press, Salt Lake City.

Lentz, D.L. and Lane, B., 2014. Residual Effects of Agroforestry Activities at Dos Hombres, a Classic Period Maya Site in Belize. In: *The Social Life of Forests,* S, Hecht, K. Morrison, and C. Padoch, eds. University of Chicago Press.

Scarborough, V., Dunning N., Tankersly, K., Carr, C., Weaver, E., Grazioso, L., Lane, B., Jones, J., Buttles, P., Valdez, F., and Lentz, D., 2012. Water and Sustainable Land Use in an Ancient Tropical City: Tikal, Guatemala. *Proceedings of the National Academy of Science*. 109:31: 12408-12413.

Tankersley, K.B., Lane, B., Wells, D., Hamburg, C., and Nagy, A., 2009. Last Glacial Maximum Fauna from Great Saltpeter Cave, Kentucky. *Current Research in the Pleistocene*, 26: 48-50.

Lane, B. 2009. *Hopewell Resource Collection: A Paleoethnobotanical Perspective of Twin Mounds.* M.A. thesis submitted to the department of Anthropology at the University of Cincinnati. Cincinnati.

ACKNOWLEDGEMENTS

To begin, I would like to acknowledge all the support that I have received from my family. Raquel, Isabel, and George have been abundantly patient and supportive. I want to thank Lisa and Don for all the love and support that they have provided over the years that have enabled my education. I would not be here without all your patience and gentle encouragement.

I would like to sincerely thank Terry Hunt for all the support and guidance in my academic formation. Without him, I would not have been on this journey. My deepest thanks to Scott Fitzpatrick, who’s mentorship gave me the support and encouragement to finish this dissertation. I also thank my mentors at University of Cincinnati, Vernon Scarborough, Kenneth Tankersley, and David Lentz.

Two organizations were instrumental in providing spatial data in this research. I’d like to thank both The Digital Globe Foundation and the Service de L’Urbanisme, Polynesie Francaise.

There have been many individuals and groups who have assisted me in my academic journey and research that I would like to thank, in no particular order my deepest thanks to John O’Connor, Robert DiNapoli, Damion Sailors, Tuanainai Narii, Veronique Gervais, Jerome Walczak, the staff and teacher at Moss Street Children’s Center, Alex Morrison, Chris Filimoehala, Tim Reith, Madonna Moss, Maria Fernanda Escallón and the students of her writing class, Frances White, Lisa Clawson, Leah Frazier, Dan Gavin, Mary Walworth, Kirsten Vinyeta, Kate and Max Gessert, Marry O’Connor, Armando Morales, Elizabeth Kallenbach, Pam Endweig, Jaime Kennedy, Chris Ruiz, Julia Knowles, Steve Athens, David Burney, Lida Pigott Burney, Hannah Wellman, Matt Napolitano, Jessica Stone, Brendan Galipeau, Atholl Anderson, Doug Kennett, and the archives at the Bernice P. Bishop Museum, Honolulu.

To Jeremy Hollander, thank you for all the conversations that helped guide and direct my thoughts during the research. To Adam Rothi and Matt Trabout, my sincere thanks for providing support and distraction over the years.

Para Raquel y mis gemelos

TABLE OF CONTENTS

Chapter Page

Chapter Page

LIST OF FIGURES

Figure Page

LIST OF TABLES

Table Page

CHAPTER I

INTRODUCTION AND BACKGROUND

1.1. Introduction

Austronesian speaking peoples achieved one of the greatest human dispersals of our species' history – the colonization of hundreds of islands in a territory that spans 1/3rd of the Earth's surface. A result of this massive migration event was the incredible amount of diversity of human adaptations to the unique settings presented by islands across this vast region. Alongside diverse ecological conditions, human groups adapted to new social environments shaped by culture, history, geography, and resources of their new homes. These considerations are in part, what makes islands ideal for studying trends of divergent human adaptation (DiNapoli et al. 2018; Fitzpatrick et al. 2007; Fitzhugh and Hunt 1997; Kirch 1997; 2007). Here, I continue in this tradition by examining the emergence of endemic intergroup competition and territoriality on the small East Polynesian Island of Rapa in the remote Austral Islands archipelago (Figure 1.1 and 1.2).

This dissertation contains analyses that further our understanding of the influences on human groups' decisions concerning resource use and territorial behavior in a circumscribed environment. This research evaluates the relationships between territorial groups and the environment through utilizing archival archaeological, geographic, and ethnohistoric data. To date, much of the research conducted on Rapa has focused on the monumental hilltop terraced settlements (*pare*), interpreted as fortified villages and sociopolitical seats of power (Figure 1.3). However, explanations concerning the emergence of territorial behavior on Rapa remain under-explored, and my research aims to fill this gap. I accomplish this by examining the resource

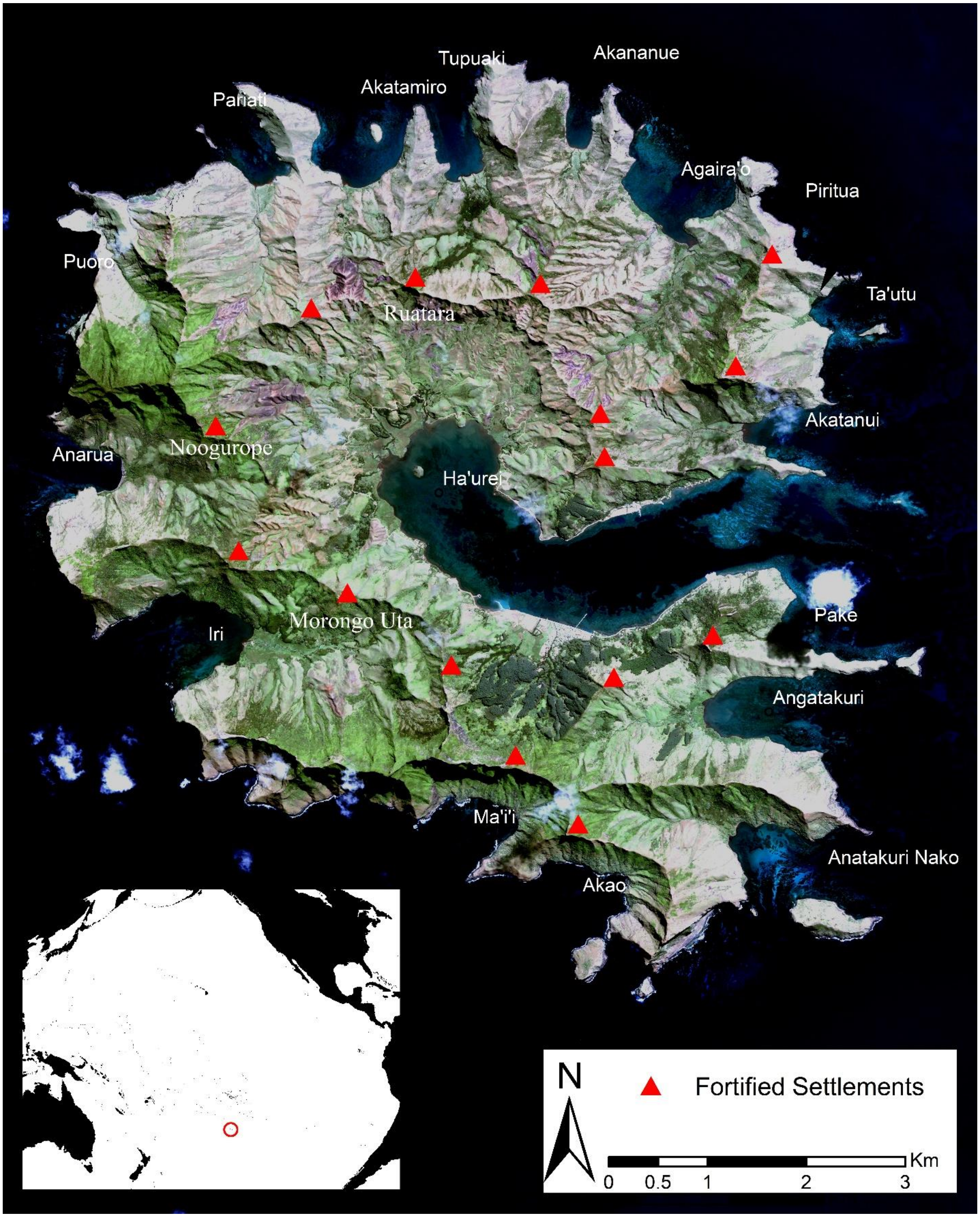

Figure 1.1. Satellite imagery of Rapa from 2002 with fortified sites and bay names.

conditions and adaptive responses that led to intensive intergroup competition on the island. Rapa is an ideal location to explore the emergence and stabilization of territorial behavior. The island presents a clearly bounded research area, has archaeological and ethnohistoric evidence of territoriality, and has extant agricultural and defensive features that can inform on the interplay between territoriality and key resources. Although archaeological and ethnographic research on the island has been comparatively limited, the available data still provide sufficient chronological control and key insights to guide a theoretically informed exploration of the island's deep history. I use these sources as the basis for testable models concerning the intensification of the subsistence base of the island, the importance of monitoring territorial borders, and the role that fortified sites played within an endemic territorial strategy. This body of work acts as a critical step for future work that can test hypotheses regarding Rapa's precontact history.

Figure 1.2. Photo of Rapa looking west into Ha'urei Bay (photo J. Walczak).

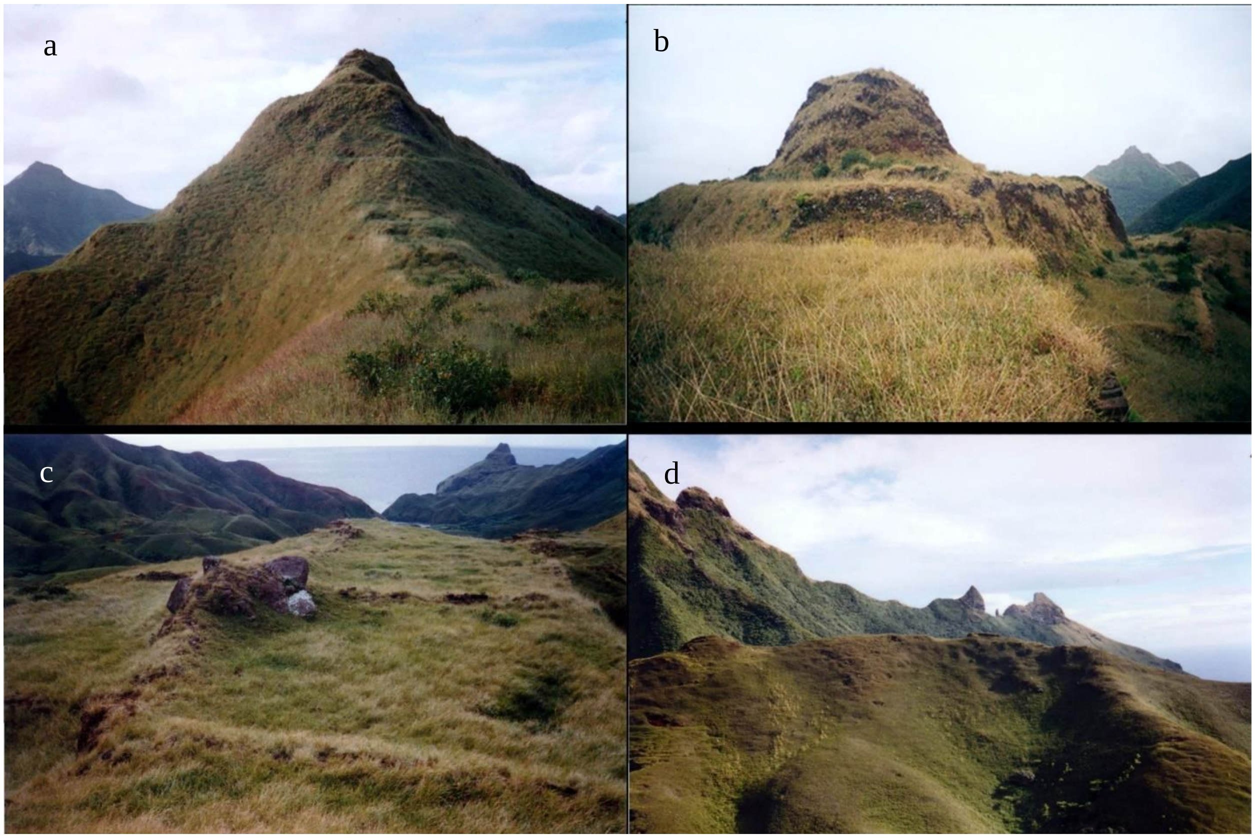

Figure 1.3. Photos of Morongo Uta central tower (a and b) and overviews of terraces (c and d). (Photos a, c, and d by J. Walczak, photo b. by Sardon, distributed under a CCBY 3.0 license.)

1.2. Broader Impacts

This research informs on strategies that human groups have used in competitive relationships in circumscribed environments, especially pertinent in today's political and ecological setting. Unlike other islands used in studies of territoriality in the Pacific (e.g., Field 1998; 2004; 2008; Field and Lape 2010; Smith and Cochrane 2011), Rapa offers a smaller and more clearly defined boundary which permits consideration of the whole island. As such, issues of sampling and defining boundaries on the landscape more accurately account for the past social environment. Such coverage offers new insights on how multiple territorial groups cooperate or compete in the same environment and if such systems can become stable strategies.

1.3. Theoretical Foundations

Archaeology on Rapa has primarily been conducted with an emphasis on constructing baseline culture history and historical ecology (Anderson and Kennett 2012; Ferdon 1965a, 1965b; Kennett et al. 2006; Mulloy 1965; Prebble et al. 2013; Smith 1965a, 1965b). As a result, there has only been broad application of theoretically informed explanations for the documented archaeological social processes. This dissertation makes explicit use of theory to explore Rapa's endemic territoriality by assessing the relationship of physical and social environments on human decisions related to intergroup competition. The theoretical framework of human behavioral ecology (HBE), and the related evolutionary ecology (EE), offer internally consistent models that contribute to our knowledge and understanding of past human behavior and how individuals and groups adapt to their physical and social environments (Boone 1986, 1992; Brown 1964; Cashdan et al. 1983, Cashdan 1992; Dyson-Hudson and Smith 1978; Durham 1976; Wilson and Wilson 2007; Winterhalder and Smith 1992). HBE has been widely applied in anthropology since the 1970s (Winterhalder and Smith 2000) and has seen increasing application in Pacific archaeology (e.g., DiNapoli and Morison 2017; Field 2004; Giovas et al. 2017; Kennett et al. 2006; Reith and Morrison 2017; O'Connor et al. 2017).

HBE studies how the physical and social environments influence and pattern human behavior through an evolutionary adaptive framework (Winterhalder and Smith 1992, 2000). This evolutionary ecology-based theory is predicated on the fact that humans are the products of biological and cultural evolution and that selective pressures influence the making of our societies and patterns our behavior in advantageous ways (Winterhalder and Smith 1992). Two primary types of models are employed in HBE, optimality models of environmental response and game-theoretic models that address the decision-making process and assumptions behind behavioral strategies. Both types of models begin with an assumption that complex phenomena are best understood through a reductionist framework (Winterhalder and Smith 2000:52), a perspective intended to reduce overcomplication that has historically deep roots (Levins 1966). In this dissertation, I make use of the logic behind both types of models to analyze the related topics of habitat selection and the emergence and stabilization of territoriality as a strategy in resource competition on Rapa.

Particularly pertinent are models that deal with human decision-making concerning settlement location (Cashdan 1992), economic defendability and competition (Boone 1992; Brown 1964; Dyson-Hudson and Smith 1978), and to a lesser extent costly signaling theory (Bliege Bird and Smith 2005; Zahavi and Zahavi 1999). However, before moving forward, it is worth noting that although individuals are often the subject of many HBE studies, the basic unit of analysis I will be discussing is the cooperative group. By emphasizing the level of the group, territorial cooperative entities can be modeled as “individuals” competing at a higher level to further simplify models accounting for multiple groups (Wilson and Sober 1994; Spencer and Redman 2001).

The ideal free distribution (IFD) and the ideal despotic distribution are related optimality models that explain the decisions behind the selection of space and resources (Cashdan 1992; Kennett et al. 2006; Kennett and Kennett 2000). The IFD predicts that the first locations to be settled have the highest net returns in relation to a critical resource/currency. Subsequent decisions of settlement are based on what space is currently occupied, costs of joining an existing group, and net costs of moving to an uninhabited lower ranked location (Cashdan 1992; Giovas and Fitzpatrick 2014; Kennett, Anderson, and Winterhalder 2006; Sutherland 1996). Although this is an ideal model for understanding colonization, the application of the IFD is not limited to such situations. Here, I use the logic behind the IFD as a basis for territory selection and predicting the expansion of competing groups based on agricultural potential (Chapter 2).

The economic defendability (ED) model is a useful framework through which to study territoriality as an adaptive strategy (Brown 1964). At the core of ED is a cost/benefit analysis of the invested costs of resources and time weighed against the net gains from maintaining exclusive access to a resource. Territorial strategies are most effective and selected for when the net gains outweigh the invested costs (Brown 1964). This calculus has often been applied to food resources and measured through kilocalories, but the model can be applied to other measurable resources (physical or social) that are deemed essential. In many scenarios, however, the incurred costs and risks can be expansive and the net gain or loss influenced by a variety of considerations: including the physical aspects of a territory (shape, size, and composition), cultural practices, material culture that can reduce costs and/or risk, the actual and perceived aggressiveness of neighbors (intrusion rates), and the overall stability of the strategy to name a few (Adams 2001; Bamforth and Bleed 1997; Brown 1964; Davies and Houston 1981; Fretwell and Lucas 1969). Territorial strategies can become stable within a competitive system where a resource is dense and predictable, intrusion rates into a territory are relatively low, and the costs of maintaining exclusive access are less than the total gain (Brown 1964; Cashdan 1992; Dyson-Hudson and Smith 1978; Hinsch and Komdeur 2010). Ultimately, these factors require researchers to identify and focus efforts on the most likely influences to best understand the local conditions through a shared theoretical framework.

Applying the above considerations to Rapa’s precontact history presents an opportunity for significant insight into past behavior. The reliance on wet taro agricultural and strong evidence for intergroup competition is an ideal context through which to analyze the emergence of territorial strategies. Irrigated agriculture requires sustained cooperation for the construction, operation, and maintenance of infrastructure and can form the basis for social power within corporate groups (Scarborough 2003). Further, irrigated systems often support a dense and predictable resource that can support territoriality. It is also likely related to one of the first agricultural systems to be established by a colonizing population in the Pacific who need a reliable supply of carbohydrates (Addison 2008). Significant investment and strong links to landed infrastructure provides strong incentives for the maintenance of stable cooperative groups and has been logically linked to proposed models of territoriality and competition elsewhere in the Pacific (Kennett et al. 2006; Kirch 1994). Therefore, evidence of the expansion of such infrastructure presents an ideal proxy for demographic and territorial expansion (Prebble et al. 2013; 2019). Indeed, the presence of irrigated agriculture and fortifications in proximity has often been linked to one another using territorial models throughout the Pacific (Field 1998; Field and Lape 2010; Kennett et al. 2006; Kirch 2000). Of these cases, the island of Rapa offers the most complete and accessible dataset through which to evaluate the emergence of intergroup competition and subsequent strategies.

1.4. Rapa, Austral Islands

Rapa (Rapa Iti, Oparo) is a small high island (38 km^2) located in the southern periphery of central Polynesia. The highest point of the island is Mount Perau (650 masl) and is on average high enough to generate orographic rainfall (2500-3000 mm annually, Prebble et al. 2012). Located outside of the tropics (27º 35’ S) in a latitudinal band described as the ‘subtropical depriment’ zone (Anderson 2001; Anderson et al. 2012b). This region of the South Pacific is characterized by lower average air and sea temperatures which results in reduced diversity of tropical species and prevented or inhibited the growth of some important economic species (e.g., coconut, breadfruit, and pearl shell not known to occur precontact). Exacerbating the marginal location, the island is ca. 500+ km from the nearest inhabited island, making it relatively isolated at the southern periphery of the Austral Islands.

Geographically, the island has a severely dissected topography which greatly reduces the area of flat lands for agriculture and settlement (Figure 1.4). The result is that easily accessed resource bases are geographically concentrated within the lowlands of the narrow valleys and near the rocky shores. Many of these conditions set Rapa apart from other Polynesian Islands and made it a unique setting for Polynesian colonists accustomed to the tropics. The cultural and technological adaptations necessitated by the setting make Rapa an important location to study divergent cultural evolution and human response to novel environments (see DiNapoli et al.

Figure 1.4. Photo of Mt. Perau (650 m) that highlights the heavily eroded topography (photo by J. Walczak).

2018). One of the most striking local adaptations was the shift in primary settlement from the lowlands, where resources were located, to fortified ridge top terraced settlements.

Evidence for the first human settlement of Rapa, from Tangarutu rock shelter, indicate that colonization most likely occurred between AD 1100-1200 (Kennett et al. 2012). Recent linguistic subgrouping of Old Rapan indicates that the initial population was closely related to the people that colonized Mangaia, Southern Cook Islands (Walworth 2015:201). Coinciding with human arrival is a documented trend in the loss of a lowland swamp forest, dominated by *Pandanus* and an extinct palm, a rise in charcoal particles, and the first documentation of pollen from *Colocasia sp.* (Prebble et al. 2012, 2013). The shift from swamp forest to taro cultivation is markedly rapid and evidence for land clearance trends continue in the analyzed sediment cores.

Rapa's settlement history initially follows similarities seen on other Pacific Islands during Polynesian colonization. The early period is characterized by lowland and coastal settlement with many economic activities being documented in coastal rock shelters in the outer bays (Anderson et al. 2012a). Evidence for lowland habitation comes from observed earth ovens and terraces near the shores of the central bay, and although the chronology of these sites remains unknown, they are assumed to be from this early period (Anderson et al. 2012a: Smith 1965a; Stokes 2021). Colonization was supported through economic and domestic activities that focused on harvesting and processing marine resources (fish, eels, and invertebrates) and the expansion of wet taro agriculture into the swampy lowlands.

Within a century of colonization, between AD 1300-1400, the first of the *pare* were constructed at Noogorupe and Ruatara (Figure 1.5). This is a significant departure from the settlement patterns observed elsewhere in Polynesia. These two sites, like subsequent *pare*, were collections of ridgetop domestic terraces, of flattened bedrock and constructed walls centered around a central tower, similarly carved from the peak of the ridge. Archaeological investigations of these terraced sites clearly indicate domestic activities, but also significantly make note of various defensive features including fosses, low walls, and artificial embankments (Kennett and McClure 2012; Mulloy 1965; Stokes 2021). Morongo Uta was the third, and largest, *pare* constructed, between AD 1500-1600.

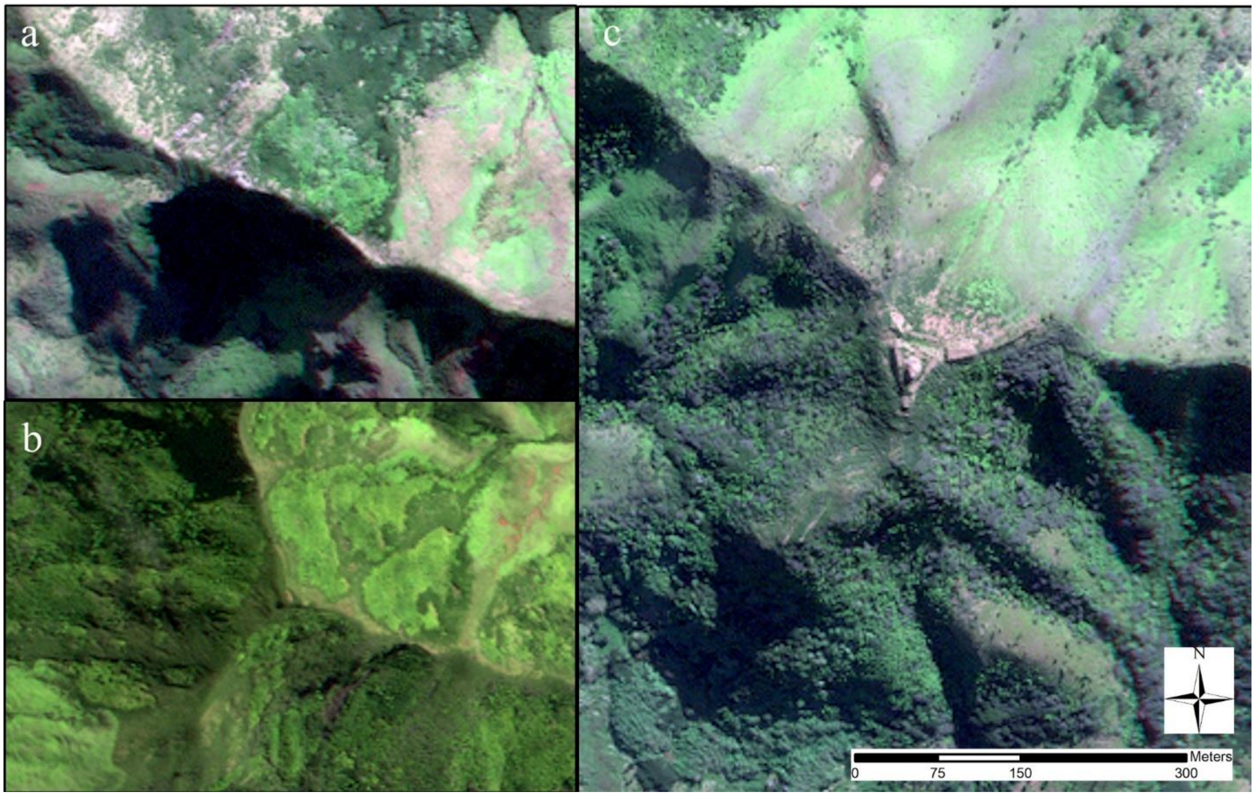

Figure 1.5. Satellite images of *pare* (a) Ruatara, (b) Noogorupe, and (c) Morongo Uta.

The middle period of Rapan settlement is not well documented but did see more intensive use of the coastal rock shelters and expansion of irrigation infrastructure between AD 1400-1600 (Anderson et al. 2012a). Settlement and subsistence/domestic activities have been documented in the lowlands and lower flanks of hills in the form of earth ovens, domestic terraces, and in the coastal rock shelters (Anderson et al. 2012a). However, the open-air sites are under-documented, generally lack chronological control, and currently are not well understood spatially. Early occupation on Rapa was centered more closely to agricultural and marine resources, though the early shift to *pare* construction a century or two after settlement points to a poorly understood middle period when populations began shifting further up slope.

The last settlement phase is characterized by the expansion of *pare* construction. Most of the fortified ridgetop settlements were constructed between AD 1700-1830. In addition to the larger *pare,* at least 10 smaller fortified satellite settlements were also in use at this time, though the chronology of these sites is less clear, they likely correspond with the expansion of *pare* during this period. Additional highland settlement was also documented by Stokes (2021) in the form of 10 or more additional unfortified habitation terraces, also located in the upper flanks and ridges of the island. The later centuries characterized by ridgetop settlement that mark the height of intergroup competition has often been emphasized in narratives of the island.

Based on ethnographic research, traditional Rapan social organization was divided into extended families or clans ruled by a chief and a group of elders based within valleys, and each was free to create alliances amongst themselves (Hanson 1970:19; Stokes 2021). Anderson (2012a:26), summarizing land rights, notes that ownership was directly held by a clan and could be apportioned by the leader to individuals and their descendants. It is evident from the various oral traditions that a strong history of competition between family ramages based on valley occupation became a predominant theme throughout Rapa’s history. Details of the nature of intergroup competition or conflict are elusive, however, pointing to territorial conquest as at least one goal.

Specific examples of competition can be seen through some of Rapa’s oral histories and place names. Stokes (2021:43-44), in a summary of the history of the island, made specific note of the clans that were in ascendance (dominant) on the island at different periods. One of the first recorded struggles between clans occurred between the Gate Mato and the Takatakatea groups, each centered around Tupuaki and Anarua Bays respectively. Each of these clans and their traditional territories are also associated with the first *pare* at Ruatara and Noogorupe. Other traditional stories from the island also recount conflicts such as the capture of the *pare* Napiri and the vengeance of a warrior from Ruatara against Tevaitau (Make et al. 2008; Stokes 2021). Even the name of the *pare* Tevaitau is related to a fight over fresh water (Walworth 2015:196). A glimpse of the nature of conflict can be seen through these traditions, including some of the strategies employed during conflict. Stokes’ (2021:44) summary of Rapa’s history of competition and conflict culminated with the island’s unification by Auariki I, possibly as early as AD 1600. The period of unification, which overlaps the height of *pare* construction and fortification continued up to European contact.

Captain George Vancouver and the crew of the *Discovery* were the first Europeans to approach the island on December 22, 1791. The English ship approached the island, but the land was deemed too small for resupply and left the same day without any crew going ashore. Of immediate note upon close approach were what appeared to be six visible ridge top fortified settlements, described as palisades. These were a sample of the 30+ terrace locations known to have been built. Fourteen of these were of considerable size and characteristic of fortified villages (Kennett and McClure 2012; Stokes 2021). Though never leaving the ship, prominent in the officers’ notes were descriptions of the *pare* and postulations of their purpose (Balfour 1945; Vancouver 1798). Subsequently, the *pare* have been given a place of prominence in most accounts of the island’s history and culture (Anderson 2012a; Balfour 1945; Buck 1958; Caillot 1932; Hanson 1970; Newbury 2011; Shineberg 1986). This is even more pronounced in the notes and publications concerning the archaeological record of this diminutive island (Anderson and Kennett 2012; Caillot 1932; Ferdon 1965a, 1965b; Kennett et al. 2006; Mulloy 1965; Newbury 2011; Routledge and Routledge 1921; Stokes 2021; Walczak 2003a; 2003b). This focus on a narrow aspect of the island’s archaeological record has influenced the nature of the explanations for the evolution of Rapan society. These treatments often involve the growth of territoriality, conflict over agricultural resources, and the movement of habitation from the lowlands to the ridge tops (Ferdon 1965b; Kennett et al. 2006; Stokes 2021). The result is that there is a direct need to fill in gaps in the data such as demographic/settlement and agricultural expansion as well as a need for more nuanced explanations of the decisions behind territorial behaviors.

1.5. Past Work and the Current State of Knowledge

To date, four archaeological investigations have been conducted on Rapa. In 1921, John F. G. Stokes, of the Bishop Museum, conducted ethnographic field work along with a general archaeological survey. Although his notes and manuscript were only accessible through archives and references for nearly a century, a translated edition was recently published (Stokes 2021). During his time on the island, he made note of more than 30 ridge top habitation terraces (*auga*), 15 of which were fortified settlements or redoubts (*pare*). Among the predominantly descriptive comments of archaeological features in the lowland regions, Stokes (2021) also mentions coastally located monolithic territorial markers, multiple fishponds and weirs, four untested potential village sites, and three locations of possible *marae* (traditional Polynesian ritual spaces characterized by paved courtyards with an ahu or altar at one end). This body of work continues to form the foundation of subsequent studies.

In the mid-1950s, the Norwegian Archaeological Expedition to Easter Island and the East Pacific conducted reconnaissance surveys and excavations at four *pare* and sundry lowland locations (Ferdon 1965a; Ferdon 1965b; Mulloy 1965; Smith 1965a; Smith 1965b). The investigations covered many aspects of the island's archaeological record, but focused on mapping Morongo Uta and three additional forts with limited subsurface testing (Mulloy 1965; Ferdon 1965b). The *pare* were concluded to be the primary location of ancient settlement based on the surveys and recovered archaeological assemblages. Smith (1965b) made note of two additional habitation sites from low lying areas around Ha'urei Harbor and Mai'i Bay (the former provided an uncalibrated radiocarbon date on unidentified wood charcoal of AD 1337±200 and was the earliest date from this expedition). Other domestic features recorded during this project were from coastal rock shelters, potential villages, and a small *auga* complex (the term *auga* is a Rapan word to denote terraced settlement that were not fortified; Smith 1965a).

In the late 1990s, after limited archaeological testing in rock shelters and on a few *pare* terraces, a French archaeologist hypothesized an alternative explanation for the highland settlements. Emphasizing the absence of distinct architectural features indicative of ceremonial *marae* (Polynesian temple platforms), he proposed that the primary role of the *pare* was as social/ceremonial structures as opposed to forts and redoubts (Walczak 2003a, 2003b). Support for this argument was drawn from comparing new radiocarbon dates from Tangarutu rock shelter and the NAE's earliest date ranges for Morongo Uta. Walczak (2003a) argued that such a short period was not sufficient for creating the population growth that would have led to resource competition and territorial strategies previously relied upon in explanations.

In 2002, an international team renewed investigations on Rapa. Their project aimed to improve the chronology of colonization and *pare* construction using paleoecological and archaeological data (Anderson et al. 2012b; Kennett et al. 2006). Coastal surveys targeting rock shelters recovered the richest faunal assemblages from the island to date and corroborated the earliest radiometric determinations for the island (Anderson 2012b; Prebble and Anderson 2012a). Data from lowland domestic features were limited, primarily consisting of opportunistically sampled oven features found in road cuts and other recently disturbed settings.

A primary goal of the 2002 expedition was to gain a better understanding of the island's chronology and settlement periods. Radiocarbon assays established the colonization event in the 13th century. Dates of construction of 10 *pare* were also established, beginning with Noogurope and Ruatara between AD 1300-1400, shortly followed by Morongo Uta (Kennett et al. 2012). The construction phase in which most of the dated fortified settlements were constructed occurred between AD 1700-1830.

Due to the emphasis on colonization and fortification in these investigations, the chronology for lowland domestic and agricultural contexts remains limited. The clearest data for these contexts comes from paleoecological core samples taken from lowland swamp sediments. Pollen cores from several of the bays corroborate a rapid transition from lowland swamp forest to cultivated wet taro following colonization (Prebble and Anderson 2012b; Prebble et al. 2013, 2019). Although the presence of taro has been dated through pollen, the accompanying infrastructure and intensification of pondfields remains unclear. Coastal resources such as fishponds and weirs have also yet to be fully described or placed chronologically.

Midden assemblages from rock shelters and fort terraces offer the most detailed glimpse of subsistence practices on Rapa (Cameron 2012; Prebble and Anderson 2012a, 2012b; Szabo and Anderson 2012; Szabo et al. 2012; Tennyson and Anderson 2012; Vogel and Anderson 2012). The archaeological data are supplemented through remote sensing and palynological analyses. Satellite imagery documented the extent of irrigated systems and was used to measure the cultivated land-area. Calculations of yield and energy capture using the Bayliss-Smith model were used to provide population estimates of between 2000-3000 individuals (Bartruff et al. 2012). Additional analysis of pollen cores from Tukou Marsh, at the west end of Ha'urei Harbor, documented the loss of coastal forest associated with rapid establishment and expansion of *Colocasia*-based agriculture in the most productive portion of the island (Prebble et al. 2013; 2019). These lines of evidence along with ethnographic data point to a largely taro-based diet supplemented by nearshore marine resources. Notably, no dogs, pigs, or chicken remains were recovered from any archaeological assemblages, and faunal assemblages indicate that all animal protein was obtained from marine resources such as near shore fish species (especially Scaridae and Chaetodontidae), invertebrates (especially crab and urchin species), and eel (Szabó et al. 2012). Although, the Pacific rat (*Rattus exulans)* was introduced to the island, no evidence points to it as a food source.

Ultimately, the data from Rapa provide a compelling basis from which to understand the ecological and cultural processes that occurred during its precontact occupation. Although holes remain in the demographic contexts and chronology, especially concerning settlement and agriculture in the critical "middle phase" (Anderson et al. 2012:255), there is a significant basis from which to build an understanding of the under-developed emergence and nature of intergroup conflict.

The current narrative of Rapa’s precontact history is built upon archaeological data from the *pare*, coastal rock shelters, and ethnohistoric accounts (Anderson 2012a; Anderson et al. 2012b; Smith 1965a; Stokes 2021; Walczak 2003a). These lines of evidence point toward a state of endemic competition expressed through territorial strategies. The most obvious basis for such competition has consistently been identified as the dense and predictable irrigated fields located in the valley lowlands. Despite the lack of fine-grained settlement chronologies, the existence and physical relationships between fortified sites provide a strong basis from which to begin developing testable hypotheses that can shed light on the nature of competition and the variety of roles that fortified settlements played in old Rapan society.

1.6. Dissertation Organization

In this dissertation I utilize the available archaeological and geographic data to analyze aspects of the emergence of intergroup competition and the role that fortified settlements played in supporting and stabilizing a territorial strategy. The following analyses are based within an HBE perspective to understand these processes in a context of a marginal and circumscribed environment. I accomplish this through theoretically informed application of geographic and spatially explicit statistical modeling. The objective of the following chapters is to combine and process spatial data from various sources to provide a series of testable hypotheses related to the emergence of territoriality, the nature of intergroup competition, and the stability of the competitive strategy exhibited by the archaeological record on Rapa. These chapters are comprised of one previously published paper and two unpublished manuscripts that together form the core of a focused stepwise research project.

Chapter 2 analyzes habitat selection and how expansion of irrigated agriculture on Rapa was likely patterned as predicted through the optimality model of the IFD. Instead of looking at initial settlement selection based on a colonizing event, as is often the case with the IFD, I apply the model logic to predict the order in which investment in irrigated taro agriculture occurred by valley. I identify agricultural potential using physical attributes that influence productivity and lower the costs of constructing irrigation systems. Using subsistence infrastructure as a proxy for territorial investment and emerging competing groups, I rank valleys on their suitability/productivity based on agricultural capacity by predicting locations capable of supporting irrigated taro agriculture. This work follows similar models utilized elsewhere in the Pacific for irrigated agriculture and settlement (Kurashima and Kirch 2011; Ladefoged et al. 2009; Müller et al. 2010; Reith et al. 2008), but is one of the few to then rank the results and frame them within a larger theoretical question. I argue that this tailored application of the IFD offers a useful tool for understanding the emergence of the social environment that fostered endemic intergroup competition as expressed through territorial behavior. Further, this approach facilitates the creation of data driven hypotheses that can be tested against existing and future archaeological data. This chapter was initially published as a sole authored piece in an HBE themed issue of *Archaeology in Oceania* (Lane 2017).

Chapter 3 bridges the focus on resource distribution with a spatially driven evaluation of the fortified settlements. Specifically, I test the importance of visibility as a driving factor in predicting the locations of defensive sites. Continuing the application of HBE, I employ logic from economic defendability (ED) to highlight the importance of monitoring in territorial behavior and evaluate to what degree, if any, the *pare* were intentionally placed in locations that are meant to take advantage of a given location’s viewshed. This chapter improves on similar work from Fiji and Rapa (Lane and DiNapoli 2015; Smith and Cochrane 2011) by using a spatially explicit form of statistical modeling, point process models (PPMs), to evaluate the predictive capability of theoretically linked environmental variables. This chapter is a co-authored manuscript prepared for submission to *The Journal of Island and Coastal Archaeology*.

Chapter 4 delves further into understanding the placement of fortified sites and their role in making territoriality an evolutionarily stable strategy. In this spatial analysis I introduce additional site locations, divide the sample into classes based on the size of the settlement, and employ newly measured environmental variables. These data are again modeled with visibility, but I also employ covariates directly related to the costs of defense. Two parallel analyses are conducted to determine if there are differences in the influence of site placement based on class. The results of this analysis highlight the importance of cost-reductive adaptation as a means of stabilizing territoriality as an element of pre-contact Rapan culture. This chapter is a sole-authored manuscript prepared for publication in a peer-reviewed journal.

Chapter 5 concludes the dissertation with a synthesis of the previous chapters’ findings and a discussion of the emergence of territoriality and the nature of intergroup competition on the island. This chapter forms the core of a planned publication that emphasizes the theoretical underpinnings of this dissertation as supported through the geospatial modeling.

CHAPTER II

GEOSPATIAL MODELLING FOR PREDICTING THE IDEAL FREE SETTLEMENT OF RAPA

This chapter was previously published as:
Lane, B. G. (2017) Geospatial modelling for predicting the ideal free settlement of Rapa. *Archaeology in Oceania*, 52(1), 13-21.

2.1. Introduction

The people who spread into East Polynesia were intimately acquainted with tropical island environments and shared a common cultural ancestry from West Polynesia (Kirch 2000). Following permanent colonisation of new islands, new populations would acquire knowledge about resource potential and distribution. As demographic growth occurred, populations would intensify resource extraction/production in locations of lesser quality. Irrigated agricultural infrastructure is often an archaeologically visible consequence of this spread coupled with demographic growth. On islands outside of the tropics, like Rapa in the Austral Islands (Figure 2.1), the reliance on a few tropical crops became integral components of subsistence and irrigated taro agriculture a highly desirable resource. To further explore processes of expansion of intensive agriculture into new resource areas a tailored geospatial model and a narrowed application of a theoretical framework are applied to Rapa. This approach is designed to predict locations of the earliest agricultural intensification and its subsequent spread, which can better help explain the settlement process on Rapa, especially in relation to the construction of fortified ridge top settlements (*pare*).

The human behavioural ecology (HBE) model, the ideal free distribution (IFD), is one framework through which to understand and make archaeological predictions about demographic

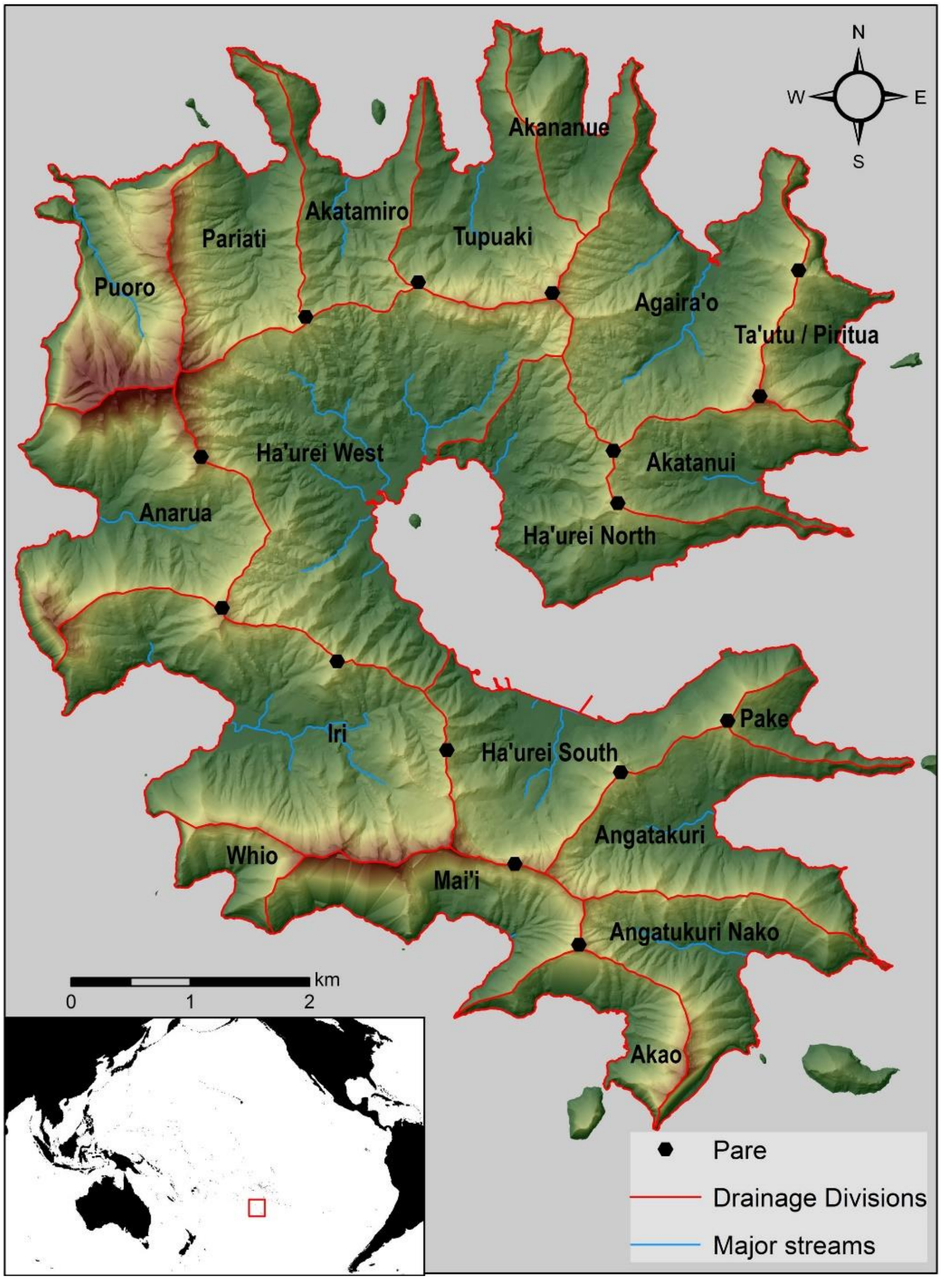

Figure 2.1. Map of Rapa depicting valley divisions, *pare*, and major streams.

expansion following island colonisation (Fretwell & Lucas 1969; Giovas & Fitzpatrick 2014; Kennett et al. 2006; Winterhalder et al. 2010). The IFD typically describes decisions concerning expansion into new habitats and subsistence intensification through measures of suitability using multiple characteristics (Winterhalder et al. 2010). However, the basic model assumptions could be generalized to a single resource in order to make predictions about a specific type of habitat expansion, in this case the spread of irrigated agriculture. In the model presented here, pondfield irrigation is used as the single resource due to the emphasis of intensive irrigation in explaining the prehistory of many islands throughout the Pacific (e.g., Buck 1938; Kirch 1994, 2000; Spriggs 1990; Stokes n.d.).

This paper presents a geospatial method which produces a generalized relative ranking of irrigable land. The model's utility is as the base to which the logic of the IFD can be applied to create testable archaeological predictions about agricultural intensification. Such modelling is essential when addressing questions central to the deep history of Rapa such as: where and in what order do we expect intensified irrigation to develop and what role did expansion of intensified agriculture play in relation to the well documented emergence of territorial behaviour on Rapa? Geospatial and environmental data for Rapa are utilized to identify irrigable land and relatively rank valleys based on suitability for irrigation. Rapa is an ideal location to exhibit the wider utility of the model because: 1) the available geospatial and environmental data for Rapa is typical in terms of the quantity and type of data available for islands throughout Polynesia; 2) like other islands in Polynesia, irrigated taro agriculture is central to explaining the island's history of group competition and territoriality (Anderson et al. 2012a; Kennett et al. 2006; Stokes n.d.); and 3) the island is small enough to develop an island wide model.

2.2. Background

2.2.1. Rapa

Rapa is a small (38 km^2) high volcanic island with abundant rainfall (2500-3000 mm annually). Due to its location outside of the tropics (27º S) there is comparatively less biodiversity and biomass than other Central Eastern Polynesian islands (Anderson et al. 2012a). In addition to reduced resource diversity, initial colonizers were also faced with environmental conditions that precluded several Polynesian crops. Breadfruit, yams, coconut, and most banana varieties are noticeably absent in the archaeological and ethnohistoric record for Rapa (Anderson 2012a; Stokes n.d.). Subsequently taro, *Colocasia esculenta,* was the principal source of carbohydrates on the island capable of supporting a sizable population.

Current estimates for the colonisation of Rapa fall in the mid-12th to the mid-13th centuries (Kennett et al. 2006). Intensive survey of coastal rock shelters has found rich evidence for initial coastal occupation and exploitation starting with colonisation (Anderson et al 2012). There is also paleoenvironmental evidence for the initial settlement phase from cores from Tukou marsh at the head of Ha'urei Bay indicating the presence of *C. esculenta* pollen and an initial decline in coastal *Pandanus sp.* forest environments (Prebble et al. 2013).

Little archaeological evidence exists concerning the development of initial Rapan society, but paleoevironmental cores indicate the expansion of taro agriculture around the central bay with an eventual zenith in production around AD 1590-1740 (Prebble et al. 2013). Direct dates from agricultural settings in the outer bays are still absent, but survey data and satellite imagery confirm the presence of a widespread and intensive irrigated agricultural system in more than two thirds of the islands valleys (Bartruff et al. 2012). The early oral traditions and ethnohistoric evidence from the island confirm archaeological indications that taro agriculture constituted the majority of agricultural carbohydrates for ancient Rapa with continued exploitation of marine resources for protein (Hanson 1970; Stokes n.d.). The striking reliance on irrigated taro agriculture on Rapa means that to understand the evolution of social processes in detail we must have a firm grasp on the development of agriculture. Especially when considering that population estimates based on irrigation systems and *pare* suggest a population of around 2000-2500 individuals at the height of production (Bartruff et al. 2012; Stokes n.d.)

The culmination of social development on Rapa is often seen in the form of the fortified *pare,* suggesting a period when competition and territoriality were strongly institutionalized. The importance of irrigable land as a dense and predictable subsistence base is often the primary resource cited as playing a part in territorial behaviour on Rapa in the form of raiding, competition, and *pare* construction (Anderson et al. 2012a; Hanson 1970; Kennett et al. 2006; Stokes n.d.). Radiocarbon determinations for the first *pare* fall within AD 1300-1400. Initial construction occurred at just two locations, Noogorupe and Ruatara, with a possible hiatus at Ruatara that suggests that pressures for initial fortification may not have been felt evenly or consistently during this phase (Anderson et al. 2012a). All *pare* had been constructed by AD 1700-1830, just prior to eventual abandonment of all settlements around the time of more intensive European contact in AD 1825 (Anderson et al. 2012a). Despite what is known of the archaeological record of Rapa, details concerning agricultural development in valleys known to support irrigation is limited, leaving a significant gap in the island’s history necessary for fully understanding the context of later social development.

2.2.2. Ideal Free Distribution

IFD models have been used to understand island colonisation from the Caribbean (Giovas & Fitzpatrick 2014), the Northern Channel Islands (Jazwa et al. 2016; Winterhalder et al. 2010) and Polynesia (Kennett et al. 2006). Such models describe how individuals choose which locations to settle based on comparing habitat suitability and population density in the place of origin against other potential locations (Figure 2.2). When presented with the option to stay in an occupied location or move into a new location the IFD simplifies the decision by assuming that individuals are aware of the qualities of each location and make rational choices based on suitability and density (Fretwell & Lucas 1969; also see Kennett et al. 2006; Winterhalder et al. 2010), making an *ideal* selection based on accurate information. This model also assumes that there are no constraints on movement and individuals compete equally, allowing individuals to *freely* enter a new habitat.

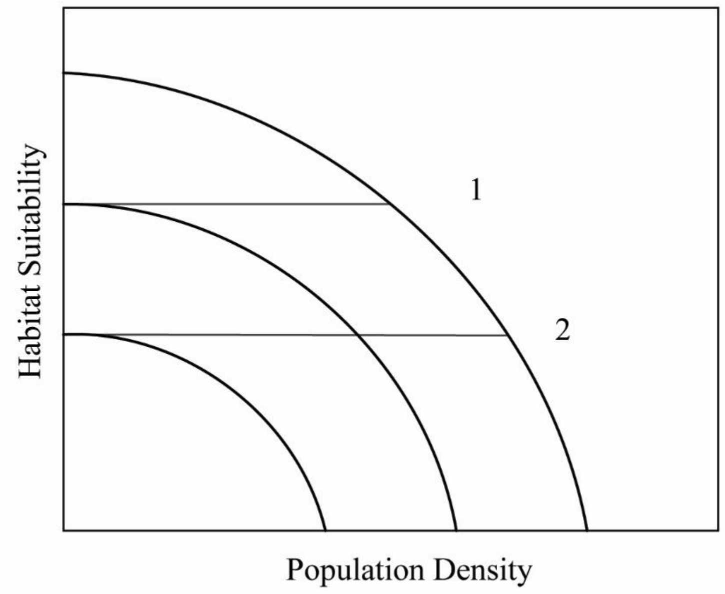

Figure 2.2. Graphic representation of the ideal free distribution. As population increases suitability decreases until it reaches the same degree of suitability as the next ranked habitat. As the best suited habitat grows in population the next lowest becomes ideal when levels reach 1, and likewise for both at 2.

The application of the IFD in this paper has been narrowed to predict where intensive agriculture should expand to after colonisation based on a single measure of suitability. Despite multiple exploitable resources on an island, specific decisions about the expansion of pondfield agriculture can be modelled using a single generalized measure of the landscape's suitability for supporting irrigation. Although other factors like social structure and relations can play a role in deciding where new agricultural plots are placed, the focus here is on the most basic requirement, the physical environment. Generalizing a measure for suitability to only the physical requirements reduces the chances of potentially erroneous assumptions about the expansion process in the absence of direct archaeological data concerning island wide irrigation. As time progressed, increasing limits on irrigable land would place pressures on the population and effectively decrease the suitability of the habitat, encouraging individuals to occupy the next best location. This would continue until all irrigable locations were occupied.

2.2.3. Irrigation and Geospatial Model

Irrigated aroid agriculture has long been recognized as an important agricultural system throughout Oceania (Kirch 1977, 1994; Spriggs 1984). The most intensive form utilizes canalized pondfields, whose productivity has been recognized as sources of sustained intensive agriculture production (Allen 1991; Kirch 1977; Palmer et al. 2009). Compared to dry land agriculture, sustainable production and faster returns made irrigation highly efficient where possible. This form of dense and predictable agriculture was a key resource for islands and for specific valleys. Irrigation has often been cited as the impetus for raiding, conflict, and for increased social complexity (Allen 1991; Earle 1978; Kirch 1989, 2010). Due to the inferred connection between irrigation and increased raiding and competition in the Pacific, a focused investigation of the irrigation base of Rapa would be key to understanding the social development of the island and the emergence of competition.

Geospatial modelling of the physical requirements of intensified pondfield agriculture allows for a systematic means of understanding resource potential. Similar analyses have managed to identify the maximum extent of irrigation in the Hawaiian Islands (Kurashima &

Kirch 2011; Ladefoged et al. 2009; Müller et al. 2010). These works highlight the utility of such data in understanding agricultural potential and physical constraints on different production systems. These geospatial analyses utilized environmental factors such as slope, soil, geology, and rainfall, to identify the potential for different production systems. Ladefoged and colleagues (2009) went further and calculated energetic returns based on area and juxtaposed these data with the emergence of social complexity. Another analysis specific to Molokai modelled the potential area for four different production systems (Kurashima & Kirch 2011).

2.2.4. Geospatial Analysis Predictions

Each of the above analyses estimated the potential extent of these agricultural systems. Geospatial analysis can be taken a step further to relatively rank degrees of suitability within an agricultural system, allowing for predictions of the archaeological record based on theoretical models. Here, a generalized measure of energetic costs for construction and maintenance of irrigation systems is used as a measure of suitability to create a relative ranking. General knowledge of topography and water courses of the island would be sufficient to meet the requirements of ‘perfect knowledge’ assumed by the IFD.

Following IFD logic, intensified irrigated agriculture is expected to first arise in the most suitable locations, and then in descending order of suitability as demographic pressure increases. Archaeologically we would expect to see high ranked locations have deeper chronologies directly related to irrigation infrastructure than middle and low ranked areas. This could be tested within a single drainage, as the model is conducted at a sufficient scale, or could be aggregated to talk about larger generalized land units, such as drainages or a valley as a whole. This paper addresses the latter scale.

Even with the limited amount of archaeological data directly from agricultural contexts, the model aids in structuring theoretical arguments concerning the move into new resource areas and for social processes resulting from changing population structure (e.g., cooperation or competition). Model predictions that can be empirically tested are an important step in inductive reasoning. Additionally, such paring of theoretical and geospatial models aids in directing future data recovery by targeting key locations likely to contribute suitable chronological data.

2.3. GIS Determination of Irrigation Potential

Relatively ranked classification was conducted for irrigation on Rapa. The predictive model was based on a combination of the physical requirements of taro and geographic constraints to Polynesian pondfield agriculture. The foundation of the analysis was a 2 x 2 m resolution digital terrain model (DEM) originally derived from a triangulated irregular network (TIN).

A generalized measure of the amount of energy required to create and maintain irrigation systems is the basis for creating relative rankings of suitability within the predictive model. For this analysis, it is assumed that energy input for construction and maintenance accounts for the primary differences in net energy returns between otherwise equal land area. The differences between rankings within this geospatial analysis are intentionally general and relative. Attempting to calculate specific net energy returns in this model would give a false impression of precision within the relative ranking, whereas a simple and generalized model is more manageable and desirable. This results in a flexible model that can be used in the application of various ecological theories, but like any model there are simplifying assumptions (Levins 1966). It is assumed in this model that population is constantly increasing, which creates pressures on limited agricultural land, and that suitability for irrigation in the simplified form of physical requirements are the primary driving factor among many that drive decisions about where to expand intensive irrigation.

Multiple variables were initially considered for modelling irrigation suitability: slope, distance from water, elevation, geology, and soil. Age of geologic substrate has proven to be an important factor in agricultural potential elsewhere (Kurashima & Kirch 2011; Ladefoged et al. 2009). Geological survey of Rapa indicates uniformity in its substrate (alkaline olivine-basalts) but lack specific differentiating data concerning age (Brousse & Gelugne 1986; Chubb 1927), ultimately making these data unavailable for spatial modelling. Additional data considered for inclusion were soil classifications, but no soil maps for Rapa are available. Limited pedological data from the island suggest uniform distributions of leached and eroded ferralitic soils on higher slopes and colluvial and alluvial fill in valley bottoms (Trichet et al. 1986). The published soil chemistry of the island is also too spatially limited to develop an accurate and useful distribution. Slope, distance from water, and elevation as a proxy for temperature proved to be the most useful variables for this model (Table 2.1).

2.3.1. Slope

Slope is an important determining factor in the construction of any water management system. Measures of slope can provide a generalized measure of energy required for construction and maintenance of irrigation systems, with lower degrees of slope requiring less energy to construct and maintain (Kirch 1994). Slope was calculated for the DTM. Cells were reclassified

Table 2.1. Description and rational for attributes used in the productivity ranking.

	Relative Rankings				Rational
	High	**Medium**	**Low**		
Slope (degrees)	0.1-8.0	8.01- 13.5	13.51 – 19.1		Slope is necessary to ensure continuous running water. It also influences the amount of effort required to build and maintain irrigation systems. The max slope was determined from the most extreme ethnohistoric accounts from Polynesia (Handy 1940). The high rank threshold was determined based on the degree of slope identified in irrigated systems (McElroy 2007 and Ladefoged et al. 2009).
Temperature Cº (from annual averages)	20 – 19.6	19.6 – 19.2	19.2 – 18.8	18.8 – 18.4	Temperature calculated based on lapse rate from lowest average temperature at sea level. Four intervals of 62.5 m of elevation were used that signify a difference of 0.4° C. Ranking then compared to optimal temperature for *C. esculenta* growth.
Hydrology	5th Order Streams	4th Order Streams	3rd and 2nd Order Streams		High tolerances for flow accumulation were used to determine where streams occur. Stream order was then assigned as a proxy for volume and permanency. Based on satellite imagery 4th and 5th order streams appear perennial in large drainages. 3rd and below still show water but with less volume and shorter courses. This acts as a proxy for available volume.

and ranked based on physical limitations determined from ethnohistoric and archaeological documentation (Handy & Handy 1972; Ladefoged et al. 2009; Kurashima & Kirch 2011; McElroy 2007). The cells were then divided into three ranks. The cells of highest suitability had slope values of 0.1º to 8.0º. This rank accounts for the majority of documented pondfield systems and requires the least amount of energy to construct and maintain (Earle 1980). The range between 8.01º and the highest limit 19.1º was evenly split (13.5º) to differentiate a difference in energy required for steeper terrain.

Additional editing of the classified slope raster was conducted to account for gravitational flow. TINs occasionally generate erroneous irregular step-like flat surfaces along ridges as a result of their calculations giving a false interpretation of the actual slope; these cells' data were removed from the slope raster to prevent false identification of areas that would otherwise be above potential water sources. This better reflects the physical constraints of gravity on water flow.

2.3.2. Water Source

Pondfield irrigation requires a constant flow of slow-moving water to cover the taro corms. Distance from water sources and a general measure of potential water volume from source streams were used to rank water requirements for irrigation. To model water requirements the flow direction and accumulation for the DTM were determined and then used to generate a stream network for the island. The streams were classified using the Strahler Stream Order as a measure of the relative volume of each stream. The generated streams were compared to IKONOS and World View 2 satellite imagery from the driest months to verify that generated streams could be considered perennial (typically 2nd order and above).

Variable buffers were used to determine areas that could feasibly be fed from each stream ranking. Varying buffer size is used as a generalized measure of suitability based on the area of irrigation plots that could be fed by different volumes, with smaller streams being able to supply less area than streams with higher volumes. Additionally, the scale and purpose of this model is to generate data that could be differentially ranked, so incremental buffer sizes were used. This resulted in streams of the 2nd and 3rd (smaller) order both receiving 60 m buffers, 4th order streams a 120 m buffer, and 5th order streams a 180 m buffer. These intervals best fit the constraints of Rapa's size and topography.

2.3.4. Elevation and Temperature Lapse Rate

Elevation was considered as a proxy for the lapse rate effect on air temperature (6.4º C drop for every 1000 m). Temperature is an important variable in this model because average temperatures on the island at their lowest are close to the lower tolerance limits for *C. esculenta*, 21º C (Onwueme 1999). This directly impacts the suitability for irrigation based on the potential risk of low temperatures decreasing yield or available planting months.

To calculate temperature thresholds the DTM was reclassified into 62.5 m interval bands to create 10 distinct elevation classes for the island. Starting at sea level the lowest average monthly temperature was entered as the feature value and then reduced by 0.4º C for each subsequent step up in elevation. Only the lowest four bands overlapped with perennial streams and slope thresholds and therefore only four elevation bands applied in the ranking.

2.3.5. Combining Ranks

To calculate the final ranks each dataset was clipped and then summed. The cells in the resulting layer were reclassified into four classes. Classes were differentiated by a relative generalized conceptualization of the degree of energy investment required to construct and maintain irrigation systems and temperature limits of taro. Slope and distance from water are the most important factors that contribute to ranking the potential based on simplified assessments of the amount of energy required for constructing and maintaining pondfields (e.g., length of canals, height, and angle of walls). The island was divided into 19 primary drainages and the total area of each class was calculated for each valley (Figure 2.1). The land area of each class was then multiplied to a weighing factor to create a relative ranking of valleys based on a final measure of area (Table 2.2).

Table 2.2. Total area calculations and weighted calculations of potentially irrigable land on Rapa.

	Irrigable Area by Potential (m2)				Total (ha)	Weighted Total [t]	IFD Ranking
	High	Mid-High	Mid-Low	Low			
Ha'urei West	519,880	490,513	266,169	53,446	133.00	103.42	1
Iri	260,106	197,075	143,806	74,504	67.55	49.84	2
Ha'urei South	214,801	218,155	164,680	35,075	63.27	46.95	3
Agaira'o	182,587	162,670	233,282	68,929	64.75	43.85	4
Ha'urei North	51,283	196,496	106,263	10,687	36.47	25.45	5
Tupuaki	71,854	130,781	118,566	15,878	33.71	23.32	6
Angatakuri	64,260	130,540	103,371	1,810	30.00	21.43	7
Akatanui	62,098	81,095	83,271	5,774	23.22	16.60	8
Anarua	27,841	116,628	56,315	21,791	22.26	14.89	9
Angatukuri/Nako	32,950	58,848	21,841	2,494	11.61	8.86	10
Akatamiro	11,902	63,165	50,058	2,680	12.78	8.50	11
Pariati	0	50,149	65,002	28,783	14.39	7.73	12
Akananue	0	60,041	45,547	122	10.57	6.78	13
Mai'i	1,795	18,928	48,644	678	7.00	4.05	14
Puoro	1,967	7,846	7,853	2,690	2.04	1.25	15
Ta'utu	0	8,508	7,544	38	1.61	1.02	16
Akao	0	2,616	6,483	6	0.91	0.52	17
Pake	0	5,221	2,446	0	0.77	0.51	18
Whio	0	49	176	3	0.02	0.01	19
Total (ha)	**150**	**200**	**153**	**33**	**536**		

t = Weighted totals calculated by multiplying the areas of rank 4 by 1, rank 3 by 0.75, rank 2 by 0.5, and rank 1 by 0.25. This is an arbitrary division that generalizes the cost of maintenance and construction of irrigated plots and therefore a generalized estimate of total energy return against labour.

2.4. Results

The classified ranking accounts for two measures of suitability of irrigated systems: 1) the physical limits of taro; and 2) the relative energy requirements for the construction and maintenance of irrigation infrastructure. Physical requirements indicate where irrigation is possible while generalized concepts of energy investment add a new dynamic to geospatial prediction of pondfield irrigation. Broadly speaking, this relatively ranks potential pondfield plots in relation to perceived suitability based on energy investment and net gains without specific knowledge of actual agricultural productivity (soil chemistry, substrate age, etc.).

The model identified over 500 hectares (Figure 2.3), divided into four suitability classes, which could support traditional pondfield irrigation. This accounts for only 14% of the total land area of Rapa. A quarter of suitable land is ranked as the highest quality. More than 70% of the area indicated falls within the alluvial terraces and fans in the valley bottoms. These areas match expectations of what is typically recognized as prime locations for taro cultivation throughout the Pacific (Kirch 1994; Spriggs 1984). The highest concentration of land suitable for irrigation falls within the inner caldera surrounding Ha’urei Bay and in Iri and Agaira’o valleys.

The resulting model can be compared to satellite imagery and existing archaeological data concerning the distribution of irrigation systems on Rapa as a benchmark for the success of the model as well as to understand different ranked classes of land (Figure 2.3). Initial comparison of suitable land area with Worldview 2 imagery indicates that the majority of high and mid-high classed cells overlap with extant pondfield systems. Likewise, when compared to existing spatial datasets, there is a similar co-occurrence of high and mid-high ranked cells

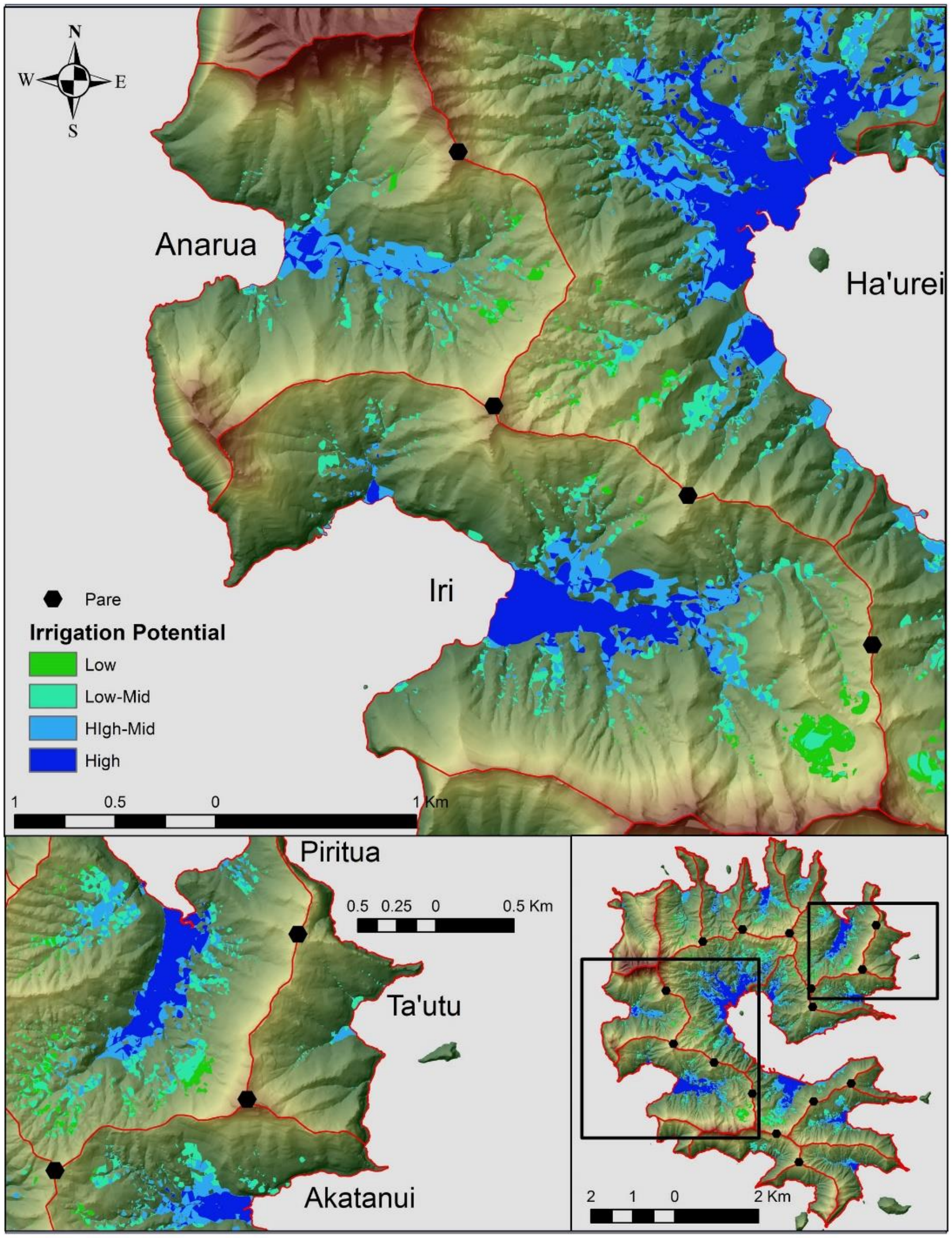

Figure 2.3. Detail of the ranked raster showing valleys of differing ranks of productivity.

matching with documented archaeological pondfields. These observations are also corroborated through comparison of Bartruff and colleagues (2012) calculations of visible extent irrigation features during their estimates of prehistoric population sizes. This suggests that although the mid-low and low ranked locations are capable of supporting irrigation in this model, they are not informative in predicting existing archaeological features. These result makes sense when considering that the highest cut off for variables were the most extreme limits of observed irrigation systems in Hawaii (Handy & Handy 1972; Ladefoged et al. 2009; McElroy 2007).

2.5. Discussion & Conclusion

The geospatial model presented here is a generalized relative ranking of the suitability for irrigation on Rapa. In this specific model, the relative ranking was based upon three variables that describe the physical requirements of irrigation and differentiated suitability based on generalized concepts of energy investment in the construction and maintenance of pondifeld agriculture. Such ranked spatial data are especially well suited for the application of models from HBE because of the common use of decision logic that evaluates suitability factors between multiple locations. This paper has specifically focused on a narrowed version of the IFD to predict the spread of intensive agricultural practices during the period of demographic expansion in Rapa's prehistory. The geospatial rankings could also be useful in other applications of HBE such as evaluating territories and territorial behaviour through visibility analysis or in agent-based modelling where actors need a classified landscape based on variation in productivity.

Most archaeological applications of the IFD have been more broadly focused on a regional scale (Giovas & Fitzpatrick 2014; Kennett et al. 2006). The application in this paper is island specific, similar to application in the Northern Channel Islands (Jazwa et al. 2016; Winterhalder et al. 2010). Unlike these latter models, the IFD logic is not meant to describe initial colonisation of different parts of the island, but instead to describe a process of habitat infilling for the post-colonisation expansion of intensified irrigated agriculture. Because of the specific interest in agriculture, suitability was generalized to physical aspects of irrigation systems in relation to energy investment and requirements for taro. This required a new geospatial means of relatively ranking suitability. Future treatments of this model could be modified to incorporate dry land agriculture and other critical resources like marine based protein.

Archaeologically, the predictions from the combined geospatial and theoretical model identify an expected order for the expansion of intensified irrigation on Rapa (Table 2.2). The model predicts that the most suitable location for irrigation would be in the land around Ha’urei bay, in Tukou Marsh, and later expand to other valleys like Ta’utu and Puoro. Currently the limited archaeological data from paleoenvironmental cores support the presence of *C. esculenta* in Tukou Marsh and a rapid decline in the Pandanus forest within the first century and a half after colonisation (Prebble et al. 2013), suggesting that the Ha’urei Bay area was indeed an ideal location for initial agriculture. However, direct evidence of the chronology of irrigation infrastructure is still lacking for the whole island, and archaeological data directly from irrigation features will be necessary to directly test this model’s predictions. Archaeological confirmation of the model logic would be supported through radiocarbon assays indicative of a progressive spread of intensive irrigation to valleys in the order presented in Table 2.2. The earliest evidence within a valley would be expected to be found in areas classified as having the highest suitability with later construction in areas of lower suitability.

Substantiating the model’s claims with archaeological evidence would provide a sounder empirical foundation from which to understand the deep history of Rapa society. This is especially important due to the emphasis on irrigated taro agriculture in explaining the eventual rise of competition, raiding, and territorial behaviour in Rapa. Currently due to the lack of further archaeological investigations, explanations lack an empirically testable link between taro agriculture and the rise of *pare* construction as defensive features. Ecological modelling of the spread of agriculture lends itself to pairing with HBE models that can contribute to hypothesis building concerning decisions over resource use, cooperation, competition, and territorial behaviour with potential interlocking models that provide a more coherent explanation of the island's human history and direct future archaeology. Ecological and evolutionary models can address a diverse array of processes and can provide a logical and theoretical consistency in explanations that improve our overall understanding. This geospatial modelling method is just one new tool in a growing arsenal.

The following chapters build off the theoretical foundation and modelled environment that were presented here. Beginning with the use of highly ranked agricultural land as the basis for testing the importance of resource visibility in the placement of the fortified *pare*.

CHAPTER III

SPATIAL MODELING SHOWS THE IMPORTANEC OF VISIBILITY FOR FORTIFIED SETTLEMENTS ON RAPA (AUSTRAL ISLANDS, EAST POLYNESIA)

A Manuscript prepared for the *Journal of Island and Coastal Archaeology* by myself and a co-author, Robert J. DiNapoli. I was the primary contributor, and an earlier version was initially presented at the Society for American Archaeology annual meeting (Lane and DiNapoli 2015). DiNapoli provided significant input on the spatial statistical methods and coding in this version.

3.1. Introduction

Understanding the emergence of group-level conflict and its importance for social dynamics is an important and ongoing challenge for archaeologists across the globe (e.g., Carneiro 1970, 1990; Choi and Bowles 2007; Glowacki et al. 2017; Gómez et al. 2016; Keeley 1996; Kintigh et al. 2014; Turchin et al. 2013; Zefferman and Mathew 2015). Defensive features, such as ditches, embankments, palisades, and other aspects of fortifications provide some of the clearest archaeological manifestations of inter-group conflict (e.g., Keeley et al. 2007; Lape 2006; Martindale and Supernant 2009; Moss and Erlandson 1992; Parkinson and Duffy 2007; Rosco 2008; Scherer and Golden 2009). Because their construction required significant investments of time and energy among sets of individuals, fortifications offer direct evidence for coordinated cooperation for collective defense of the community. Resolving the chronological and spatial patterns of fortification construction is thus critical for understanding the processes underlying the emergence of group-level conflict in the past (e.g., DiNapoli et al. 2018; Field 2008).

Fortifications form an important component of the archaeological record in many areas of the Pacific, including in Timor (Lape 2006; O’Connor et al. 2020), New Guinea (Rosco 2008), Fiji (Best 1993; Field 1998, 2004, 2008; Smith and Cochrane 2011), Sāmoa (Best 1993; Cochrane and Mills 2018), Aotearoa New Zealand (Bellwood 1971; Davidson 1987; McCoy and Ladefoged 2019), the Marquesas (Handy 1923; Suggs 1961), and the Austral Islands (Edwards 2003:160; Ferdon 1965b; Kennett and McClure 2012). Several explanations have been offered to explain the emergence of Polynesian fortifications, including increasing territoriality, resource monitoring, inter-group signaling, adapting to changing environmental conditions, and competition during the centralization of chiefly power (e.g., DiNapoli and Morrison 2017; DiNapoli et al. 2018; Field 1998, 2008; Field and Lape 2010; Kennett et al. 2006; Kirch 1989; Smith and Cochrane 2011). Despite the importance of fortifications in Polynesian archaeology, relatively few studies have attempted to test these hypotheses using explicit quantitative models. Several applications of geographic information systems (GIS), however, have provided important insights into the potential explanations for the placement and roles of defensive sites in the Pacific (e.g., Field 2004; Ladefoged 1995; McCoy 2017; McCoy et al. 2014; McCoy and Ladefoged 2019; Smith and Cochrane 2011).

In this paper, we present a quantitative framework for testing hypotheses about fortification construction through point-process modeling of archaeological survey and environmental geospatial data. We apply this framework to evaluate the influence of several environmental variables on the placement of fortifications on the island of Rapa in the Austral Islands of East Polynesia, (Figure 3.1). We use a high-resolution digital terrain model (DTM), a geospatial model of highly productive agricultural zones (Lane 2017), total viewshed analysis (Llobera 2003), and survey data for 15 fortifications (*pare*) on Rapa. We use formal model selection techniques to compare multiple hypotheses regarding the spatial patterning of *pare,* focusing on the relative importance of resource monitoring, landscape visibility, defensive positioning, as well as the role of social interaction between these fortified settlements across the island. We argue that this study of Rapa offers a useful model for the emergence of group-level collective defense (DiNapoli et al. 2018), and our methodological approach can be usefully extended to other regions where similar questions remain surrounding the emergence of fortifications.

3.2. Background

3.2.1. Rapa

Rapa is a volcanic high island at the southern end of the Austral chain in East Polynesia (Figure 3.1). The island is small (38 km^2) and remote, located more than 500 km from Raivavae, the nearest inhabited island. Topographically, the island is highly dissected with a long central ridge that follows the ‘C’ shape of the island. Multiple branching ridges divide Rapa into more than a dozen major valleys and a large central bay. From the ridges, the valley slopes steeply down to the relatively flat areas at the mouth of each valley, resulting in less than 10% of the land area having a slope of 10° or less. The majority of the flat land is concentrated around the large protected Ha‘urei Bay in the center of the island, where the majority of reef growth is also located. In addition to constraints on human habitation due to topography, the southerly latitude (27º 35’S) places it firmly in the subtropical zone of the South Pacific, resulting in relatively cool temperatures, high winds, and abundant precipitation. This environmental context presented several hurdles for colonizing Polynesians in the 13th century AD, as several traditional cultigens (coconut, breadfruit, and most banana varieties) were absent at European contact and likely unproductive in this environment (Anderson 2012a; Prebble 2008). Despite the climatic conditions, taro (*Colocasia esculenta*) was introduced and became a significant food source that supported the local population (Prebble et al. 2019). Additionally, faunal analyses have also indicated that marine resources, including reef habitat species of fish and mollusks, were generally smaller in both size and diversity compared to tropical Polynesian islands as a result of

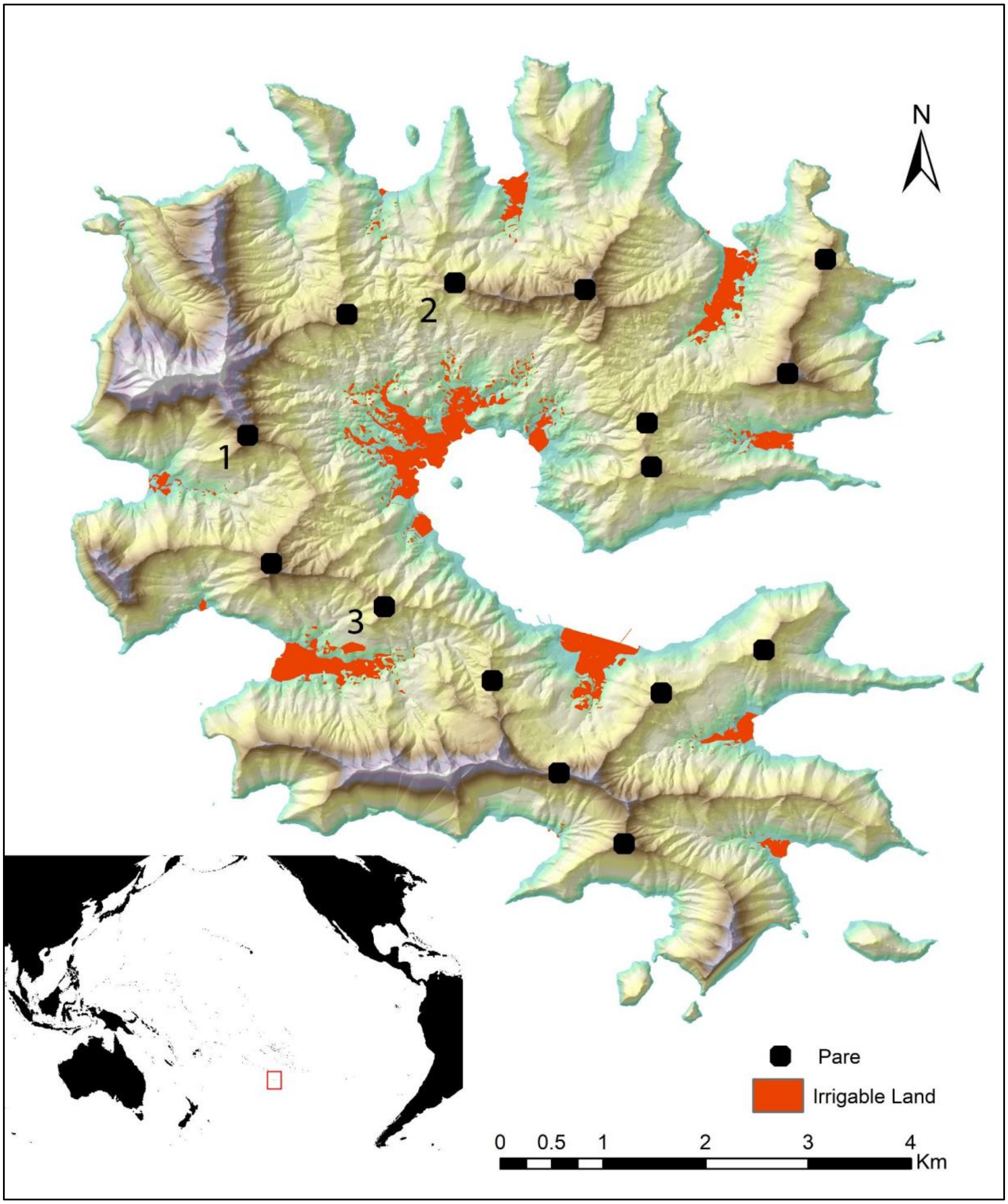

Figure 3.1. Map of the island, including forts, and areas capable of supporting irrigated agriculture. 1 = Noogurope, 2 = Ruatara, 3 = Morongo Uta.

the cooler water temperatures and distance from other landmasses (see Anderson 2001; Anderson et al. 2012a:254; Vogel and Anderson 2012:129). Despite the geographic limitations on subsistence and habitation, it is estimated that the island was capable of supporting between 1,500-3,000 individuals (Bartruff 2012; Vancouver 1798:77), primarily through the cultivation of taro and the harvesting of marine resources. Evidence of the primacy of taro agriculture is present in the paleoenvironmental record from sediment cores from Tuko Marsh at the head of Haʻurei Bay, where a transition from dominant lowland swamp forest to cultivated taro occurred after colonization and expanded significantly from AD 1590 to 1740 (Prebble et al. 2013).

At the time of European contact in AD 1791, George Vancouver reported that much of the Rapan population lived in upland settings on terraced sites along the ridges and upper flanks of the hills. Ten of these habitation areas were larger fortified villages (known as *pare*) that contained central towers with a handful of smaller fortified satellite communities and redoubts; the remaining habitations were unfortified terraces (Stokes n.d.). Two of the smaller fortified sites also had towers (Ngapiri and Pukutai). In the time prior to European contact, there were likely as many as 12 primary clans that held territory on Rapa (Walworth 2015:197 citing Stokes n.d. and personal communications), which makes the 12 fortified sites with towers likely candidates for the seats of each territory.

The *pare* were constructed along ridgetops at elevations ranging between 260 and 380 m above sea level. They were composed of flattened terraces, central towers carved from bedrock, ditches, low walls, embankments, covered traps, and wooden palisades (Kennett and McClure 2012; Stokes 2021; Vancouver 1798:77). Current archaeological evidence indicates that the earliest forts were constructed between ca. AD 1300-1400 at Noogurope and Ruatara, with the addition of Morongo Uta at the earliest a century later between AD 1500-1600, followed by the establishment of the rest through the 18th century (Kennett et al. 2012). Anderson et al. (2012a:253) argued that the overall sequence of elaborated fortification suggests increasing status rivalries and competition between polities that escalated over several centuries into aggression and warfare. Excavations within the forts indicate primarily domestic activities within the terraced portions, while oral traditions, spatial organization of the sites, and the increase in construction of *pare* over time all point towards a defensive role (Kennett and McClure 2012: 233). Indeed, the linguistic roots of the word *pare* are noted as either relating to the Proto-Polynesian words *pale* “defense” or *pa* for “enclosure/fence” (Walworth 2017:113). These are the same roots as the term *pa* used for fortifications in Aotearoa New Zealand. *Pare* is differentiated linguistically from unfortified ridgetop habitation terraces, *auga*, as noted by Stokes (cited in Ferdon 1965b:69). Despite the attention to defense and conflict that permeates current explanations for the island’s past, there have been no published accounts of skeletal trauma and few possible archaeological weapons; however, this absence of evidence may be due to the limited archaeological research conducted thus far on the island.

The ethnohistoric and archaeological records both suggest that there was a tradition of territoriality along with the construction of fortified villages. Oral histories indicate raids and violent conflict between different clans centered around control over territory and its resources (Caillot 1932:63-64; Hanson 1970:23-26; Kennett and McClure 2012:233 citing Stokes n.d.). At European contact, at the height of inter-group competition, Vancouver (1798:77) specifically noted the presence of palisades and made a direct connection to conflict and defense. This interpretation has faced little dispute. The principal alternative suggests a religious role for the *pare*, using the absence of obvious *marae* on Rapa and the prominence of the central towers of the *pare* as support for this non-defensive role (Walczak 2001). However, the specific role(s) that these settlements played in the territorial behavior has yet to be tested, especially relating to their placement on the landscape. This gap in our understanding is the basis for our current analysis.

3.2.2. Competition, Territoriality, and Fortifications

Competitive behavior can range from individual social cues to group-level organized physical violence. Competition often occurs in relation to a resource that is deemed valuable, but has limited or concentrated spatiotemporal availability and is one of many behaviors that can be employed to acquire resources. Systemic competitive behavior can be sustained in a population if it has reasonable chances of being successful and outcompetes alternative strategies through time. Sustained competitive behavior can also give rise to further adaptive strategies, including territoriality through maintaining exclusive access to the resource. Archaeologically, intergroup competition is typically seen through evidence of warfare, which is often cited as playing a formative role in past societies (e.g., Carneiro 1990; Glowacki et al. 2017). Material evidence for warfare is seen through weapons, defensive features, stylistic representations, and specific kinds of skeletal trauma (e.g., DiNapoli et al. 2021; Dolfini et al. 2018; Keeley et al. 2007). The prevalence of fortified sites on Rapa has provided ample support for a stable cultural tradition of competition and territoriality spanning several centuries, although the evidence from the other data sources is less clear.

Territorial behavior can be conceptualized through the economic defendability model (ED) from human behavioral ecology, which seeks to explain the conditions under which defending a resource outweighs the costs associated with defensive actions (Brown 1964; Dyson-

Hudson and Smith 1978). The underlying assumption of ED is that it is costly to defend and maintain exclusive access to a resource. The resource can be anything that is deemed important to the individual or group (e.g., food, water, raw materials, social or political capital, etc). Two primary costs associated with defending a resource are: 1) those in time and energy associated with monitoring the resource which then cannot be directed to other essential activities; and 2) the costs of deterring competitors from accessing the resource. The latter can be significantly costly if physical confrontation results in injury to the defender, as additional costs in time and resources are associated with recovery. Losing a confrontation can also lead to a loss of resources, which further complicates the decision-making process. Together, these costs highlight the complexities of the decision-making process behind maintaining exclusive access to a resource.

The spatiotemporal distribution of the resource heavily influences the success of territorial behavior, with dense and predictable distributions most amenable to supporting territorial behavior because defensive efforts can likewise be patterned to be more efficient (Dyson-Hudson and Smith 1978). Geography also influences the decision to defend as the size, shape, and topography have their own impacts on movement and monitoring costs. These details of the territory affect the incentive and ability to repel encroachment as they relate to differences in time and effort that a smaller area requires to defend compared to a larger territory. This includes natural or artificial barriers that affect response time and increase costs of entering a territory (Adams 2001). Therefore, territory shape and composition are directly related to resource density, but also require consideration of the surrounding environment. Ultimately, the resource that is being defended must be able to offset the immediate and long-term costs associated with defense to be a successful strategy.

In addition to physical considerations of the territory, defenders must also evaluate the risks related to potential competitors and differences in the effectiveness of the defenders and potential invaders. An important part of this assessment is of the potential for competitors to cross boundaries and the loss of resources. This is intrinsically linked to the productivity of the resource/territory weighed against the costs that competitors accrue through incursion and possible conflict (Hinsch and Komdeur 2010). These costs are evaluated through determining physical distance to a resource and associated boundaries or hindrances that can also incur costs to cross (e.g., hills, streams, fortified walls, etc.) as well as social aspects related to group size, ability, and motivation to fight (Adams 2001). The social considerations require that both sides account for social conditions within the cooperating groups such as social cohesion to avoid the collective action problem of cooperation and improve overall competitive ability (Willems and van Schaik 2015). Therefore, any means of evaluating these qualities in a group would increase the accuracy of calculating the tradeoffs and increase chances of success.

The high cost and risk associated with defending territories can be mitigated through cooperation and group formation to distribute immediate cost and risk. This social strategy decreases individual chances of engaging in direct physical conflict and reduces individual time dedicated to defense, making cooperation a significant means of increasing the relative payoff and reducing the inherent risks of territoriality. This strategy often requires more cooperation at the individual level to prevent free riders and support cooperation (Willems and van Schaik 2015). Aside from group formation, technological responses can also reduce defensive costs and risk, especially through the use of weapons, physical barriers, or other means of deterring incursion into a territory or reducing the risk of losing a physical confrontation (Bamforth and Bleed 1997). The most obvious technological mitigation on Rapa is the *pare*. Their physical location in difficult to access locations with commanding views, defensive features including low walls, fosses, and possible palisades are all capable of mitigating long-term costs associated with monitoring and defense of a territory. This is a strong indicator that the social and physical environment was capable of supporting sustained territorial behavior through technological innovation.

The above framework articulates well with the archaeological and ethnohistoric data from Rapa. Territories center on valley systems, with irrigated taro as the primary resource with fortified villages, observation towers, and weapons as the primary technologies deployed to reduce costs and risk of defense. Social organization centered around ‘clans’ or ramages provided the cultural framework that permitted the technological adaptations to function reliably. Therefore, we frame the question of the role and placement of the *pare* through the theoretical framework laid out above. In this view, the location of the *pare* can serve multiple roles that go beyond the immediate scope of this analysis. Here we will focus on their role in monitoring resources and territorial boundaries in an effort to reduce costs and risks of territorial strategy. Specifically, we use two different measures of landscape-scale visibility to: 1) test the importance of monitoring agricultural resources as a means of reducing defensive costs; and 2) test the importance of general monitoring of the landscape and competing territories in the placement of the *pare*.

3.3. Methods

The goal of our analysis is to assess the ability of various environmental factors, especially the visibility of agriculturally productive areas, to be predictors of the placement of fortified sites on Rapa. We base this analysis on a series of 15 fortified archaeological sites and four principal environmentally derived raster datasets that include elevation, slope, total visibility, and agricultural visibility. These data are combined into a series of point process models that assess the relationship between these independent spatial variables and the spatial location of the forts using methods that account for first-order and second-order interactions.

3.3.1. Spatial Data

3.3.1.1. Rapan geospatial data

A sample of 15 fortified sites are the archaeological basis for this study. These data include the locations for the 10 largest *pare* as well as five smaller fortified habitations or redoubts. These locations account for the 10-12 principal communities that held territory and three additional satellite communities which strengthens the overall analysis as the sample specifically tests the primary territories at the height of fortification construction (Kennett and McClure 2012:232-233; Stokes 2021). Our sample is a relatively complete sample of ridgetop sites, as Ferdon (1965b:69) noted the presence of 25 such sites that were identified by locals as *pare*, but only 15 sites unanimously so. This is in line with observations made by Walczak (2003a) that all peaks on the island were modified except for the highest peak, Mt. Perau (650 m). Therefore, our sample is representative of the principal territories on the island at the culmination of intergroup competition, which likely ended shortly after European contact and population decline changed group dynamics on the island. Lastly, the elevation and slope rasters were generated from a two-meter resolution DTM (Figure 3.2 a and b). This raster layer also acts as the basis for both visibility rasters, detailed below. The slope raster was generated using R (version 4.0.3; R Core Team 2020).

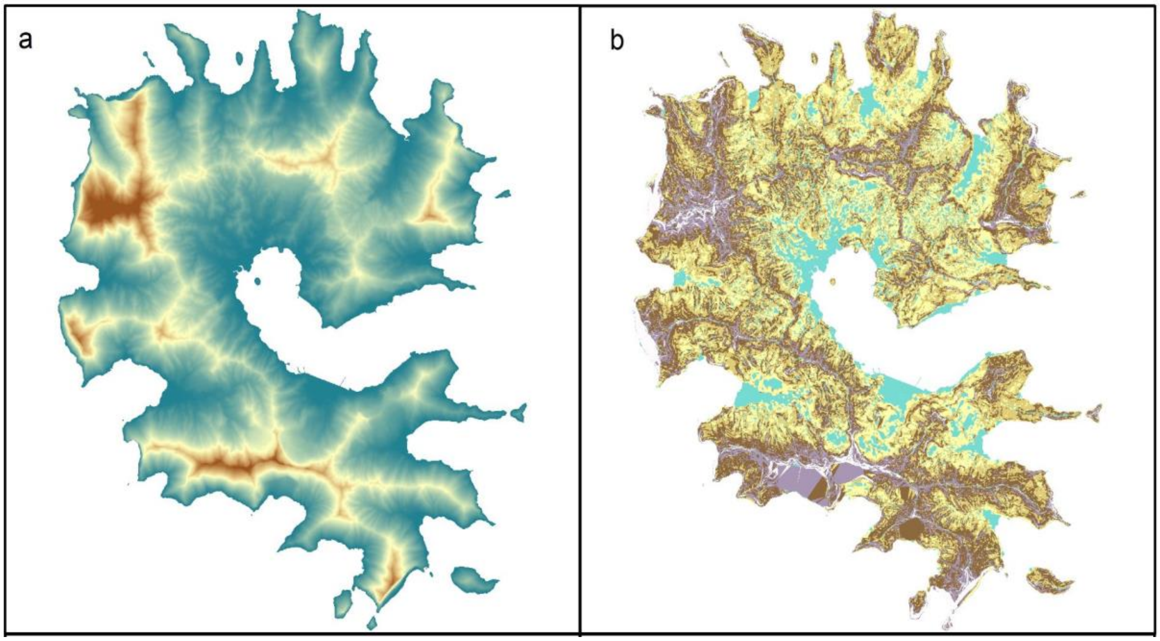

Figure 3.2. Visual examples of the raster data for elevation (a) and slope (b).

3.3.1.2. Total viewsheds

We use a total viewshed analysis (Llobera 2003) to examine the relationship between fortification construction on Rapa and landscape visibility. Total viewshed analysis is a powerful analytical tool for modeling the visibility of landscape features that is increasingly being applied in archaeology (e.g., Dungan et al. 2018; Eve and Crema 2014; Wheatley 1995), but has not yet been applied to Pacific Island environments. At its core, this method counts how many times a cell is visible from every other cell to create a cumulative measure of visibility for a given spot. Total viewsheds are particularly useful as they allow for formalized spatial modeling of the relationship between archaeological features and visibility (Eve and Crema 2014). In the case of

Rapa, the island is small enough to accommodate a total viewshed calculation for the whole island.

We use the DTM to generate two visibility rasters to test the effect of visibility on the placement of Rapan fortifications: (1) total visibility of the entire island (Figure 3.3a and c); and (2) total visibility of highly productive agricultural zones (Figure 3.3b and d). The visibility rasters were created to address the hypothesis that the *pare* locations were primarily driven by resource monitoring. In a total visibility raster each cell is given a value based on the sum of how many observer points (at the scale of the entire island) are capable of viewing that location, creating a standardized measure of how much area can be seen from a given cell location. To capture the island wide visibility, but manage computational demands of a high-resolution raster, the original DTM aggregated from 2 m to 5 m cell resolution, and a grid of observer points spaced out in the center of every 5th cell (25 m) was created (following similar methods as Dungan et al. 2018). The grid of observer points was used to run in the "visibility" tool in ArcGIS (version 10.7.1; ESRI 2019). The resulting raster then had a cumulative value for each cell that relates to the number of observer points that are intervisible with the cell.

To create a measure of agricultural visibility, observer points located exclusively in areas capable of supporting irrigated taro agriculture were used. To define the areas of irrigable potential, a prior model of agricultural productivity was used (see Lane 2017). We use the top two productivity ranks from this model, which correspond with archaeological irrigation features in satellite imagery and historic maps, to define the areas in which observer points are located. We use the same spacing of 25 m for observer points to keep them consistent with those used for total visibility. The agriculturally located observer points were then used in the "visibility "tool in ArcGIS to create a raster that measures how many agricultural observation points a given cell can see. Both visibility rasters provide the empirical basis for modeling the influence of total visibility of the forts and their location on the landscape which acts as an alternative visibility

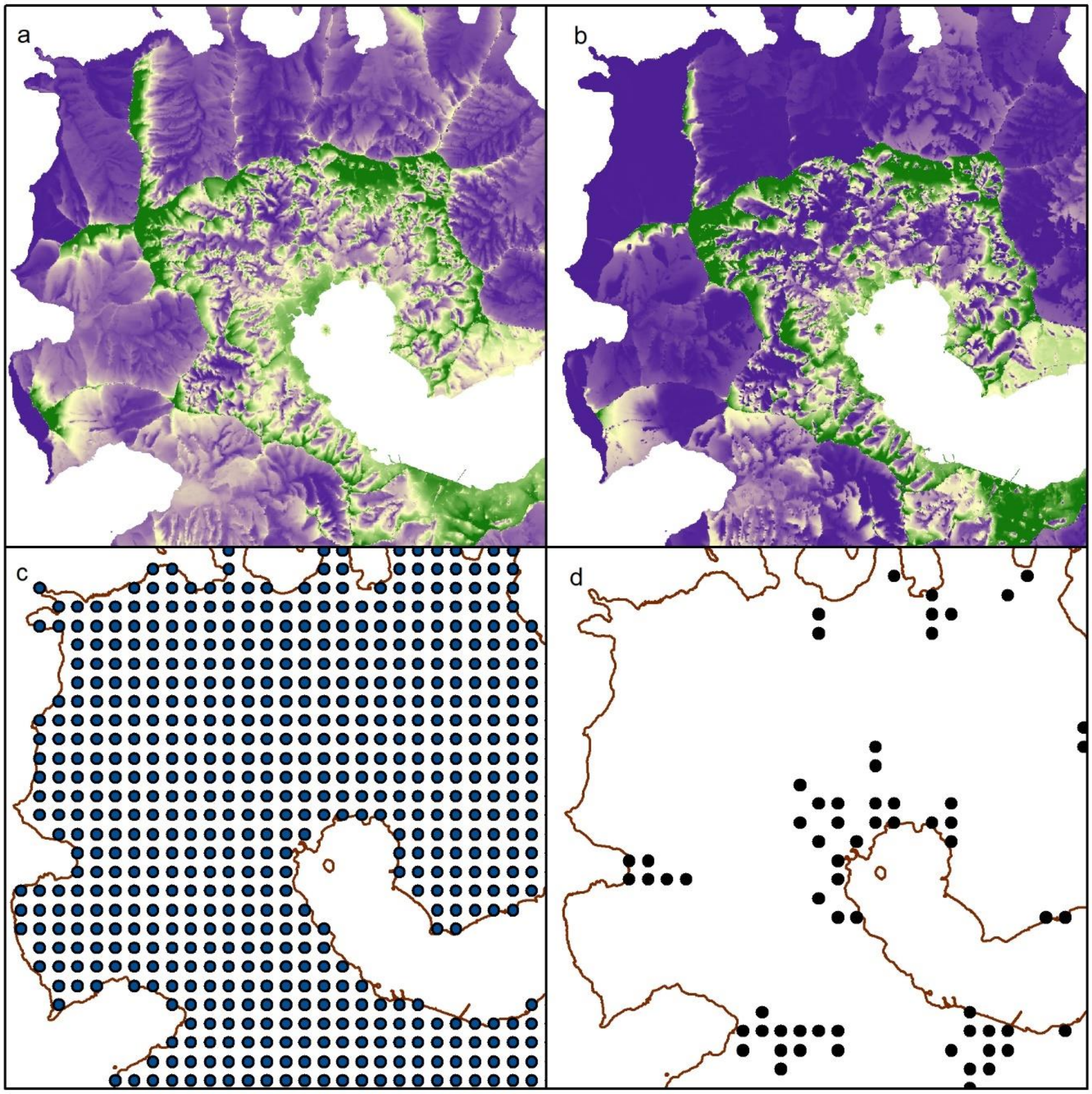

Figure 3.3. Visualization of the visibility raster data. Total visibility (a) was created through a grid of observer points spaced out 5 m apart (c). The agricultural visibility raster (b) was created with a similar grid of observer points spaced 5 m apart but constrained to locations predicted to be productive for irrigated agriculture (d; see Chapter 2).

measure to which agricultural visibility can be compared against. Including both measures of visibility allow for a more direct and clearer link to resource monitoring versus prominence on the landscape.

3.3.2. Spatial Analyses and Modeling

We first explore the relationship between *pare* locations and the four environmental variables using summary spatial statistics. Point-pattern analysis is useful for examining the overall relationship between fort locations independent spatial variables (i.e., first-order intensities) and also accounts for potential clustering or dispersion among points (i.e., second-order interaction) (O'Sullivan and Perry 2013). To explore the relationship between fortification locations and the environmental variables, we generate relative distribution graphs using nonparametric regression that visualize the spatial density (i.e., intensity) of points as a function of each variable (Baddeley et al. 2016:179). To examine the degree of spacing between fortifications, we calculate the nearest neighbor of each *pare* and the mean nearest neighbor for the sample. We also use Besag’s L-function to test for clustering or dispersion in the *pare* dataset by comparing the empirical L-function to a Monte Carlo simulation envelope of Complete Spatial Randomness (CSR), where regions of the empirical function falling above the envelope indicate clustering and below suggests dispersion (Baddeley et al. 2016: 207). We performed this test using 39 iterations of CSR, which is equivalent to a significance test with $p=0.05$.

Following these exploratory analyses, we use point process modeling (PPM) to formally model spatial trends in the *pare* dataset. A PPM is a kind of spatially explicit generalized linear modeling (see Baddeley et al. 2016) that is increasingly applied in archaeological spatial analyses (see Beven et al. 2013; Carrero-Pazos et al. 2019; 2020; Davis et al. 2020; DiNapoli et al. 2019; Eve and Crema 2014; Riris 2020). We take an interactive approach to modeling the location of forts on the landscape. We first construct a null model of CSR to evaluate whether fort locations are adequately explained by a random spatial process. We then build a series of inhomogeneous Poisson point process models that assess the relationship between the first-order intensity of forts and a series of combinations of landscape variables, including elevation, slope, total visibility, and agricultural visibility. We do not combine total visibility and agricultural visibility in the same model as the agricultural surface is a subset of the total visibility surface. Therefore, the comparison between visibility is strictly total visibility against visibility from productive agricultural areas.

We then created separate iterations of these models that allow for second-order dependence (i.e., clustering or dispersion) among points. Given the spacing of *pare* along Rapa's ridgelines and their apparent defensive function, we employ a Gibbs PPM, which is useful for modeling spatial inhibition processes (Baddeley et al. 2016:487). A Gibbs point process specifically assumes that interaction occurs between the points modeled in the process and can variably be used to produce spatial patterns that are strongly clustered or regularly spaced (inhibited). The primary means of modelling a Gibbs process is through measures of conditional intensity (i.e., new points are influenced by the locations of other points) (Baddeley et al. 2016:488-489). This allows for fitting models that can account for second-order influences between points.

Here we model the potential second-order dependence between *pare* as a Strauss process, where points are dispersed according to a threshold distance *R* and are unlikely to co-occur below *R* (Baddeley et al. 2016:497). This is considered a hard-core process because the threshold is rarely violated in the modeling. We set the threshold distance *R* based on the mean nearest neighbor and L-function results. A Strauss process is useful for the present study given that competing groups are less likely to settle in spaces directly adjacent to one another. This is predicted by the ideal despotic distribution (IDD) model which is used to explain settlement restriction resulting from resource competition, both of which have been applied on a broad scale to explain island colonization (Fretwell and Lucas 1969; Giovas and Fitzpatrick 2014; Kennett et al. 2006; Kennett and Winterhalder 2008). The effect of a ‘push’ from established *pare* would therefore create a type of buffer, creating a threshold or interaction distance between sites which later satellite communities could fill in.

For each set of models, we applied multimodel selection tools to assess which models best predict the spatial configuration of forts on Rapa. Information criteria are now commonly used to formally compare statistical models in terms of tradeoff between predictive accuracy and model complexity. We use the Akaike Information Criterion, (AIC), this method of selection is parsimonious, meaning that it adds weight to simple models or in this instance models with fewer covariates (Akaike 1974). The logic being that a less complex explanation is a more powerful explanatory force than one that is more complex and requires more assumptions. Generally, the best-fitting models are those that provide the best fit to the data in the simplest way. Here we use the second-order AICc adjusted for small sample sizes (Burnham and Anderson 2002). Each model is assigned a ΔAICc score and an associated weight used to determine the best-fitting model.

Once a model was selected, we performed model validation procedures in the form of a residual K-function to test the goodness-of-fit between the site locations and the model. This function compares the archaeological site distribution to 99 Monte Carlo simulations to detect dispersion or clustering not accounted for in the selected model. Visually, if the model is a good fit to the empirical reality when the empirical function stays within the envelope of the Monte Carlo simulations. If the empirical function is outside of the envelope, then this will indicate that additional correction for second-order interaction is necessary. An additional check is to view the partial residual plot of the covariates in the selected model. This is done for the highest ranked model as a diagnostic to show the effect of a specific covariate and for a nonlinear covariate effect (Baddeley et al. 2016:427).

The point-process analysis was run in R (version 4.0.3; R Core Team 2020) using the spatstat and MuMIn packages (Baddeley et al 2016; Barton 2020). These core packages were facilitated with the use of the packages here (Müller 2020), maptools (Bivand and Lewin-Koh 2020), raster (Hijmans 2020), rgdal (Bivand et al. 2021), rgeos (Bivand and Rundel 2020), and sp (Bivand et al. 2013; Pebesma and Bivand 2005). All data and R scripts necessary for reproducing these analyses is available at https://github.com/rdinapoli/RapaFortsSpatial.

3.4. Results

The results of the exploratory summary statistics are seen in Figures 3.4 and 3.5. Figure 3.4 shows the results of the nonparametric regression. The resulting distributions show the spatial intensity of the *pare* as related to each of the covariates. The distribution of the nearest neighbor calculations of the *pare* cluster around one kilometer with a mean of 971 m (Figure 3.5a). This regularity in placement distance reflects a degree of inhibition in fort placement. This can be further evaluated with the results of the L-function (Figure 3.5b), in which the empirical function falls outside of the significance envelope ca. 900-1000 m indicating second-order inhibition near the nearest neighbor mean. This indicates that there is a significant influence on site placement that is not captured in the CSR models.

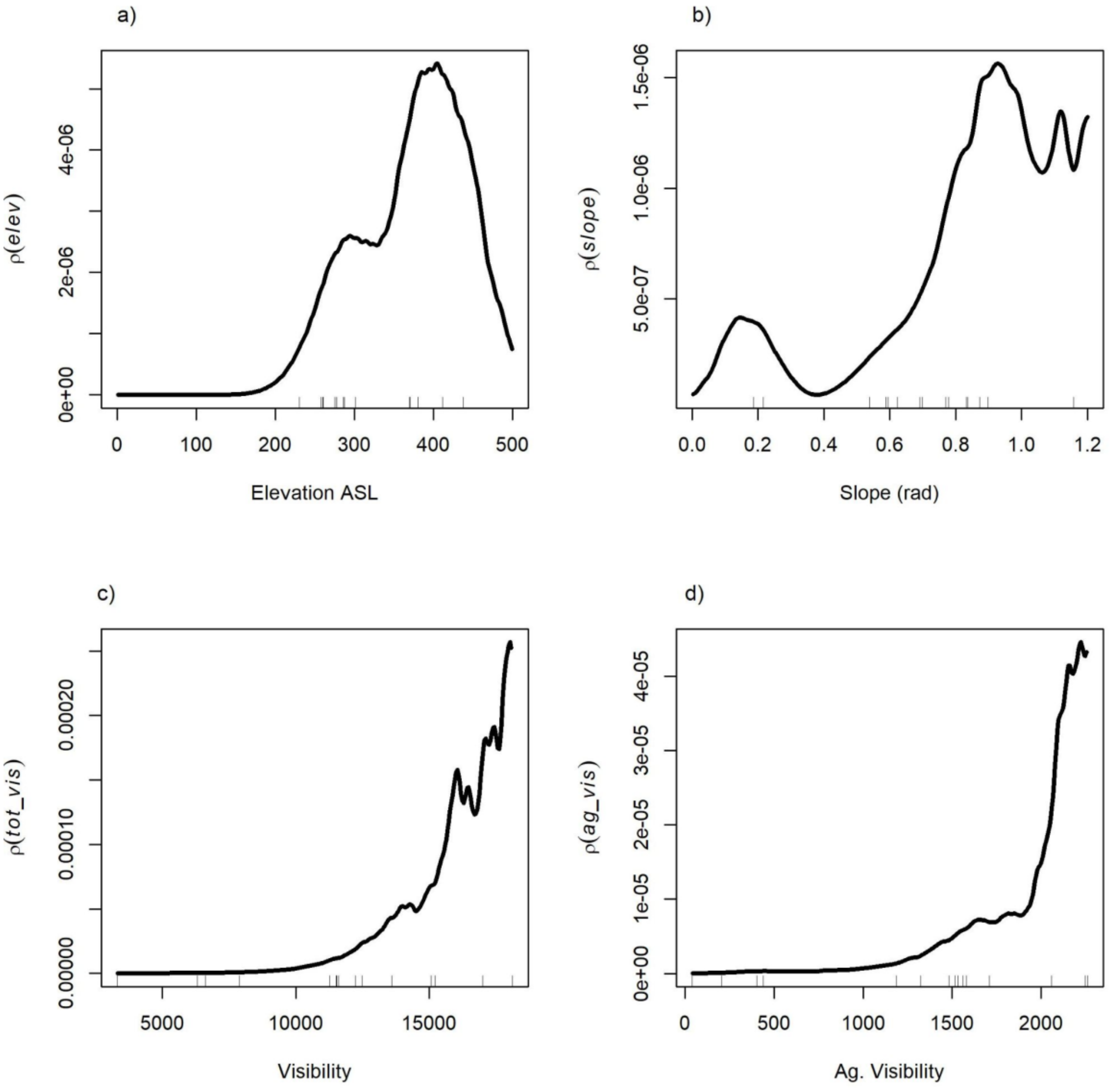

Figure 3.4. Relative distributions. Nonparametric estimate of intensity for four environmental variables a) elevation, b) slope, c) total visibility, and d) agricultural visibility. The y-axis indicates the intensity of the point process as dependent on a covariate on the x-axis. Each curve is a measure of intensity in relation to the location of sites.

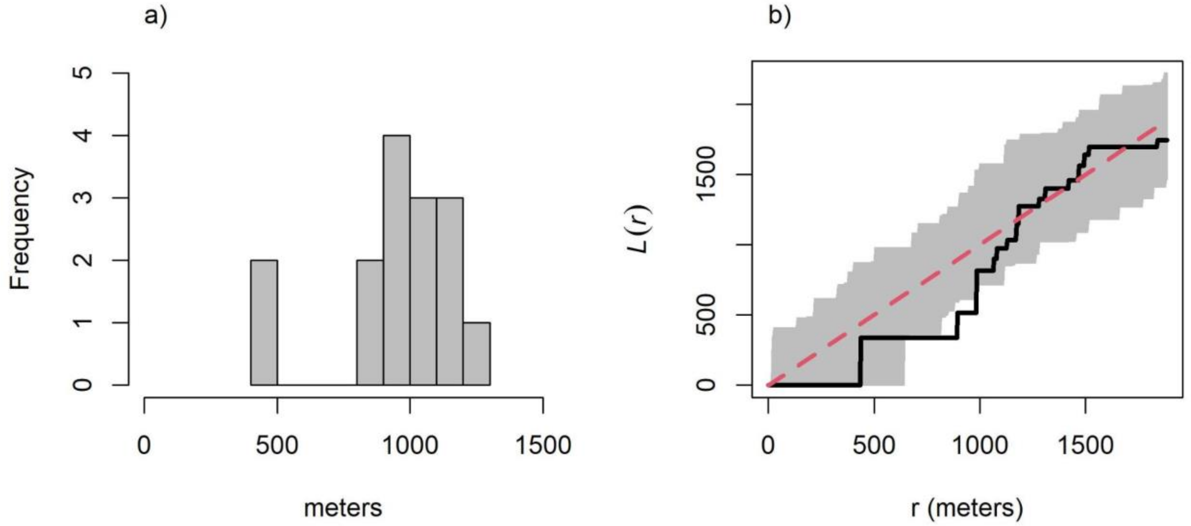

Figure 3.5. Nearest neighbor and L-function a) A histogram of nearest neighbor distances between fortifications (mean =971m). b) L-function of the homogeneous poisson process, a transformed version of the K-function, where the dashed line represents the poisson process and the solid line the empirical function, the gray shading represents the modeled simulations with areas above the dashed lines being more clustered and below more dispersed.

Table 3.1. Model selection of covariates

Model	**Covariates**	**df**	**ΔAICc**	**AICc weight**
Model 3	Total Visibility	2	0.00	0.615
Model 5	Elevation and Total Visibility	3	2.04	0.221
Model 8	Slope and Total Visibility	3	3.17	0.126
Model 9	Slope, Elevation, and Total Visibility	4	5.61	0.037
Model 4	Elevation and Agriculture Visibility	3	18.48	0.000
Model 2	Agriculture Visibility	2	22.38	0.000
Model 1	Elevation	2	48.76	0.000
Model 7	Slope and Elevation	3	51.44	0.000
Model 6	Slope	2	74.02	0.000
Model 0	CSR (null model)	1	75.97	0.000

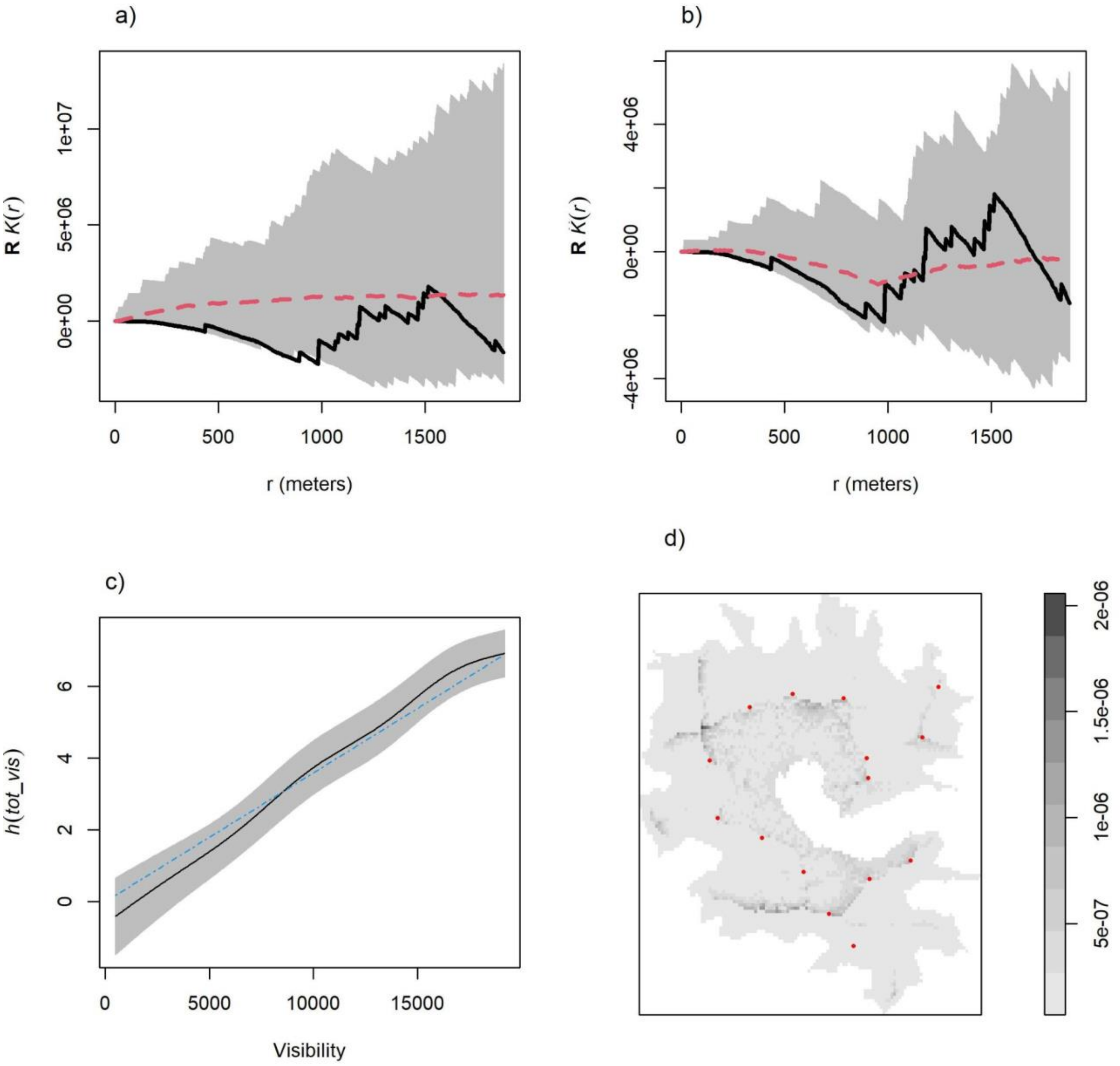

Figure 3.6. Model validation checks. Residuals plots a and b) A plot of the Residual K-function to validate for possible second order interactions for Model 3 (a) and Model 11 (b). The black line shows the empirical function of the fortifications, the dashed red line is the theoretical expectation based on model assumptions, the gray is an envelope based on simulations of the model with areas above the dashed lines being more clustered and below more dispersed. c) A partial residual plot for Model 11, looking specifically at the relationship between the empirical intensity of forts and the modeled intensity as a function of total visibility. The envelope represents the 95% confidence interval, the dashed line is the fitted relationship, and the solid line is the smoothed partial residual reflecting the tactual relationship. d) Geographic distribution of modeled intensity for Model 11 with the locations of the sampled forts in red.

The results of the multi-model comparison of the inhomogeneous point process models indicate that models incorporating total visibility better predict *pare* locations than other environmental factors tested (Table 3.1). Model 3 ranked as explaining the most variability, accounting for total visibility with a ΔAICc = 0 and $w_i = 0.615$. With the selection of Model 3 and its comparatively high weight, model validation through the residual K-function (Figure 3.6a) indicate that the empirical pattern of the forts is more dispersed than model predicts, falling outside the significance envelope at ca. 900 m. This suggests that a 2nd-order inhibition process likely accounts for a component of the *pare* spatial pattern.

To account for this second-order interaction between points, a Strauss inhibition process was incorporated to each model using an interaction distance (r = 950 m) derived from examination of the nearest neighbor mean and the range of pairwise interaction. Multimodal selection using AICc resulted in similar rankings (Table 3.2). Again, total visibility was the best predictor of the empirical spatial pattern when the Strauss process is included (Model 11), with a ΔAICc = 0 and $w_i = 0.688$. Table 3.3 presents the covariate estimates for Model 11.

Figure 3.6b shows the results for the model validation procedure using 99 Monte Carlo simulations of the residual K-function. The results show that Model 11 is a better fit to the empirical spatial pattern of *pare* locations and falls entirely within the significance envelope for the model. This suggests that there is an aspect of second-order interaction between the forts that is captured by the Strauss process that is better able to predict the fort placement than total

Table 3.2. Model Selection with Strauss variation of Gibbs model (threshold of 950m) and Covariates

Model	**Covariates**	**df**	**ΔAICc**	**AICc weight**
Model 11	Strauss and Total Visibility	2	0.00	0.688
Model 13	Strauss, Elevation and Total Visibility	3	2.62	0.186
Model 18	Strauss, Slope and Total Visibility	3	3.76	0.105
Model 19	Strauss, Slope, Elevation and Total Visibility	4	7.19	0.019
Model 15	Strauss, Elevation and Total Visibility	3	12.13	0.002
Model 14	Strauss and Agriculture Visibility	2	13.66	0.001
Model 12	Strauss and Elevation	2	45.12	0.000
Model 17	Strauss, Slope and Elevation	3	48.19	0.000
Model 10	Strauss (Null model)	2	65.75	0.000
Model 16	Strauss and Slope	1	67.23	0.000

Table 3.3. Result details of the best-fit Model 11 incorporating a Strauss component and Total Visibility Covariate.

Coefficient	**Estimate**	**S.E.**	**CI 95.lo**	**CI 95.hi**	**Ztest**
(Intercept)	1.635628e+01	1.633363e+00	-19.557614346	1.315495e+01	***
tot_vis	3.5986993e-04	9.550803e-05	0.000171507	5.458916e-04	***
Interaction	-8.837738e-01	1.292799e+00	-3.417612480	1.650065e+00	

visibility alone. A partial residual plot for total visibility for model 11 is also presented (Figure 3.6c), highlighting the fitted effect of the covariate and showing the empirical intensity of forts and the modeled intensity. Figure 3.5d displays the modeled intensity for the Strauss process and total visibility as it occurs spatially.

The results of this analysis indicate that, of the covariates modeled, total visibility and inhibition in spacing are the best predictors of fort placement on Rapa. Of the other covariates, elevation and slope also appear to have some degree of influence, though the weights of those models were considerably lower. Of the four environmental covariates, agricultural visibility was the least powerful predictor of fort placement, though it remains a subsample of total visibility.

3.5. Discussion

Use of visibility analysis in Pacific archaeology has notably been used in understanding placement of fortifications in Fiji (Field 1998; Smith and Cochrane 2011). Smith and Cochrane (2011) applied this technique rigorously by comparing viewsheds from a sample of fortified sites against a sample of random locations to assess inter-visibility with other forts and arable land. Their work considered the role of defensive monitoring of Fijian forts, though they concluded that large viewsheds from elevated sites was important, intervisibility between forts was not (Smith and Cochrane 2011:77).

3.5.1. Influences on Site Placement

This analysis indicates that total visibility and second-order interaction between forts are the strongest predictors of fort construction on Rapa. This runs contrary to our initial hypothesis that agricultural visibility had a strong influence on site placement as a means of reducing costs associated with defense. The low ranking of agricultural visibility is noteworthy, as is the fact that total visibility ranked so strongly. This does not preclude monitoring of agriculture as a role of the *pare,* as agricultural visibility is a subset of total visibility. It does, however, indicate that aspects related to visibility beyond agricultural monitoring are strong predictors of site placement. Other potential interests related to monitoring could be the near-shore marine resources that were the other critical component of the diet as well as visibility of rival territories (intervisibility between forts). This opens the possibility that the *pare* potentially have other roles that relate to their prominent placement on the landscape.

There is also the second-order interaction that is captured by the Strauss component of model 11. The interaction is inhibitive, creating a more ordered pattern on the landscape and suggesting that *pare* were established with a preference for distance between settlements, roughly a kilometer apart. The interaction between sites is most likely related to socially and environmentally influenced decisions by groups establishing a new exclusive territory. A newly fissioned group would seek to avoid direct conflict with others over resources and also require a sufficient resource catchment to support them and their growth. Upon claiming a territory, construction of a highly visible settlement would establish a clear claim. These decisions closely reflect the theoretical considerations of the IDD model as new resource areas are selected in the shadow of competition with established groups.

3.5.1. Other Influences on Placement

Beyond the above considerations there remain other potential influences on the placement of fortifications. Total visibility is a strong predictor but does not necessarily preclude other influences, this is visible in the non-significant empirical deviations from the modeled K-function. Additional influences are likely related to physical aspects of the territories (Adams 2001) and the diachronic nature of settlement construction, both of which have the potential of enhancing our understanding of *pare* placement. Although chronological considerations were not directly addressed in our modeling, the historic ordering of fort construction can have an impact on where neighboring forts are constructed. This is partially captured in the application of the Strauss component of the model. Although our interaction threshold was ca. 950 m, this only represents the culmination of fortification construction, and this distance could have been larger in the past. Current archaeological understanding of the establishment of *pare* indicates that Noogurope and Ruatara were the first fortifications to be constructed between AD 1300-1400 a century and a half after human colonization. This was followed by the largest fortification, Morongo Uta, established between AD 1400-1650 (Kennett and McClure 2012:197-200). A quick visual inspection of the location of these three settlements indicates that they are spaced two kilometers apart, double the interaction threshold used in this analysis. This specific ordering of construction could then preclude desirable high visibility areas from being considered for future forts, but also establish buffer areas in which competing groups would be less likely to construct a rival *pare*. This boundary is reflected in the regularity of spacing between forts as captured in the Strauss process in model 11.

Topographic considerations also help explain the empirical distribution of *pare* placement. This is partially captured within the models presented here in that elevation and slope are also predictors of site placement in models 13 and 18. Elevation clearly influence the *pare* as they are built exclusively on the ridges, though the specific elevation varies. The *pare* included in this analysis all fall between 230-430 masl. The unifying characteristic being that the fortifications are all well above the lowlands. This aligns with what has been observed in that *pare* were constrained to the ridgeline with preference for peaks and where ancillary ridges break off of the primary spine between drainages (Ferdon 1965b:69; Kennett and McClure 2012). Turning to slope, this was the weakest of the covariates in the top three models. Slope alone had no predictive weight and was likely only an ancillary influence, as it is well documented that the sites were terraced and the natural slope on the ridges were modified into a more habitable configuration. Slope outside of the *pare* has been noted as being important as a command defensive feature of many of the *pare* (Ferdon 1965b), but this is not necessarily captured in these models.

3.5.3. Roles of the Pare and Nature of Competition

Understanding the influences behind placement of the fortified settlements permits an informed consideration of the likely role(s) that they filled in Rapan society of the past. Beyond simple habitation sites, we considered their role in monitoring. The weak influence of agricultural visibility in our modeling suggests that this was not a primary role. Nonetheless, monitoring resources is essential in territorial behavior, one that was likely supplemented by other sources. Ferdon (1965b:72) made note of towers that were not associated with specific villages, similar to those found in the *pare*, that were placed away from major habitations. These towers could explain where additional territorial monitoring took place. This strategy of constructing supplemental monitoring sites would allow *pare* placement to be more freely driven by other considerations and still help mitigate the high costs and risks of territorial behavior. The additional towers do not preclude monitoring as a role of the *pare* but begs the question of what their primary role may have been.

The obvious role relates to the obvious defensive benefits of the *pare*. Having a strong defensive location within a territory has its own benefits that improve the ED calculations in favor of the defending group. Technological manipulation of the environment improves defensibility through use of natural features like steep slopes, digging fosses, and building walls or palisades, all of which reduce the risk and cost of physical confrontations (Bamforth and Bleed 1997). These environmental modifications increase the likelihood of successfully repelling direct attacks as well as reduce the chance of direct physical harm. A defensive role for the *pare*, however, begs the question as to the nature of past conflict and what advantage a competing group would gain from attacking a fortified settlement if the primary contested resource was the cultivated taro located a distance away from the fortifications. One answer may be that the primary means of conflict was through raiding processed taro in the form of fermented paste. Stokes (n.d.) notes the storage of agricultural products both inside the fortified limits of terraces and close to unfortified settlement in the form of pits designed to ferment and store taro paste. Archaeologically, cylindrical storage pits have also been described within the *pare* (Kennett and McClure 2012: 232), though specific testing has not been conducted in order to identify stored contents. This seems a likely scenario as elsewhere in Polynesia taro is known to be processed and fermented in storage pits (e.g., Marquesas' *ma* pits). On Rapa in the early 20th century, Stokes (2021) noted pits lined with grass and used to ferment taro into *tioo*. In this light the forts could be fulfilling a role centralizing resources to highly defensible locations to reduce the risk of resource loss from the irrigated fields. This would reduce the number of people required to actively defend their resources but also lowers the risks associated with physical violence during raids.

In addition to fights over agricultural resources, another important resource to consider would be sources of freshwater. Headwaters are located close to the ridgelines and therefore the forts, so some aspect of control over these locations could help explain fort placement. Accounting for headwaters and springs in the upper valley would be worthwhile in looking for other driving factors in fort placement, especially when considering that the name of one of the large *pare*, Tevaitau, literally translates as “the fresh-water fight” (Walworth 2015:196).

An alternative to raiding for resources would be direct territorial conquest to secure a territory, its resources, and the sociopolitical capital achieved through conquest. A meaningful way of acquiring a neighbor’s resources would be to conquer their *pare* and then demand tribute, having established one group over the other. Territorial conquest has support through oral traditions described to Stokes (2021) and Walworth (2015:197) by Rapan informants. A deeper look at the oral histories of Rapa offers interesting clues about the history and nature of intergroup competition and the role of the forts. From Stokes’ work (in Anderson 2012a and Hanson 1970) it is suggested that the initial fortification phase derived from a series of aggressions between clans as various lineages began to expand into the central region around the head of Ha’urei Bay at the center of the island. These conflicts originated in the northwest of the island and resulted in the first *pare* being constructed. The oral histories make direct mention of violent conflict and some clans taking over rival *pare* during this expansion, though eventually this apparently stabilized when the island was somewhat unified by a clan through a combination of alliances and military force over their principal opposition. This resulted in a “loose control” over the rest of the island through marshal power (from Stokes in Hanson 1970:25-26).

A further defensive consideration for the forts is related to the geographic shape of a territory, which typically center around a bay and the ensuing valley (Hanson 1970). This would leave many potential routes into a territory crossing the ridge from one valley to the next, but not all routes would be equally accessible. *Pare* may act as guarded gateways into a territory, located at the points along the ridges that most easily facilitate travel. Placing the defensive feature at the border of the territory helps control access but also has the added benefit of creating a space for monitoring competing groups as well. Instead of directly monitoring agriculture, the emphasis would be on views of external territories and routes that were not directly under the influence or control of the group that had constructed the *pare*. This more closely aligns with the modeled influence of total visibility and regular spacing captured in our models but is not directly tested in this paper.

A final role of the forts tentatively supported by our findings is viewing them as forms of monumental architecture that act as a costly signal to deter conflict (see DiNapoli et al. 2018:216; Kennett et al. 2006:351). Costly signaling is a means of truthful communication between a sender and observer that conveys unobservable qualities (e.g. cooperative ability of a group, resource holding potential, strength and competitive ability, etc.) which then impacts decisions made by the observer that are beneficial to both sender and receiver (Bliege Bird and Smith 2005; Neiman 1997). Such signals are often found near territorial boundaries, to enhance the visibility to other groups, like along the ridges of Rapa (Bliege Bird and Smith 2005; Neiman 1997). The highly visible forts could have filled a role as deterrents against conflict and therefore reduced the short and long-term costs incurred through direct physical violence. Their placement on the borders of territories with an emphasis on high visibility from outside of the defended territory supports this hypothesis. Although this is tentatively supported by our analysis, it is corroborated by observations made by Vancouver when roughly 300 lightly clothed men came out to meet his ship at the height of fort construction in the 18th century: “Independent of the protection their fortified retreats may afford, it did not appear that they were subject to much hostility, as scarcely any scars from wounds or other marks of violence were observed on their bodies” (1798:78). The lack of obvious physical trauma was so contrary to the presence of the palisaded forts that Vancouver and his fellows conjectured that the primary threat of violence came from another island. Although this remains speculative, it is worth considering the broader implications, especially in the light that 300 individuals represented between 10-20% of the total population (Bartruff et al. 2012; Stokes 2021; Vancouver 1798) and likely a greater proportion of those considered fighters (e.g., age, sex, social status). Taken together, this observation and the tendency for placing *pare* in highly visible locations points to a role as costly signals and merits further testing.

Despite the strong influence of visibility there are still other candidates that could be modeled to understand fort placement and their roles in Rapan society. Considerations for future work include the addition of other resources that also require monitoring such as fishponds and weirs, productive patches of reef and other marine resources, sources of fresh water, and where routes between territories likely existed. Additionally, a means of excluding portions of the island where fort construction would be impossible could improve future models, but this requires careful and systematic consideration, especially considering that many of the terraces were constructed in extreme topographic locations. Social and historical considerations, like those mentioned previously, could also offer insight if accounted for empirically, like the inclusion of aoristic analysis to account for construction chronology. With these considerations a more nuanced interpretation of behavioral considerations behind construction of fortifications and their roles can be more clearly understood.

3.6. Conclusions

The prominent fortified settlements of Rapa have been at the center of discussions concerning Rapa's history. On a broader stage, the island has been used as an example of hyper-fortified endpoints as the result of intergroup competition in the Pacific (Kirch 1989). The archaeology of the forts has only recently been more completely described (Kennett and McClure 2012) and systematically dated (Kennett et al. 2012), opening the door for a more nuanced understanding of the nature of competition on the island and the role that the iconic *pare* played within the culture of competition. The small size of the island and the relatively complete nature of the spatial data presents a unique opportunity to have a more complete understanding of how competition was established within the Rapan culture. In this paper we have presented a series of formal models that point to the importance of total visibility in influencing where monumental fortified settlements were constructed and that interaction between settlements occurred that inhibited construction too close to another settlement. The significance of total visibility is indicative that the forts fulfilled at least one role as part of a strategy involving costly signals to competing groups, which reduced the costs and risks associated with formalized territorial behavior through reducing direct physical conflict.

This chapter has provided significant insight into one aspect of *pare* placement. However, there remain many unanswered questions regarding the habitation of the highlands. One unexplored aspect is what, if any, cost reductive strategies were used to counter the additional costs of living far from resource bases. Additionally, although this chapter focuses on large *pare*, there are also questions about the role and placement of the smaller fortified terraces that have been documented on the island. These issues will be explored in the following chapter.

CHAPTER IV

DEFENSIVE INFLUENCES ON PLACEMENT INDICATE MULTIPLE ROLES FOR FORTIFIED SETTLEMENTS ON RAPA, AUSTRAL ISLANDS

Manuscript prepared for *Archaeology in Oceania*

Brian G. Lane[1]

4.1. Introduction

The short occupational history of the small, remote, and rugged island of Rapa in the South Pacific is dominated by the presence of fortified ridgetop settlements that took monumental efforts to construct, occupy, and maintain. Explanations for the hyper-fortification of the island have often focused on territorial control over agricultural resources, but the nature of intergroup conflict remains poorly understood. Additionally, questions remain about why fortified settlements were placed where they were, why so much time and effort were put into their construction, and importantly, why the island's population lived in such inaccessible locations that required constant investments in time and energy to support?

Rapa presents a unique dataset from which to study colonization events and adaptation to novel environments (DiNapoli et al. 2018; Lane 2017; Prebble et al. 2013, 2019), behavioral choices in the context of intergroup competition (Anderson et al. 2012a; DiNapoli et al. 2018), the underlying reasons behind why fortifications may have been built on such remote islands, and measuring the influence of environmental variables on the placement of those fortifications (Lane and DiNapoli 2015; Ch. 3). Indeed, Rapa continues to provide an excellent opportunity to explore these themes and build a more nuanced understanding of the human processes and decisions that pattern the island's archaeological record.

The fortified settlements of Rapa are highly visible and tangible features of the island's sociopolitical organization and history (Anderson et al. 2012a; Stokes 2021). Oral histories note that there were at least 10 chiefly lineages that controlled territory from the monumental fortified terrace settlements known as *pare* (Kennett and McClure 2012:232; Stokes 2021; Walworth 2015:197 citing Stokes n.d.). Also located in the highlands along the ridges were smaller satellite communities consisting of clustered terraces which were at least partially fortified and like the larger *pare* (Ferdon 1965a). The smaller sites were aligned with larger settlements as a component of Rapa's hierarchical political organization (Kennett and McClure 2012; Ferdon 1965a). However, our understanding of the specific influences on placement of these sites is incomplete. Further work is required to better understand the island's settlement history, especially relating to the middle period of occupation when habitation moved from lowland occupation to the ridges and uplands.

Identifying specific factors that influence human activity across space is critical for understanding settlement patterns and can be difficult to discern given the many variables considered. Key to such investigations is understanding the decision-making process behind actions that leave archaeological signatures. One means of approaching this problem is the application of spatially explicit statistical processes. Through linking theoretically informed measurable variables to the archaeological record, results have more explanatory power**.** This strategy is especially useful in relation to studying the distribution of sites on a landscape (e.g., Davis et al. 2020; DiNapoli et al. 2019). The utility of this strategy is demonstrated below in relation to the placement of monumental defensive habitation sites found on Rapa in the Austral Islands.

The current study builds on previous work by evaluating new environmental variables related to defense, the addition of five defensive sites to the sample, and an evaluation of the possibility for differential influence based on site size. These additions specifically test the influence of territorial defense on the placement of fortified sites against the proven influence of visibility. Lane and DiNapoli (Ch. 3) highlight the strength of total visibility in predicting placement, but their discussion points to the possibility of costly signaling driving this influence, leaving additional defensive influences for the *pare* an open question. This study focuses on defense and cost reducing strategies that facilitate ridgetop settlement and fortification placement that can help amplify our understanding of various strategies that may have been used in establishing *pare* locations

Below, I provide a background on Rapa's environment and settlement history and then outline the theoretical premise behind spatial modeling, which uses 20 archaeological sites to determine what defense-related variables best predict their distribution. After an explanation of the methods and results, I discuss the results of visibility and proximity to access routes into territories as the best predictors of fortified sites within the broader context of competition on Rapa.

4.2. Rapa, Austral Islands

Rapa is a small volcanic island (38 km^2) known for its prominent fortified settlements constructed at elevation along steep ridges and its heavy reliance on wet taro agriculture (Figure 4.1). These conditions have contributed to the island being used as a prime example for intensive competition and hyper-fortification in the Pacific (Anderson et al. 2012a; Kennett and McClure 2012; Kennett et al. 2006; Kirch 1989). The island is remote and relatively isolated, with

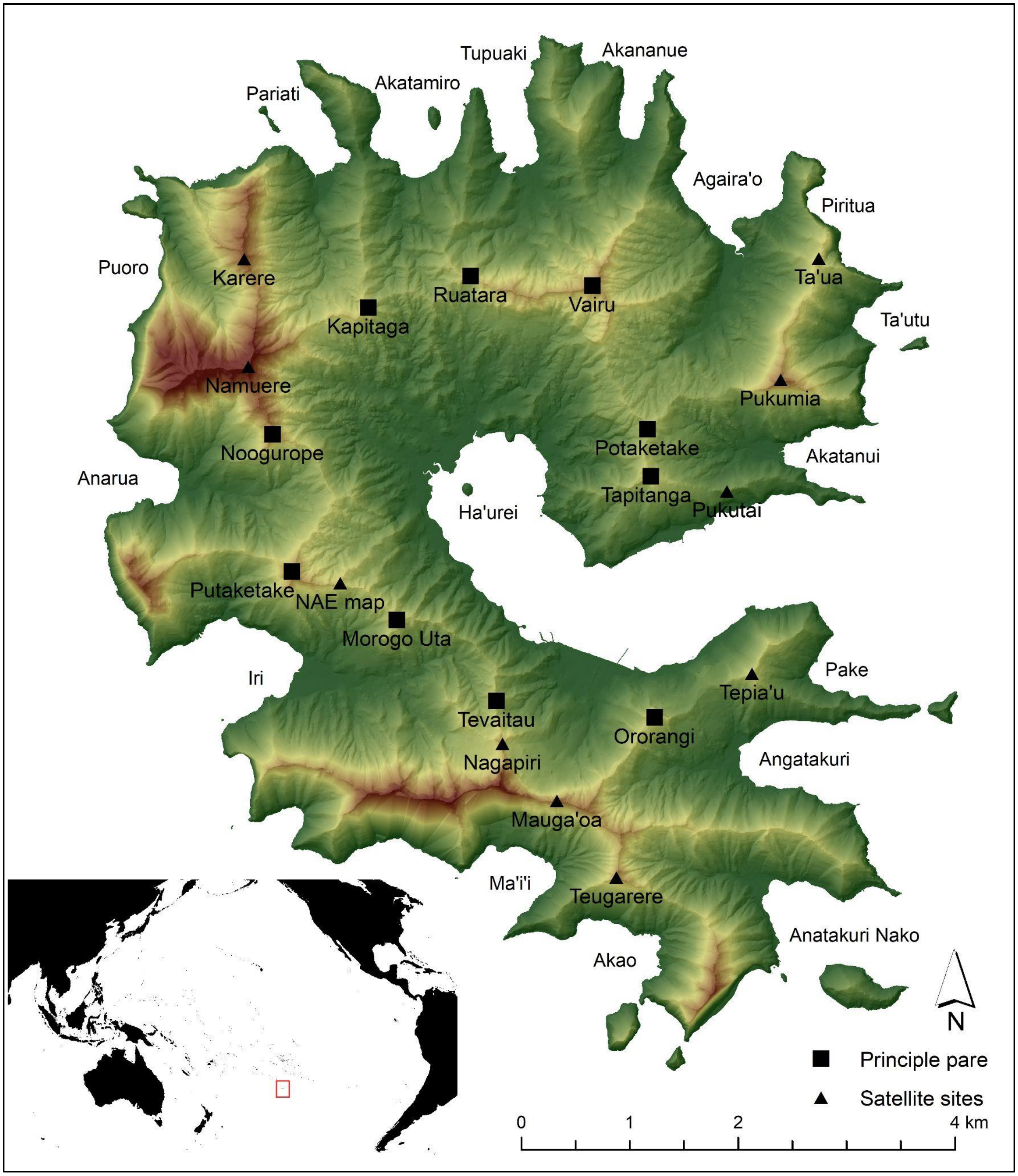

Figure 4.1. The island of Rapa with principal and secondary fortifications and bay names.

Raivavae being the closest populated island ca. 500 km away. Geologically, Rapa is a breached caldera with a highly dissected topography and a maximum elevation of 650 m at Mount Perau. Steady wind and water erosion have formed steep hills and valleys with many smaller ridges forming off the central spine. The island is roughly ‘C’ shaped with a large sheltered central bay where most of the coral reef growth occurs. Outer bays have more limited coral growth along with predominantly rocky beaches. Marine resources, as documented through midden assemblages from coastal rock shelters, emphasize the use of near shore species, including fish, marine mollusks, urchins, crab, and eel, though size and species diversity are constrained by the island’s subtropical latitude and remoteness (Anderson et al. 2012; Szabó et al. 2012). Rapa is located within a region that has been referred to as the “subtropical depriment zone” where lower average sea temperatures, combined with remoteness, lead to a relative drop in resource diversity and size of marine resources and fewer seabird colonies (Anderson 2001; Anderson et al. 2012a:254; Vogel and Anderson 2012:129). This led to the absence of several marine species found in the rest of French Polynesia, including *Turbo* sp., that were important for producing a variety of tools such as fishhooks.

4.2.1. Human Colonization and Early Settlement

Human colonization of Rapa occurred between AD 1100-1200 (Kennett et al. 2012:201), coinciding with a rapid wave of exploration and colonization in East Polynesia (Allen and Kahn 2010; Anderson et al. 2019; Wilmshurst et al. 2011). Based on linguistic subgrouping, the colonizing population was closely related to the group that also colonized Mangaia in the southern Cook Islands, and possibly sustained prolonged contact that further cemented the linguistic similarities (Walworth 2015:201). Initial settlements occurred near the shore, especially in rockshelters and protected outer embayments (Anderson 2012b). Through oral histories recorded by Stokes (2021; Hanson 1970), the initial phase of settlement and growth occurred in the northwestern portion of the island.

Although there were limited endemic carbohydrate sources available to colonizers, agriculture and land clearance quickly took hold in the limited swampy lowlands (Prebble and Anderson 2012; Prebble et al. 2013; Prebble et al. 2019). Like elsewhere in Polynesia, Polynesian colonists brought with them a transported landscape of cultigens and other commensal species, but there are several notable absences in Rapa's archaeological and ethnographic records. Economic species, including coconut, breadfruit, sweet potato, yams, pigs, dogs, and chickens all appear to be absent on Rapa before European contact, along with most varieties of banana. The Pacific rat was the only vertebrate introduction (Anderson et al. 2012a). The principal staple was taro (*Colocasia* sp.), which was cultivated primarily in wet terraces in the flat land of the valley bottoms. The severe restriction of irrigable land has been central to discussions of the intense intergroup competition and territoriality that arose on the island (Anderson et al. 2012a; Stokes 2021).

The period after initial colonization of Rapa is primarily documented through two coastal rock shelters, paleoenvironmental cores, and general survey of the lowlands. Concurrent with colonization was an immediate move to clear lowland swamp forests to make space for taro cultivation (Prebble et al. 2012, 2013). Occupation of the lowlands is not well recorded, though evidence from two rock shelters from the outer bays documents an expansion of use and marine resource harvesting between AD 1400-1600 (Kennett et al. 2012). Other than a few domestic terraces and oven features from the lowlands, the primary domestic contexts that have been recorded come from the ridges and the fortified settlements that began appearing as early as

AD1300-1400. This early shift toward settlement of the highlands of Rapa represents one of the most visible and unique adaptations in the island's settlement history.

4.2.2. Conflict and Competition on Rapa

Oral traditions and archaeology provide two lines of evidence for intergroup competition on Rapa (Anderson et al. 2012a; Ferdon 1965a; Stokes 2021). Physically violent competition over territory, culminating in the conquering and consolidation of territory, is described in various oral histories, and the presence of archaeological defensive features offers the clearest evidence for conflict (Ferdon 1965a; Kennett and McClure 2012; Make et al. 2008; Stokes 2021). Based on these reports, and in light of the occupational chronology of the island, Anderson and colleagues (2012:253) concluded that intergroup competition was initially brought to the island in the form of status rivalry, like that found in other parts of Polynesia. Competition became endemic, sometimes violent, as population increased, and more demands were placed on the island's limited space and resources. These conditions culminated in the widespread construction of defensive features in the 18th century.

Apart from defensive features associated with settlements, there has been little direct archaeological evidence for violent conflict. Weapons and skeletal trauma are common lines of evidentiary support for the presence of warfare (Dolfini et al. 2018), and apart from possible sling stones (Mulloy 1965:52), neither have been documented in Rapa's archaeological record. This absence may be due to the limited excavation contexts from the island thus far, but also may reflect a possible subset of cultural traditions related to the disposition of the dead in the sea or by cremation (Stokes 2021:229). Stokes (2021:136-139) also noted various types of weapons reported by his informants, although these were predominantly made of perishable materials which the soils and weathering on Rapa would not likely preserve. Weapons included spears, staves, clubs, slings, strangling cords, and war nets. Intriguingly, one line of evidence may suggest that later periods of competition reduced the frequency of physical violence as Vancouver (1798:78) made specific note of the stark lack of scars and signs of physical violence on roughly 300 lightly clothed Rapan men that came out to meet the *Discovery* in 1791, as well as the small number of weapons they brought with them (Vancouver 1798:75). Together, these data suggest that the nature of competition of Rapa was not static, but rather the intensity and form of competition changed through time.

The most visible feature of intergroup competition on Rapa are the *pare* (Anderson et al. 2012a; Ferdon 1965a; Ferdon 1965b; Stokes 2021; Walczak 2003). Not all fortified sites were considered *pare*, and only 15 sites were consistently given this classification by local informants (Stokes 2021:63). The *pare* were the largest domestic settlements on the island for the majority of its occupational history and consisted of multiple terraces organized around a central tower cut from bedrock. According to oral histories, these towers were the sites of chiefly residences, and excavations have recovered evidence for domestic activities on their top surface (Anderson et al. 2012a; Kennett and McClure 2012; Stokes 2021). These sites were built on the ridges around a peak along the central spine of the island and were fortified with fosses, embankments, low walls, covered traps, and wooden palisades (Kennett and McClure 2012; Ferdon 1965a; Stokes 2021; Vancouver 1798:77). The *pare* containing central towers likely served as the seats of the 10 chiefly lineages (Kennett and McClure 2012:232-233; Stokes 2021; Walworth 2015:197). Though the first *pare* in the 14th century AD are most likely explained through status competition, the majority of fortified growth occurs in the centuries that follow, under conditions that point to more violent intergroup conflict within a territorial framework.

The *pare* were not the only habitation sites. There were up to 25 smaller terraced sites also located on the ridges and upper elevations (a small handful also noted for lower flanks of some valleys), which Stokes estimated could house 3,027 individuals (Stokes 2021:96). However, it is not clear if all terraced sites were occupied contemporaneously, and his estimate is likely the upper end of what the island was capable of supporting based on agricultural estimates; more conservative population estimates are closer to 2,000 (Bartruff et al. 2012). The smaller ridgetop settlements tend to comprise a few terraces and vary in the degree to which they were made defensible. These are often referred to as satellite communities and a few as refugia, but are intrinsically linked to the competitive social environment due to the presence of defensive features (Ferdon 1965a:69). The smaller fortified sites are linguistically separate from unfortified habitation terraces which Stokes (2021:63) identified as *auga*. These types of sites were part of a larger defensive network that functioned as forward outposts for the *pare*, but some were also in proximity to agricultural and fishing grounds and locations where ridge trails could be controlled (Stokes 2021:65-66). Overall, there are at least three types of ridgetop terraced settlements on Rapa: the large *pare,* the smaller fortified satellite communities, and unfortified settlements. There is no current established chronology for the smaller fortified and unfortified sites, but the relatively well dated *pare* indicate initial fort constructions began at Ruatara and Noogurope between AD 1300-1400, followed by sporadic additions until the height of fortification occurring in the 18th century AD where the dated *pare* had contemporaneous occupation (Kennett et al. 2012).

In sum, the current evidence suggests that Rapa's fortified settlements were physical manifestations of a competitive territorial behavior centered around limited agricultural lowlands in the outer bays. The large fortified *pare* were centers for political ramages with smaller subsidiary sites organized around them, some of which were fortified or part of a wider defensive network (see Figure 4.1). The evolving nature of the competition, status rivalry to warfare, changed through time and so too would the influences on where to place defensive sites.

4.3. Influences on Settlement and Defense on Rapa

Rapa's settlement history and endemic competition present an ideal lens through which to examine underlying conditions that influenced the placement of fortified settlements. Identifying these elements provides insight into the nature of intergroup competition on the island. However, there are complicating factors that must be addressed. For example, competitive strategies are not static and can change through time, along with the conditions that influence decisions. It is possible for a behavior to become formalized within cultural practice as a stable strategy that reinforced itself across groups when payoffs are net positive (e.g., Maynard Smith and Price 1973). Violent conflict and territoriality both carry heavy costs and risks to individuals and groups (Brown 1964). As such, efforts to understand decisions of fort placement require a theoretical framework capable of accounting for these costs, as well as the costs of supporting habitation such as transportation of raw materials and food. The economic defendability model from behavioral ecology provides an ideal theoretical framework through which to assess influences on decision making.

Economic defendability explains the decision-making process behind defending a resource to maintain exclusive access, where the invested costs are weighed against the payoff of the resource itself (Brown 1964). Costs associated with defending a resource include time and energy devoted to monitoring as well as the potential and realized costs of confrontation against those trying to enter a territory, the costs of which can be quite high when violent conflict occurs.

The surrounding environment and characteristics of the resource itself are central to determining if the cost is balanced by the payoff. The spatiotemporal structure of the resources in question influences the calculation, where dense and predictable patches are capable of supporting territorial behavior (Dyson-Hudson and Smith 1978).

Additional behavioral and technological adaptations can reduce the costs and risks associated with territorial behavior (e.g., Bamforth and Bleed 1997). For example, fortifications and defensive features reduce the risk of injury and loss of physical confrontations; weapons reduce the risk of losing a fight and increases risk to opposing groups (a deterrent); monitoring resources and territorial boundaries increases response time to defend against incursion. Each of these examples highlight cultural means of reducing long-term costs and risk associated with territoriality through investing time and energy in related behaviors, but at the cost of diverting these away from other activities. The Rapan *pare*, viewed through this framework, fulfill multiple societal roles as domestic sites while improving the chances of a competition-based territorial strategy.

Recent spatial-statistical modeling of 15 fortified sites tested the importance of visibility and resource monitoring in intergroup competition on Rapa through modeling placement of the *pare*. It was concluded that visibility of agricultural resources alone was not a significant predictor, but instead the measure of total visibility was linked to placement (Ch. 3). However, the study focused exclusively on visibility and the influence of additional variables related to defense were not specifically tested. In addition to external influences, there is also the possibility that the use of both large and small fortified sites in the initial analysis conflated the influence of specific variables on different site types in a mixed sample. The principal fortified *pare*, as seats of sociopolitical power, are more likely to be patterned differently in space than smaller fortified communities, which are more likely to be ordered around the larger settlements. Therefore, testing new variables that relate to the costs associated with defense and inhabiting the high ridges is a logical place to begin expanding the search for influences on site placement.

Freshwater is an essential resource which can be costly in time and energy to collect and transport. Rapa’s abundant precipitation (2500-3000 mm annually: Prebble et al. 2013) ensures the perennial nature of many of the rivers and streams on the island. Despite the abundance of surface water, the geography of the ridgetop sites precludes direct access to streams. Stokes (2021:75) observed that at Napiri and Morongo Uta, sources were absent within 200-300 m distance and at least 140 m lower in elevation. He suggests that these distances, at two of the most significant *pare*, were not abnormal for other similarly fortified villages. Kennett and McClure (2012: 232) noted the high costs and associated need for water storage within upland sites and pointed to cylindrical storage pits as possible locations suitable for above ground storage. This corroborates observations made by Stokes (2021:75) regarding the use of accumulated rainwater in storage pits at Morongo Uta by local workers during brush clearance, although this source would be periodically unreliable, particularly for larger populations. Within the broader context of territorial defense, sites with a proximity to water sources and local storage would have lower average procurement costs and free up time and energy for defensive activities that would reduce the overall risk of territorial behavior. Local sources would also lower the risk of an enemy preventing the community from accessing their water supply. Overall, proximity to a water source reduces the risk and costs of inhabiting ridges, making it a variable worth testing in the context of defense.

A second environmental defensive variable is the distance of a site from paths that enter a territory. Placing defensive settlements in proximity to access routes reduces associated costs of defending against incursion by reducing response time, increasing monitoring, and creating physical deterrents to entry. This not only reduces cost and risk by concentrating defensive efforts to a few organized locations, but also increases both risk and cost to invaders as they are required to spend more time and energy to enter a territory, which in turn reduces the frequency of incursion (Adams 2001). The way in which territories on Rapa were organized geographically around valleys and their lowland and nearshore resources means that access from external territories required crossing the intervening ridges. In times of conflict there are multiple factors for an invading force to consider when evaluating whether the risk is worth taking. This complicates building a testable model as there are multiple potential currencies that could be used. For example, measures of movement during a confrontation in both energy and time have ramifications on success. Time is used in this study, as it is a universal resource that relates to both mounting defense and influences success of incursion. Defenders have higher chances of success when response times are low, while invaders increase their chance of success if they are able to reduce the time required to cross a boundary. Therefore, defending locations that are near time-efficient routes of entry into a territory is a direct means to countering intrusions. Although invaders could opt for stealth and surprise, the nature of Rapa and the importance of total visibility in site placement indicates that the chances of remaining unseen on approach to a territory would be low. Active monitoring and placing fortified sites near entry points would both increase the success of a territorial strategy on Rapa by reducing costs and risk associated with defense.

The following analysis expands on previous research in two significant ways. First, two new variables have been added that are directly linked to cost and risk reduction related to the placement of fortified sites, and second, an expanded sample of archaeological sites that further diversify and differentiate between large and small fortified sites is utilized. The archaeological sites used are evenly divided between 10 large and 10 small, fortified sites. This permits a more nuanced analysis of differential influences of placement between the two types of sites and helps emphasize the satellite communities.

4.4. Data and Methods

Described below are two parallel analyses of spatial variables on fort placement. The first assesses if all defensive sites in the sample can be predicted by theoretically informed environmental variables, especially the proximity to access routes between territories and/or water sources. Both spatial factors are linked to the cost and risk associated with territorial behavior, as described above. The second series of models assess if differences exist in the predictive capability of the selected environmental variables between site size by only including the large *pare* in the modeling environment. This analysis will test the assumption that large *pare* and smaller sites fill different roles as interpreted through considerations in their placement. A pair of Gibbs point-process models (PPM) are employed to test these hypotheses.

4.4.1. Spatial Data

Twenty fortified ridgetop archaeological sites form the empirical basis of this study. The sample is an even mix of 10 *pare* (territorial seats) and 10 smaller fortified sites that have been described as satellite communities or redoubts. All 20 locations are used in the first analysis to assess the ability of the variables to predict placement. The second analysis uses only the *pare* to separate out relationships between variables and the primary community centers. Table 4.1 lists the fortified sites used in this analysis. The point data for 15 sites, including all 10 *pare* and five smaller communities, were derived from shapefiles provided by Le Service de L'urbanisme of

Table 4.1. Ridgetop sites and covariate measurements. Large *pare* in bold.

Ridgetop Sites	Nearest Cost Path (m)	Nearest Water (m)	Elevation (m asl)	Total Visibility (observer points visible)	Earliest ^{14}C Age of Occupation (after Kennett et al. 2012)
Teugarere	282	322	371	6470	--
Ororangi	276	247	275	14746	200±25
Tepia'u	313	217	286	15368	--
Mauga'oa	254	242	436	16716	--
Tevaitau	116	170	261	10305	240±20
Nagapiri	150	187	333	15283	205±25
Morongo Uta	299	281	258	14204	380±2±
NAE map (Poriaruatai)	56	273	284	11236	--
Pukutaketake	227	403	380	15291	235±15
Noogurope	112	183	370	13585	615±15
Namuere	329	298	610	22457	--
Karere	183	162	464	14319	--
Kapitaga	120	225	288	12461	240±15
Ruatara	76	262	301	15862	630±15
Vairu	466	208	370	19024	190±20
Potaketake	82	182	231	9331	240±25
Tapitanga	314	241	260	2167	145±25
Pukumia	224	312	411	19178	185±25
Pukutai	122	177	130	6346	195±25
Ta'ua	266	390	278	7571	250±25

French Polynesia. Five additional sites were added to the sample using georeferenced maps and site descriptions from Ferdon (1965b), Walczak (2001), Make et al. (2008), and Stokes (2021).

A 2 m resolution digital terrain model (DTM) of Rapa was used to generate rasters for the environmental variables detailed below. Geographic data processing and raster creation were done in ArcGIS 10.7 and the point process analysis was conducted in R (version 4.0.3; R Core Team 2020) with the spatstat and MuMIn packages (Baddeley et al 2016; Barton 2020). These were supplemented with the packages here (Müller 2020), maptools (Bivand and Lewin-Koh 2020), raster (Hijmans 2020), rgdal (Bivand et al. 2021), rgeos (Bivand and Rundel 2020), and sp (Bivand et al. 2013; Pebesma and Bivand 2005).

4.4.2. Environmental covariates

Four covariates are used in the PPMs to test first order interactions (i.e., those which occur between points and environmental variables) (Figure 4.2). These covariates were selected based on their links to the costs and risk associated with territorial defense. Elevation and total visibility are selected here as they have been shown to be strong predictors for the placement of fortified sites on Rapa (Lane and DiNapoli, Ch. 3). Due to their proven influence they are used in this analysis to provide a direct comparison with two new covariates. Elevation measurements relate to defense through the time and energy costs required to supply and access a site for its inhabitants. These measurements come directly from the DTM. Total visibility relates to defense through monitoring of internal resources and external territories and its likely role in signaling between groups. The DTM was used to generate a total visibility raster from a grid of observer points spaced 25 m apart covering the whole island. The measurement indicates the number of observer points visible from a given cell (see Ch. 3 for a detailed methodology). The two new

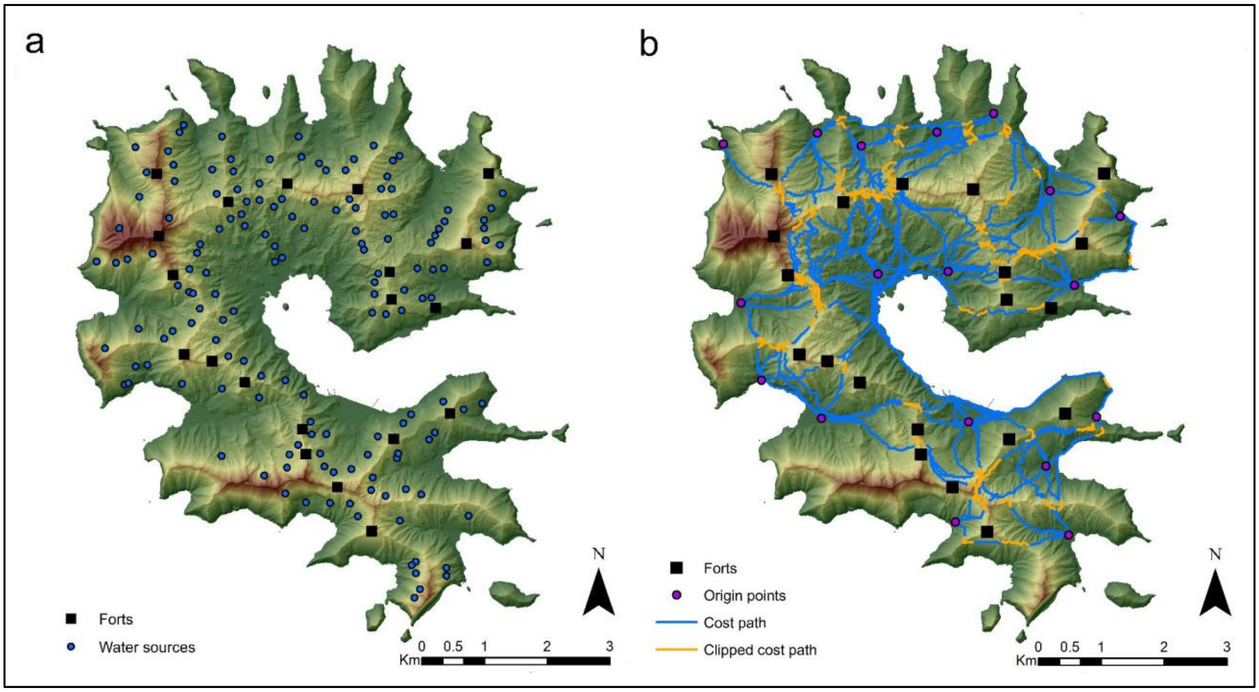

Figure 4.2. Maps of the island showing the locations of environmental variables related to defense, a) approximate locations of water sources, and b) the locations of least cost paths.

variables for the current analysis are proximity to water and least cost paths representing locations from which valleys can be quickly accessed.

4.4.2.1. Proximity to Water

To measure the distance from water for each site, a set of points were created indicating locations of headwaters for major streams on the island. Points were conservatively placed at locations where hydrological analysis (see Lane 2017) corresponds with perennial streams on a georeferenced map from the Norwegian Archaeological Expedition (Ferdon 1965b). Marked points were then visually checked against visible water courses in satellite imagery from the WorldView 2 platform taken in July of 2012. These locations were used to calculate a Euclidean distance for each cell that measured the distance to the closest water source. As conservative as the estimations of water sources are, it is acknowledged that there remains some room for error in these estimates. However, many of the distances correspond with the estimates that Stokes made regarding water sources a century ago (2021). This methodology also excludes potential springs, but the geology of Rapa would force springs to be at somewhat lower elevations as Stokes (2021:75) also mentioned for Morongo Uta and Napiri.

4.4.2.2. Proximity to Least Cost Path

Least cost analysis (LCA) is a commonly used tool in archaeology to estimate routes and trails across an archaeological landscape. This method has seen widespread use in the last two decades and is sufficiently flexible to address several archaeological questions (Surface-Evans and White 2012). The primary assumption behind the calculation is that decisions regarding which path to take relate to the least accumulated cost on a measurable scale, like energy or time, and can account for various external variables that aid or impede travel (e.g., streams and rivers, cliffs and bluffs, visibility, exclusion zones, etc.). Like most forms of geospatial analysis, however, LCA assumes a degree of perfect knowledge of the landscape and potential impediments to travel (for a more detailed explanation see White 2015). The primary goal of LCA is to calculate the accumulated cost of travel between two points while trying to keep the total cost as low as possible using a path selection algorithm. The choice of what cost to calculate must be theoretically informed based on the research question(s) being asked and as a result there is no single correct approach to LCA. However, the reality of archaeological routes depended on the specific motivations and goals of the traveler and can be difficult to identify or predict with archaeological data (Surface-Evans and White 2012:3-4).

The LCA in this paper applies a path distance tool using Tobler's time function instead of a cost path calculation (following Map Aspect 2009). The benefit of using path distance is that it can leverage a more accurate calculation of slope's effect on movement by accounting for anisotropy, the differential costs based on travel direction (e.g., uphill versus downhill). The cost used in the current analysis is time of travel, due to the importance of speed as a means of reducing risk during conflict (e.g., entering a territory more quickly than defenders can respond and increasing chances of success and reducing risk of failure).

In the PPM analysis the emphasis of the least cost path is not the path itself, but where least cost routes cross territorial boundaries, which on Rapa are defined by natural topography. Topography is often used to demarcate a territory in the natural world as it resists environmental fluctuation and sets clear limits (Adams 2001). In addition to the borders, careful consideration into where paths start and end must be tied into the research question. Since the *pare* and other fortified sites are themselves domestic areas, it could be justified to model paths from one settlement to all others, and this would most likely end in paths that follow the ridges themselves. There would be some evidentiary support for this type of movement, as Stokes (2021:76) mentioned that trails within the villages are along the ridges, though he is less clear on this matter beyond the domestic setting. There is also the complication presented by *auga* and other domestic terraces lower on the flanks which indicate that populations were more dispersed and using *pare* as origin points becomes harder to justify. To address the question of crossing territorial boundaries, path origins started within the valleys to best capture movement up and over ridges. This also discourages routes from passing through neighboring fortified sites on their way to a more distant destination, as an invading force is not likely to pass through a neighbor's village when raiding or attacking a more distant target. This is further justified because rival groups are not necessarily physically adjacent territories, as noted in Rapan oral histories (Make et al. 2008; Stokes 2021). Therefore, it was worthwhile placing origin and destination points within valley interiors.

The least cost paths were calculated using the DTM and 18 origin points. Paths were calculated from each point to every other point. These start and end points were located in the lowlands of the valleys and all but three points were placed in areas that have archaeological evidence of irrigation systems. For each point, a path distance cost surface was created using Tobler’s time function. Each cost surface was then used to generate a series of cost paths to the other 17 points. The results were then combined into a single raster showing all least cost paths between origin points. An arbitrary 75 m buffer was generated along the ridgelines of the island and the cost paths were clipped to only the extent within the buffer. The least cost path segments at this point indicate the locations deemed most efficient in terms of time for crossing the ridges between territories. Lastly, a raster was created that measures proximity to the nearest least cost crossing for each cell on the island by measuring the Euclidean distance between the individual cells and the nearest path segment.

4.4.3. Exploratory data analysis

Exploratory statistics were performed to assess the relationship between the locations of ridgetop sites and the environmental variables prior to modeling. Nearest neighbor measurements were calculated to examine the patterning and spacing of sites (Figure 4.3). Relative distribution graphs were also created using nonparametric smoothing through the application of the rho-hat function to visually plot the intensity of sites as a function of individual environmental variables (Baddeley et al. 2016:179). Lastly, Besag’s L-function was plotted for each sample to test for the presence of clustering or dispersion in the empirical data sets caused by second-order interactions (interaction between points). This was done by comparing the empirical L-function against a plotted envelope of complete spatial randomness (CSR) derived from 39 Monte Carlo simulations (Figure 4.4). This transformed version allows for an easier visual inspection of the results against the simulated envelope that is equivalent to a significance test with $p = 0.05$ (Baddeley et al. 2016:207).

4.4.4. Point-Process Models

Point-process models (PPMs), a form of spatially explicit linear modeling, are increasingly used in studies of archaeological landscapes (Bevan et al. 2013; Eve and Crema 2014; Davis et al. 2020; DiNapoli et al. 2018). This class of statistical models provides a set of tools that evaluate the distribution of point data in relation to spatial variables to model spatial trends. At the core of the analysis is a comparison of empirical points against models of complete spatial randomness (CSR), which when coupled with external variables, measures the intensity of influence that the variables exert on the spatial distribution (first-order interactions). Additionally, when applying a Gibbs process, they are capable of accounting for interaction between the sampled points (i.e., second-order interaction causing clustering/dispersion). When PPMs are applied to research questions, they increase the strength of explanatory frameworks when variables and hypotheses are theoretically informed and where clear links exist between the variables and the research questions (Davis et al. 2020).

Both analyses follow the same methods, except where specifically noted. Taking an interactive approach to constructing individual models, a series of inhomogeneous Poission PPMs were built using the four spatial covariates described above. These were used to evaluate the relationship between the empirical point patterns and the independent environmental covariates. Based on the nature of the sites being political centers and satellite communities, it was determined that a Gibbs point-process would be included for each sample. This modification specifically assumes that interaction occurs between points and therefore is a measure of conditional intensity, or the intensity of points as influenced by other placed points (Baddeley et al. 2016:488-489). The type of intensity (clustering or inhibition between points) can vary and is modeled based on the specific type of Gibbs process that is chosen, each which has different assumptions of the degree of constraint that is applied between points (e.g., hard core processes rarely, if ever, allow for violations of a set threshold).

Although the inhibition seen in the L-Function (see Figure 4.4) of both sample sizes did not fall outside the significance envelope ($p = 0.05$), there was a consistent trend towards inhibition between points at distances below ca. 1100 m. For the sample of large *pare* settlement, the Strauss component was selected, which is a hard-core Gibbs process that 'penalizes' pairs of close points instead of discounting them outright (Baddeley 2016:497). The rationalization for this application is that the *pare*, as territorial seats for each group, would be inhibited in their proximity to one another but constraints on land-area and size of valleys may force some forts closer together. A different interaction component was selected for the sample of 20 sites. A hybrid Gibbs model was created to capture the potentially different types of interaction occurring between points. A hybrid model is capable of capturing interaction at multiple scales and is ideal in this case where two classes of point data are mixed in the same model (large and small sites), but they are more difficult to interpret (Badeley et al. 2016: 527). The two Gibbs processes used here were a Strauss component as above, combined with Area Interaction. The latter process was chosen to capture the potential for clustering that would occur between satellite sites and the *pare.* Unlike other Gibbs processes, Area Interaction components can be applied when interaction between points may be inhibitive, causing regular spacing, or clustered (Baddeley et al. 2016:519-520). In other words, Area Interaction treats points as if they have a neighborhood of influence around them, as one might expect of a satellite community clustering around larger settlements (Beven et al 2013). Finally, a single null model was created that removes environmental covariates but retains the Gibbs modifications. Removing the covariates but keeping the interaction components acts as a control for the predictive strength of the covariates on the empirical distribution.

For each analysis a formal comparison using a model-selection tool was undertaken to determine the best fitting model based on information criteria. In this analysis, a variation on the Akaike Information Criterion (AIC; Akaike 1974) was used (the AICc), which is adjusted for small sample sizes (Burnham and Anderson 2002). The AIC is parsimonious, meaning that the calculations penalize models that have more parameters by adding weight to those that have fewer, which avoids problems of over-fitting caused by the integration of too many variables and biased by comparatively small influences (Eve and Crema 2014). The best fitting models will be those which have a low ΔAIC score and a high weight.

The top ranked models from each of the samples were then assessed for the goodness-of-fit between the modeled function and the empirical function of archaeological sites using the residual K-function across 99 Monte Carlo simulations of the fitted Gibbs model. This is a visual means of assessing how closely the two functions follow one another and how much deviation in clustering or dispersion occurs within the selected models. The model is deemed a good fit if the empirical function stays within the simulated envelope. A final check of the selected models looks at the partial residual plots of the individual covariates. These plots allow for inspection of the fitted effect of each covariate and to look for nonlinear covariate effects (Baddeley et al. 2016:427).

4.5. Results

An examination of the exploratory statistics highlights several characteristics of the data. First, Figure 4.3 presents the results of the nearest neighbor statistics. Looking at Figure 4.3b, there is a strong bimodal distribution with a cluster of sites that have nearest neighbor distances between 400-500 m and another at 900-1000 m and a mean horizontal distance between sites of 740 m. This provides empirical support for there being two types of sites as described in previous work on the island (Kennett and McClure 2012; Stokes 2021).

When looking at the 10 *pare*, the distribution of distance to a neighbor is 900-1200 m with a mean of 1066 m, suggesting a degree of regularity/dispersion in their spacing and placement reflective of their being political seats and distance from rival communities. Assessing this through the L-function (Figure 4.4), the resulting plots, however, indicate no significant relationship between sites (second-order interactions), but the empirical function does come close to the edge of simulated envelope close to the nearest neighbor mean. Though dispersion might be in part explained by intentional spacing, it is not enough to fully explain their placement. This is a surprising departure from previous analysis (Ch. 3), where significant dispersion occurred in a sample of 15 fortified sites between 900-1000 m. Therefore, the separation of large *pare* and the larger mixed sample appear to be influencing the results. This places more emphasis on the environmental variables as a means to explain the placement of fortified sites of both sizes.

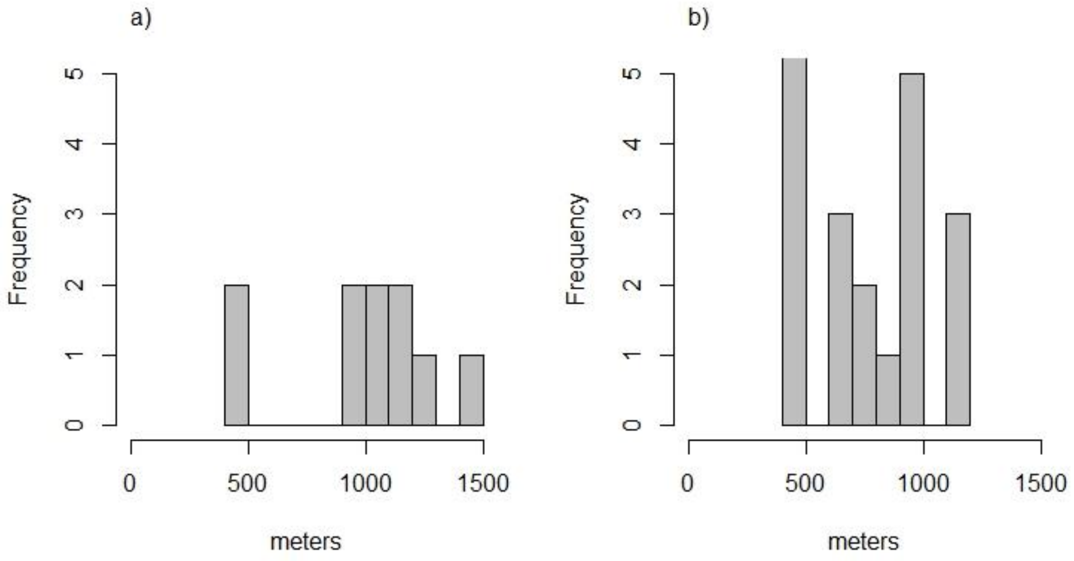

Figure 4.3. Nearest neighbor histograms a) Ten principle fortified sites and b) Sample of 20 ridgetop sites.

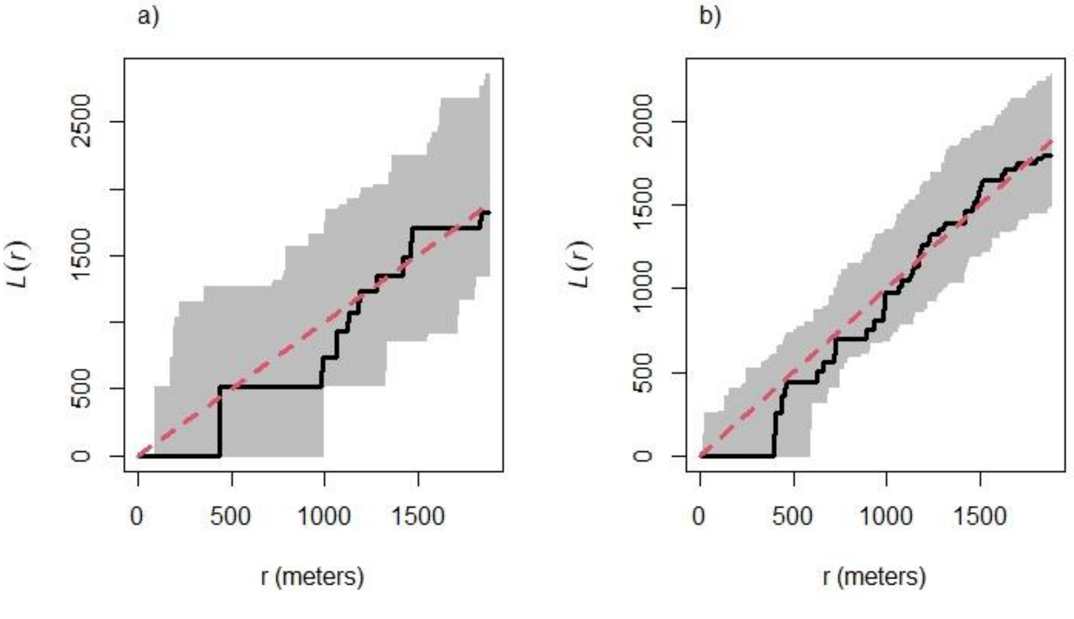

Figure 4.4. L-function plots of a) ten large fortified sites and b) the full sample of ridgetop sites. These are a transformed version of the K-function compared to 39 simulations of CSR. The gray envelope represents the modeled simulations, the dashed line represents the poisson process, and the solid line the empirical function. Deviation from the dashed line indicates more clustering above and more dispersed below.

Figures 4.5 and 4.6 show the results of the nonparametric regression of the individual variable showing the intensity of sites as a function of the covariate. These generally show a positive trend in relation to elevation and total visibility and a negative trend associated with distance from a cost path. Distance from water shows site intensity at closer distances before dropping off.

The model-selection of the series of PPMs for the sample of 10 *pare* resulted in Gibbs models that favored total visibility as the best single predictor of their placement (Table 4.2). Model 105 includes total visibility and distance from a cost path, with a w_i = 62.7%, closely followed by model 102, only total visibility with a w_i = 32.4%. Taken together, these models highlight the strong predictive relationship between total visibility and the large, fortified communities seen in Lane and DiNapoli (Ch. 3), with distance to cost paths also sharing some predictive capacity.

Model-selection for the sample of 20 fortified sites emphasized visibility and cost paths more regularly (Table 4.3). The top weighted model with the lowest AICc score was model 205, consisting of total visibility and distance from a cost path as strong predictors for site placement (w_i = 76.8%). The subsequent two most weighted models, 211 and 212, are both more complex iterations of 205, including elevation and distance from water respectively, and each having a w_i = 10%. As common denominators of the top weighted models, distance from a cost path and total visibility are equally useful in predicting fortified sites of varying size on Rapa, and possibly better at predicting smaller sites.

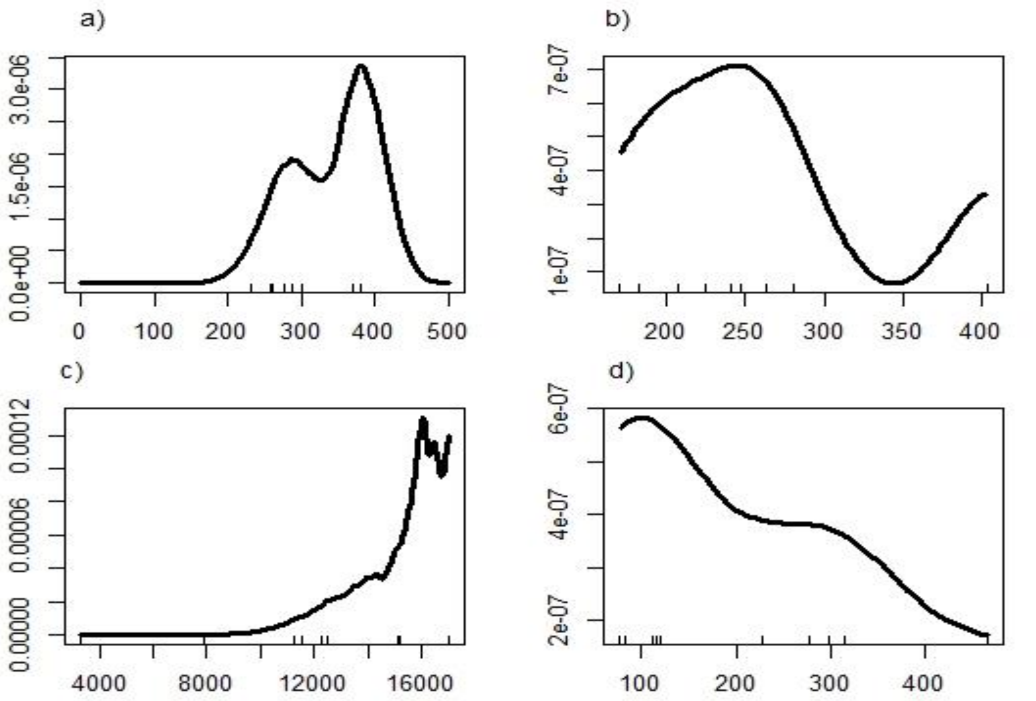

Figure 4.5. Plots of nonparametric estimate of intensity for covariates in relation to the sample of 10 *pare*: a) Elevation ASL, b) distance from water, c) total visibility, and d) distance from a cost path. Each curve is a measure of intensity in relation to the location of sites.

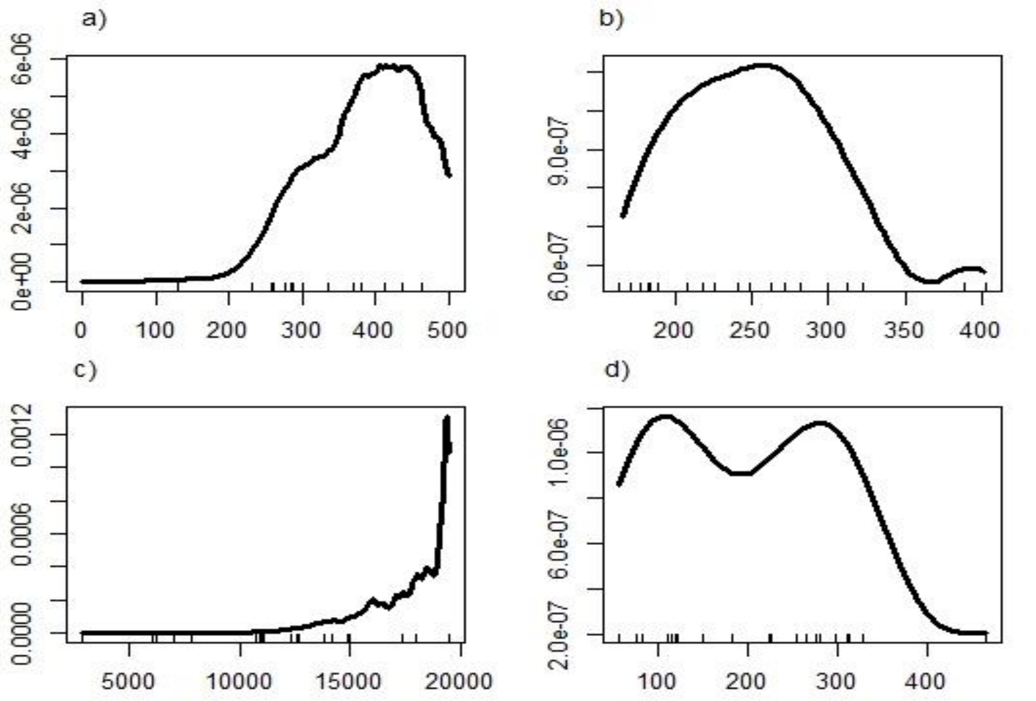

Figure 4.6. Plots of nonparametric estimate of intensity for covariates in relation to the sample of 20 fortified sites: a) Elevation ASL, b) distance from water, c) total visibility, and d) distance from a cost path. Each curve is a measure of intensity in relation to the location of sites.

Table 4.2. AICc model selection of the 10 *pare* sample. Only the top 7 and bottom 2 models are shown. E = Elevation asl, P = Cost path based on path distance, R = Ridge, V = Total visibility, W = Water

Model	**Rank**	**Covariates**	**df**	**ΔAICc**	**AICc weight /w_i**
ppm105	1	P+V	4	0.00	0.627
ppm102	2	V	3	1.32	0.324
ppm108	3	V+E	4	7.20	0.017
ppm109	4	V+W	4	7.25	0.017
ppm112	5	P+V+W	5	8.85	0.008
ppm111	6	P+V+E	5	8.96	0.007
ppm114	7	V+E+W	5	16.16	0.000
Ppm100	14	Null	2	52.99	0.000
ppm104	15	W	3	54.87	0.000

Table 4.3. AICc model selection of the 20 site sample. Only the top 7 and bottom 2 models are shown. E = Elevation asl, P = Cost path based on path distance, R = Ridge, V = Total visibility, W = Water

Model	**Rank**	**Covariates**	**df**	**ΔAICc**	**AICc weight /w_i**
ppm205	1	P+V	5	0.00	0.768
ppm211	2	P+V+E	6	3.95	0.107
ppm212	3	P+V+W	6	3.99	0.105
ppm215	4	P+V+W	7	8.63	0.010
ppm202	5	V	4	9.41	0.007
ppm209	6	V+W	5	12.16	0.002
ppm208	7	V+E	5	13.03	0.001
ppm204	14	W	4	97.17	0.000
ppm200	15	Null	3	98.46	0.000

Figure 4.7 shows the results for the model validation procedure using 99 Monte Carlo simulations of the residual K-function for the Gibbs models 105 and 205. The empirical function of the sites remains within the significance envelope for both models, indicating that there is no significant unaccounted-for interaction or second-order inhibition or clustering, though there is a general trend of inhibition below the modeled function. Figures 4.8 and 4.9 present the partial residual plots for distance from a cost path and total visibility for models 105 and 205. These plots show the fitted effect of the covariates and show the modeled and empirical intensities. Here the difference in the strength of cost paths to predict sites between the two models is clear. Figure 4.8 highlights that between 200-400 m there is significant deviation between the empirical intensity and the modeled intensity in model 105, while both intensities are near constant for total visibility. This deviation is less and does not fall outside of the significance envelope for model 205, but the modeled intensity is significant below 100 m. Again, this corroborates the predictive capabilities of distance from a cost path for the sample of 20 fortified sites.

For the sample of 10 large *pare* and the combined sample of 20 fortified sites, both total visibility and distance from a cost path are strong predictors of site placement. Total visibility appears to be the dominant variable in the sample of large *pare*, as it is present in all the weighted models, while total visibility is more equally a predictor along with distance to a cost path for the sample of 20. Of the four environmental covariates, water was the weakest predictor, while elevation only ranked in combination with total visibility.

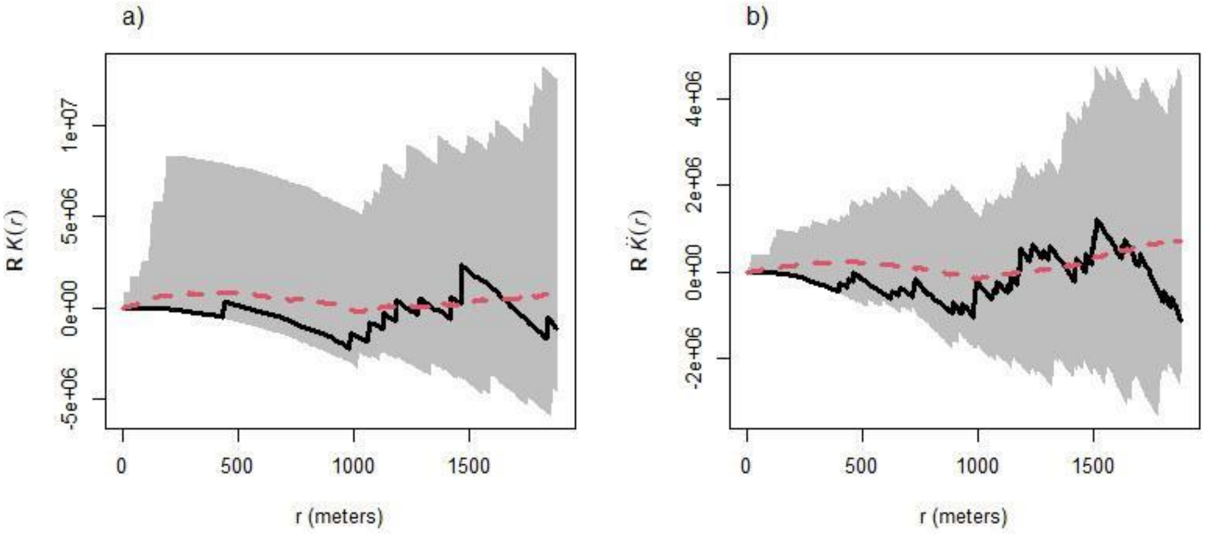

Figure 4.7. Residual K function for models a) 105 and b) 205. The gray envelope represents the modeled simulations, the dashed line represents the poisson process, and the solid line the empirical function. Deviation from the dashed line indicates more clustering above and more dispersed below.

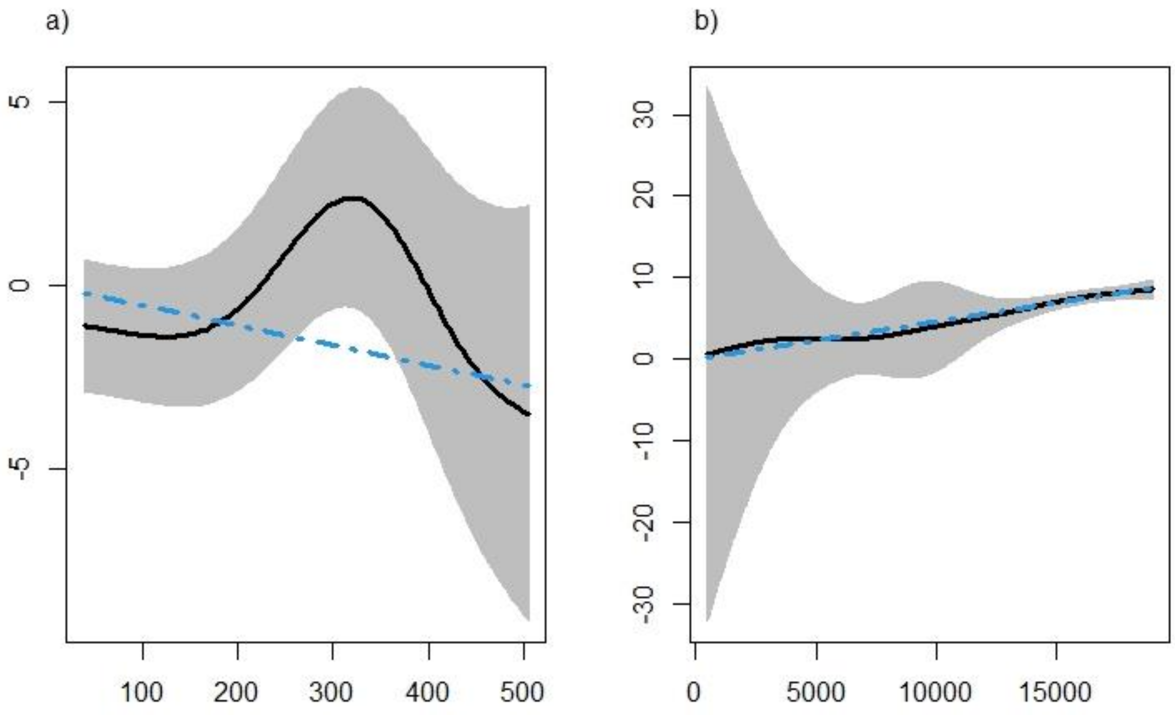

Figure 4.8. Partial residuals for model 105 a) distance to a cost path, b) total visibility Dashed line shows the fitted relationship, solid line is a measure of the partial residual that estimates the actual relationship, with the envelope indicating the 95% confidence interval.

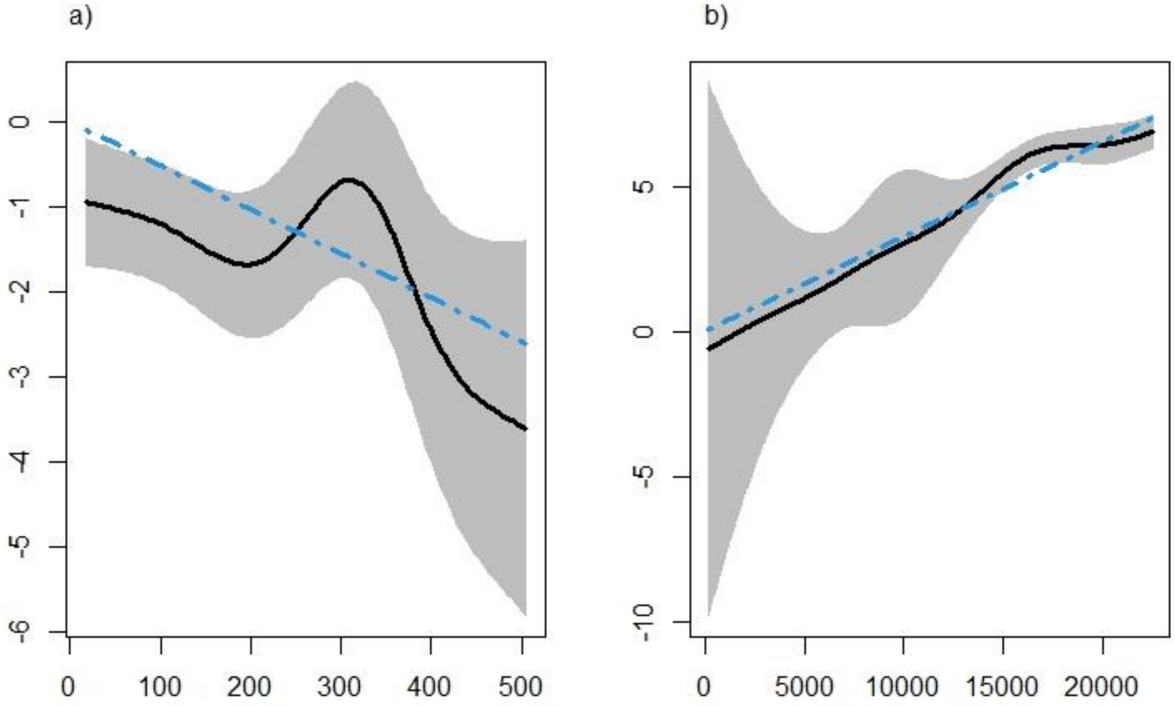

Figure 4.9. Partial residuals for model 205, a) distance to a cost path b) total visibility Dashed line shows the fitted relationship, solid line is a measure of the partial residual that estimates the actual empirical relationship, with the envelope indicating the 95% confidence interval.

4.6. Discussion

The current analysis provides an expanded empirical basis for a more nuanced understanding of the placement and role(s) of fortified sites on Rapa. It directly builds on previous work through an expanded sample of sites, additional environmental variables, and the running of parallel analyses based on site type. Lane and DiNapoli's (Ch. 3) work focused on understanding the role of visibility on site placement and identified a significant influence of total visibility over visibility of agricultural resources in predicting fort placement. Total visibility clearly links to cost and risk reduction strategies for defense as it permits uninhibited monitoring of a territory, which increases chances of detecting intrusion and reduces response time to repel intruders. The significance of visibility continues into the current analysis, although somewhat tempered by the addition of new environmental variables, especially distance from least cost paths.

4.6.1. Influence of Variables related to Defense

Two new variables were modeled alongside total visibility and elevation: distance from water and distance from cost paths. Water sources are included because of their importance for sustaining settlements. Distance from water did not prove to be a significant predictor of fortified sites. Freshwater often influences settlement patterns and can have a significant role in society (Scarborough 2003). On Rapa, however, the ubiquity of sources in proximity to the fortified settlements reduces this variable's influence in predicting site placement. There are no natural sources of freshwater within the fortified sites, but the prevalence of streams that extend to the upper flanks of the island make it a somewhat uniform spatial distribution. Water had to be transported to settlements and then stored. Archaeological evidence of pit features and trails to nearby springs or catchments provides evidence of this occurring (Stokes 2021:75-76). One caveat, however, is that the point data used in this analysis, although conservative, could be improved through ground truthing.

Distance from least cost paths crossing territorial boundaries was shown to be a significant predictor of site location in models of both sample sizes. This makes a certain degree of sense when considering that fortification placement in proximity to these paths permits at least two means of mitigating the cost and risk associated with territorial defense. First, placement of significant portions of a territory's population near access points reduces the response time of mustering a defense. A quick response lowers the costs on individuals to take up defensive locations as well as acting as a visible deterrent to opposing groups. This in turn affects the cost and risk associated with crossing territorial boundaries that potential invaders must consider when determining if the payoff is worth the expense (see Hinsch and Komdeur 2010). Secondly, placing fortified settlements near accessible pathways helps mitigate the high costs of travel and transport of agricultural products, water, marine foods, and other essential resources to high elevation sites. Due to their uniquely placed locations in the highlands of Rapa, even small gains in transporting resources could make a significant impact on the cost associated with living at these elevated sites. Defensive sites need to be able to control access to the sites themselves, and steep slopes and hard to access locations facilitate this. At the same time, these factors have negative effects on the day-to-day needs of a population associated with transporting food and water to these locations. Building elevated fortified sites in proximity to less costly travel routes make the strategy more sustainable for habitation and defense.

4.6.2. Importance of Visibility in Site Placement

The selection of models 105 and 205, with the same combination of covariates, confirms the overall significance of both total visibility and distance from the least cost paths. This generally points to a rejection of the second hypothesis–that the site size and type will be differentially influenced by covariates. However, a careful examination at the model selection tables (Tables 4.2 and 4.3) and the partial residual plots (Figures 4.8 and 4.9) detail the differences in the first-order influences. In the sample of large *pare*, there is a clear preference in the model selection for total visibility. This is seen through its inclusion in all the top ranked models with positive AIC weights. In these models, visibility is the only constant variable, including model 102, which consists of only total visibility and the Gibbs Strauss-process. In the partial residuals, this is also reflected in the closeness of the modeled and empirical functions of total visibility, which closely align in the plot. Conversely, distance from a least cost path has significant deviation from the modeled intensity between approximately 250 and 375 m, which accounts for a distance where half of the empirical sample lies. These slight differences in the top models point towards the central importance of total visibility in the placement of *pare* that acted as the seats of a territory. These results closely align with those of Chapter 3, and further support the conclusion that these monumental, terraced habitation sites function a dual cost reductive role in territory monitoring and acting as costly signals to mitigate intergroup conflict.

Total visibility also has a significant influence in model 205, using the sample of 20 fortified sites. The presence of satellite communities in the sample highlight deviations of model 205 from that of 105 that includes only large community centers. There is a strong influence of the 10 *pare* on these models as they make up half of the empirical sample. Examination of the partial residual plot, however, indicates a strong similarity between the modeled and empirical functions, though deviation is present beginning around 15,000 observer points where the empirical function shows significant second-order inhibition between sites. Due to the high visibility of the ridgeline in general, this deviation away from locations that are more visible is likely due to a weaker influence of visibility on smaller sites. This deviation was offset by a stronger relationship with the least cost paths, where only a slight significant clustering between sites is observed at the lower end of the plot. Again, the mixing of the large and small fortified sites can partially explain the differences. The presence of clustering makes sense in light of satellite communities tending to cluster within the influence of territorial seats and also that smaller communities also fulfill defensive roles relating to territorial defense. This can help explain the preference for proximity to the least cost paths in model 205, as well as total visibility. Unlike the sample of large *pare*, however, the sample of 20 sites has a strong preference for sharing both covariates in all the weighted models. Both total visibility and distance from a least cost path are present in the models with more than 1% weight. This reflects a more balanced influence that was not seen in the sample of 10 *pare*. Broadly speaking, there are clear differences in the influences between the large *pare* and the small fortified sites, although it is more a difference in proportion than different environmental variables.

4.6.3. Satellite Communities

Comparison of models 105 and 205 is the primary means of determining the influences on where smaller fortified sites were situated. Models could be constructed that only accounted for small fortified sites, but their intrinsic relationship to the larger communities would have been lost through that line of inquiry. The tendency of satellite communities to cluster around larger settlements needs to be accounted for within the models. The addition of the hybrid Gibbs process is an attempt to account for second-order interactions, but it is only an approximation. The smaller satellite communities, however, provide a new degree of understanding of the nature of competition on Rapa. Maintaining and supporting a satellite community imposes a cost on the territory's owner as they must be supported from the resources of the territory, but the tradeoff is that smaller communities then provide added benefits to defense against intrusion (Davies and Houston 1981). This comes in the form of additional individuals providing monitoring duties, fast response times across a territory's boundary, and the risk of injury to individuals within the community is reduced as the defensive responsibilities are shared by more constituents. More defenders and monitoring also impose higher costs for intruders who might consider crossing a territorial boundary, especially when high visibility permits a costly signaling strategy to exist between groups.

4.6.4. Stability of Territoriality on Rapa

All these high costs of construction, living at elevation, and the possibility of physical conflict between groups begs the question of how this territorial strategy with ridgetop settlements could be sustainable. As presented above, it seems to be an endless list of costs and investment. However, archaeologically, we see evidence that this strategy of fortified settlements only increased over time, indicating a stable strategy within the Rapan community for centuries, culminating in extensive construction of *pare* in the 18th century (Kennett et al. 2012). There are two aspects that can help explain this apparent contradiction. First, the resources within a territory were sufficient enough that the payoff for the *pare* and satellite communities in maintaining exclusive access offset the costs associated with defense. This is the basic assumption of economic defendability and territoriality (Brown 1964; Dyson-Hudson and Smith 1978). This is enough to establish a standard behavior, at least initially. But the satellite communities become important when considering the stability of a given strategy over time.

Hinsch and Komdeur (2010) point out that territoriality is only a stable strategy if the costs for intruding groups are very high relative to the benefits gained from the territory. These costs are both in fighting and the associated costs with crossing territorial boundaries. If the cost of moving between territories is high, then the rate of intrusion is less frequent, and costs are generally lowered for defenders and intruders over longer periods of time. In situations, like on Rapa, where territories are packed together and share borders, the general costs from crossing boundaries are low, which would encourage frequent raiding and destabilize the territorial strategy (Hinsch and Komdeur 2010). Therefore, any strategies that increase the costs associated with crossing into a territory or fighting would help balance the territorial strategy back towards stability. Fortified satellite communities spread out along the ridges, sites placed near access routes, and defensive technologies all fit into this structure of maintaining territorial behaviors as a stable strategy. Indeed, the satellite communities are likely a key feature of maintaining the behavior in the long term as populations increased and the pressure for resources and territorial acquisition became more acute. Archaeological dating of the smaller fortified sites and defensive features, however, would be required to confirm this.

4.6.5. Archaeological and Ethnohistoric Support

The results of my analysis show that total visibility and distance from least cost paths accessing territories are strong predictors for the location of fortified sites on Rapa. Further, the results indicate a slight difference in the strength of influence of cost paths on smaller sites, compared against the large *pare*, indicating an adaptive stabilizing strategy of satellite communities adding to defensive efforts of larger communities by controlling access into a territory. This could be archaeologically verified through further development of settlement chronologies if smaller sites come later in the sequence of settlement. These data combined with an understanding of the chronology of Rapan fortifications highlight that the nature of intergroup competition on the island was not static.

Ethnohistoric and archaeological data add support for dynamic changes in competition. Oral traditions of the island variously highlight the struggle between clans for supremacy, beginning with competition between the Takatakatea and Gate Mato clans. These two groups are also ethnographically associated with the first *pare* of Noogorupe and Ruatara (Stokes 2021). Various stories describe conflict through time including the capture of *pare* Napiri, fights over water at Tevaitau, and the vengeance of a warrior from Ruatara against the Tevaitau (Make et al. 2008; Stokes 2021; Walworth 2015:196). Many of the accounts include details about strategies used in attack or defense, such as the use of smoke, climbing, and cover of night. The culmination of these histories is the eventual unification of the island under a paramount chief, Auariki I, which Stokes (2021:44) estimates occurred as early as AD 1600 based on genealogies.

Archaeologically, the monumental displays of competition between lineages are seen through the establishment of *pare* in highly visible locations on the island, which has previously been linked to a history of status competition brought to the island by the first human inhabitants (Kennett and McClure 2012:232). This also aligns with the general competition that is described in the oral histories of the competing clans that established Noogorupe and Ruatara. The tradition of *pare* construction started slowly and gradually grew in intensity over the course of several centuries (Kennett et al. 2012). Although initially supporting status competition and territorial claims, the *pare* became more defensively focused later in time, as Mulloy (1965) noted the addition of extra defensive features that cut through pre-existing terraces at Morongo Uta and concluded that there was a period of later intensive conflict. An increase in conflict likely coincided with the intensification of fort construction in the 18th century. The use of satellite communities and small defensive sites near access routes into territories likely supported the stability of territorial strategies by lowering costs and risks of defense, therefore aiding in the stabilization of a territorial strategy across the island.

4.7. Conclusion

Aspects of my current analysis empirically support the variety of roles that the fortified terraces played through the centuries. High visibility could be argued as both deterrents through signaling and enhancing success against direct attack based on the fortified features. Small defensive communities arise as a mitigating factor to ensure that unwanted intrusions could be stopped more reliably. Together these data provide useful comparators to other similar site types found throughout the Indo-Pacific.

CHAPTER V

CONCLUSIONS

5.1. Discussion and Conclusions

Human competition and territoriality have been the subject of numerous archaeological studies (e.g. Carneiro 1970, 1990; Choi and Bowles 2007; Glowacki et al. 2017; Gómez et al. 2016; Keeley 1996; Kintigh et al. 2014; Turchin et al. 2013; Zefferman and Mathew 2015), but these efforts are often tempered by other large-scale cultural processes that occur at regional scales. Islands–as easily defined and bounded territories–are often used as model environments to compare evolutionary models of competition and avoid some of the complicating factors encountered in larger continental settings (Allen 2010; DiNapoli et al. 2018; Fitzpatrick et al. 2007; Fitzhugh & Hunt 1997; Kirch 1986; 1997; 2007). In this dissertation, I continue this perspective by applying theoretical frameworks drawn from human behavioral ecology (HBE) to construct models and testable hypotheses regarding the settlement and subsequent development of endemic territoriality on the small and remote island of Rapa in the Austral Islands of East Polynesia.

The island's monumental fortified settlements, *pare,* are frequently used as an example of the extreme endpoint of intergroup competition in Oceania (Kirch 1989:212) and as a prime example of divergent cultural evolution for studying intergroup competition (DiNapoli et al. 2018). Rapa's unique history offers an ideal source of data to explore broader concepts related to human colonization and settlement, cooperation, competition, and territoriality. This history coupled with the comparatively small land-area, allows for a more complete understanding of the landscape in which these processes developed, a situation that larger islands and continental settings rarely afford. Despite the wealth of potential understanding presented by this context, Rapa's remoteness and relatively small number of ethnographic and archaeological studies offer only a partial explanation that focuses mainly on colonization and the chronology of the largest fortified settlements (Anderson & Kennett 2012; Caillot 1932; Ferdon 1965a, 1965b; Hanson 1970; Kennett et al. 2006; Mulloy 1965; Smith 1965a, 1965b; Stokes 2021; Walczak 2003a). Nonetheless, Rapa continues to be recognized as being somewhat unusual within the broader context of Polynesia because of the monumental, fortified settlements constructed on the island's high ridges and peaks. The *pare* are striking examples of corporate construction efforts and undoubtedly played a significant role within the local culture. Explanations of their function have varied, however, including primarily as defensive sites within a broader competition over status and resources (Ferdon 1965a; Stokes 2021), as costly signals between groups (Kennett et al. 2006; DiNapoli et al. 2018; Ch. 3 and 4), expressions of status rivalry (Kennett and McClure 2012; Stokes 2021), and as political-religious structures (Walczack 2003a, 2003b). The fortified settlements of Rapa continue to be at the forefront of debate regarding the island's history.

The studies presented in this dissertation utilize powerful geospatial and geostatistical tools in concert with compiled published data to evaluate the current understanding of intergroup competition on Rapa. In doing so, testable hypotheses were formed which can be further explored with spatially explicit statistical models and tested by field work that incorporates contexts specifically associated with settlements and agriculture. Through building on previous work that has primarily described the archaeological record of colonization and forts (Anderson and Kennett 2012; Kennett et al. 2006; Prebble et al. 2013; Stokes 2021; Walczak 2003a), my dissertation contributes to our understanding of the deep history of Rapa by securely linking the archaeological record to an explicit theoretical framework to assess the nature of competition that emerged, especially, the roles of the fortified settlements and the stabilization of the territorial strategy over a period of centuries.

In Chapter 2, I presented a theoretically informed prediction for the order of occupation and agricultural improvements by valley, based on their ability to support irrigated taro agriculture. Using GIS, I assessed the growth requirements for taro and the physical limits for irrigation infrastructure to create a ranked geospatial model of irrigation potential. Applying an HBE optimality model–the ideal free distribution (IFD)--I ranked the order in which agricultural infrastructure was most likely to occur, valley by valley. Use of the IFD at this scale is a departure from other treatments in island settings, which have principally applied the model at a regional or archipelago scale (Giovas and Fitzpatrick 2014; Jazwa et al. 2016; Kennett et al. 2006; Winterhalder et al. 2010). To be clear, this was not a prediction about a colonizing population inhabiting or exploiting local resource bases, but rather an explicit prediction of the initial establishment of infrastructure for irrigation, a rough proxy for the roots of territoriality. Investment in modified landscapes is one of the first steps that lead to ownership claims, which in turn can lead to exclusionary tactics. Drawing from the theoretical framework and the geographic model I laid out, I presented a testable prediction for the order in which valley territories would form based on irrigable potential. These predictions could further be corroborated through the application of oral histories that were later published (Stokes 2021) and which broadly agree with the local history presented by Hanson (1970).

Chapter 3 introduced the first use of point process models (PPMs) to evaluate defensive settlements on Rapa. My coauthor and I operationalized spatially explicit models to test the importance of visibility in monitoring resources as a primary function of the *pare*. The fortified settlements have frequently taken a prominent role in archaeological investigations on the island

and fit into a narrative of gradual population growth leading to competition and eventual territoriality (Anderson et al. 2012; Ferdon 1965a; Stokes 2021). These same sources describe where *pare* are located, especially in relation to the natural features, and extol the natural defensiveness that the slopes and high ridges provide. However, no previous work systematically assessed empirical influences on *pare* placement. Similar to previous work analyzing visibility in relation to defensive sites in Fiji (Smith and Cochrane 2011), I evaluated the influence of visibility on the distribution of archaeological sites. This was framed through the HBE model of economic defendability (ED) to evaluate site placement. I constructed a series of theoretically informed PPMs to test environmental variables linked to defensive costs, including two measures of visibility along with elevation and slope. The significance of total visibility, as opposed to visibility of agricultural resources alone, was indicated through the use of multi-model selection, implicating its relationship with fort placement. These results fit predictions based in ED where site location was intended to reduce part of the cost and risk of the territorial strategy. The significant influence of visibility for the *pare* suggest a likely role as visible deterrents, which articulates well with costly signaling theory, also from HBE. This latter model has been widely applied in archaeology, especially in relation to monuments and elite competition (Conolly 2017; De Souza et al. 2016; Neiman 1997; Quinn 2019). The unique configuration of the fortified terraces on the ridgetops of Rapa, although linked to defense and habitation, are no less monumental in the efforts required to construct and maintain. Their prominent locations and the role that signaling plays in mitigating intergroup competition fit the results that the *pare* played a role as territorial signals.

In Chapter 4, I presented a series of PPMs that tested the predictive capability of environmental variables linked to territorial defense to identify differences in their influence on fortified sites based on settlement size. This chapter is the first analysis to systematically divide sites into classes and emphasize satellite communities alongside the larger *pare* in assessing site placement. In prior assessments of the island, smaller communities were ancillary to the central narrative of intergroup competition for territory and status (e.g., Andersen et al. 2012; Ferndon 1965a; Stokes 2021; Walczak 2003). When mentioned, they are primarily described as fulfilling roles as refuges, redoubts, and satellites to the large *pare*, but never explicitly explained within the larger context of settlement or competition. This analysis specifically tested defensively linked variables alongside total visibility to determine if differences existed between the roles of large and small fortified settlements. The results indicated that all settlements had a significant relationship with total visibility, as in Chapter 3, but also distance to least cost paths. However, differences exist between models of the *pare* and those that included smaller fortified sites. The latter set highlighted the consistency of the relationship present between least cost paths satellite habitations, but less so on large *pare.* These results provide tantalizing insight into the significant role that satellite communities played in stabilizing and perpetuating territorial strategies. Through mitigating the defensive roles of the large *pare*, smaller sites may have decreased incursion rates among densely packed territories by presenting additional barriers and costs of entry to competing groups (e.g., Hinsch and Komdeur 2010). In addition to providing a new direction of research for settlement on the island, these data also provide testable hypotheses for future archaeological dating of the smaller communities.

The three analyses presented in this dissertation provide a more nuanced understanding of the intergroup competition that became endemic within Rapan culture. By shifting the focus away from a framework of population growth and resource pressure, I have presented an internally consistent framework that treats these conditions through a lens of territorial strategy that emerged and later stabilized through time on the island. Starting with the origins of intergroup competition, the current narrative centers on demographic expansion, limited cultivable land, and importing a tradition of status rivalry as the principal foundations of territoriality on Rapa (Anderson et al. 2012; Ferdon 1965; Stokes 2021). By shifting the focus to local geography and applying the IFD to irrigable taro requirements, the work presented in Chapter 2 offers a structured and theoretically informed testable hypothesis regarding the settlement order of valleys based on agricultural productivity. The settlement history can inform on assumptions of population growth and the expansion of infrastructure for irrigated taro agriculture as the driving forces behind territorial strategies. The ranking is especially interesting when compared to oral histories of the first competing clans on the island, Gate Mato and the Takatakatea. These clans are traditionally centered around Anarua and Tupuaki valleys, which in turn are associated with the first *pare* of Noogorupe and Ruatara (Kennett et al. 2012). Though not the highest ranked valleys, they are in the upper half of the rankings which indicate productive locations for taro agriculture but are limited in land area and likely some of the first to feel stresses on their resources as populations grew. The productivity and limited land area are reflected in the productivity rankings derived from the geospatial analysis at the core of Chapter 2.

Although a territorial strategy became ingrained within Rapan society, the nature of intergroup competition remains uncertain. Competition and territoriality take many forms and can be expressed through unique cultural traditions. The presence of fortified settlements on the island does tend to point toward violence, conflict, and/or concerns about defense to one degree or another. Despite this, various lines of evidence from the island are somewhat contradictory on this matter. Oral histories recount violent conflict and territorial conquest, but archaeological evidence for conflict is comparatively absent except for the presence of fortified sites, and historic observations at the zenith of *pare* construction describe palisade-like structures around the settlements, but few visible injuries or scars on a significant proportion of the observed population (Ferdon 1965a; Kennett and McClure 2012; Make et al. 2008; Stokes 2021; Vancouver 1798). As a result of this ambiguity, I strove in this dissertation to evaluate the locations of fortified sites understand decisions about their placement as they relate to defense and inform on the nature of conflict. The economic defendability model and costly signaling theory both provide insight into the roles that the *pare* and smaller fortified sites played within Rapan territoriality. Site placement was evaluated in Chapters 3 and 4 based on the assumption that locations can provide insight into their functional roles within a territorial strategy because the underlying decisions of where to locate the settlements are inherently tied to considerations linked to the nature of intergroup competition. The results provided an expanded understanding of the emergence and stability of territorial strategies on Rapa and highlighted the careful balance between needs and costs associated with the placement of fortified settlements.

To start, I reframed the interpretation of site location through HBE. Instead of assuming that forts are primarily placed in “naturally defensible” areas along the ridges, I viewed them as primarily being placed at territorial boundaries, which happen to be defensible, but are costly locations to inhabit. The environmental context of dense and predictable resources from wet taro agriculture provides the resource-based incentive for territorial strategies and the steep ridges and dissected topography provide clear natural territorial boundaries. Within two centuries of Rapa’s settlement history, the decision was made to locate two large population centers on the ridges, likely as a cost-reductive strategy for maintaining exclusive access to the valley’s resources. However, this strategy came at a high price. There were significant additional costs that living at high elevations incurred on the group, as opposed to the lowlands and flanks of the hills; principally due to the monumental efforts of constructing settlements of shaped bedrock and terraces, followed by ongoing costs of transporting food, water, and other resources to the site coupled with the need for regular trips to the valley interiors to work. A driving force behind these costly investments was the need to place defensive settlements along borders to control access and monitor for trespassers. Otherwise, the costs of mounting effective defenses based out of the lowlands would have incurred more risk of failure and higher costs, as intruders would already be within the territory prior to an effective defense being mounted. The results from this dissertation indicate that total visibility and proximity to modeled least cost routes between valleys were the best predictors for the location of fortified sites. Viewed through the economic defendability model (Brown 1964; Dyson-Hudson and Smith 1978), both variables play a significant role in reducing the associated costs of living on the ridges and defending territory. Proximity to accessible routes lowers the time and energy required to access settlements for all economic activities. Least-cost paths are among the most probable means that non-group members are also likely to use when accessing a territory, therefore, placing populations and defense near these locations lowers ongoing investments associated with defense and responding to intrusion.

In addition to controlling access, there is an additional role that the forts fulfill, especially *pare*; that of signaling to competing groups. Monumental features are increasingly scrutinized through the lens of costly signaling theory in the Pacific (e.g., DiNapoli 2020; DiNapoli et al. 2017; 2019; Glover et al. 2020). These are large corporately organized features that are frequently placed in highly visible locations and accurately signal an underlying quality(s) of the group (Conolly 2017; De Souza et al. 2016; Neiman 1997; Quinn 2019); including resource holding potential, group cohesion, group size, etc. Signaling in competition over resources or territory can act as a deterrent to reduce the frequency of physical conflict in order to save costs associated with conflict (Bliege Bird and Smith 2005; Zahavi and Zahavi 1997). By preferentially constructing the *pare* in highly visible locations, groups on Rapa were placing imposing visible deterrents intended to reduce ongoing costs and risk associated with a territorial strategy. Avoiding frequent conflict was likely one of the primary means through which territoriality became a dominant strategy on Rapa, especially considering the relatively small size of clan groups, which only likely numbered a few hundred each (population of 1,500-3,000 / 10 territories). Sustained violent conflict would not have been a successful long-term strategy on Rapa, especially considering that injury or death of just a few individuals from small populations can have significant repercussions on demographic success (e.g., Moore 2001). This also likely explains the local history of female warriors being commonplace, in order to expand the potential fighting demographic of individual groups seeking an edge over rival territories (Walworth 2015: 202). In sum, a signaling argument casts some doubt to the original narrative, which suggests that frequent conflict, especially at an early time, was the impetus for the prolific construction of fortified sites (e.g., Stokes 2021), and in actuality may be playing a mitigating role to reduce conflict.

Although signaling group coherence and strength helped establish territoriality on Rapa, it was the addition of smaller satellite communities that helped stabilize the strategy within the island's cultural environment. Individual *pare* were intentionally located for visibility and controlling access via a single route. Small fortified sites, though prominently placed on the landscape, were primarily built in proximity to least cost paths. Despite the fact that the additional settlements detract from the overall payout from the valley's resources, they simultaneously decrease the frequency of incursion by creating additional barriers to intruders in energy cost and incurred risk of crossing a territorial border. This reduction is especially advantageous as frequent violations of territorial borders are capable of destabilizing the strategy because of the higher defensive costs associated with defending (Hinsch and Komdeur 2010). Therefore, by utilizing satellite communities to help control access, Rapans encountered an adaptive strategy that further stabilized territoriality. This is most likely seen in the archaeological record in the increase of fort construction in the 18th century AD, though further chronology building will be required to test this hypothesis in relation to the smaller settlements.

Though locally dense and predictable resources supported a territorial strategy, they by no means preordained this behavior. Several of the details laid out above regarding site placement and the island's cultural history can be seen as ongoing adaptive strategies meant to cope with a changing cultural environment in which the form of competition shifted from status rivalry to more frequent conflict, to a stabilized system of competition through signaling. Fortified ridgetop settlements are the most obvious expression of this strategy. Most population centers throughout East Polynesia were traditionally closer to shore, and the fact that settlement shifted primarily to the ridges and highlands is representative of one of Rapa's most distinctive local adaptations.

Intergroup competition and human territoriality are common research topics within archaeology globally (Carneiro 1970, 1990; Choi and Bowles 2007; Glowacki et al. 2017; Gómez et al. 2016; Keeley 1996; Kintigh et al. 2014; Turchin et al. 2013; Zefferman and Mathew 2015). Similarly, islands worldwide are used as model environments to study a variety of human adaptations to novel environments (Allen 2010; DiNapoli et al. 2018; Fitzpatrick et al. 2007; Fitzhugh & Hunt 1997; Kirch 1986; 1997; 2007). As described in this dissertation, Rapa is an ideal setting to evaluate the emergence and stabilization of human territorial strategies. The analyses and conclusions presented in this dissertation are by necessity preliminary and will require future archaeological testing of specific contexts to support or reject. In either case, the methods and theoretical perspective applied in this work is intended to further our archeological understanding and move toward a deeper consideration of the available data and demonstrating the utility and limitations of powerful geospatial modeling and statistics. It has also been a goal of this body of work to further showcase the internally consistent explanatory framework offered by evolutionary theory, and specifically models from human behavioral ecology. It has been my goal to demonstrate how this case study of published data and theoretically informed models can inform on larger issues and shape future field research related to intergroup competition in circumscribed environments, which is an increasingly important issue on a global scale.

APPENDIX A

CODE FOR THE CHAPTER 3 VISIBILITY ANALYSIS

Load the chosen packages in R.

```
#load packages
library(maptools)
library(MuMIn)
library(raster)
library(rgdal)
library(rgeos)
library(sp)
library(spatstat)
library(here)
```

Load data from the working directory.

```
#load data from working directory
pare_points <- readOGR(here('Data', "Pare_Projected.shp"))
shore_line <- readOGR(here('Data', "shore limit.shp"))
DTM <- raster(here('Data', "tingrid_Copy.tif"))
ag_vis <- raster(here('Data',"5m_ag34_vis_Copy.tif"))
tot_vis <- raster(here('Data', "5m_tot_vis2_Copy.tif"))
```

Calculate slope from the DTM.

```
#Make slope variable
slope <- terrain(DTM, opt='slope', unit='radians', neighbors=8)
#aggregate slope because pare are on flattened areas, want average slope of neighborhood
slope <- aggregate(slope, fact=5)
```

Convert the data into formats that the R packages can read.

```
#convert to spatstat format
shore <- as.owin(shore_line) #convert to window format
pare <- ppp(pare_points$POINT_X, pare_points$POINT_Y, window=shore)
#convert pare to a ppp object/ error? maybe use X_Cor
elev <- as.im(DTM) #convert DTM to a pixel image
ag_vis <- as.im(ag_vis) #convert g visibility to a pixel image
tot_vis <- as.im(tot_vis) #convert total visibility to a pixel image
slope <- as.im(slope)
```

Exploratory data analyses

```
#Compute nearest neighbor distances for forts
pare_nn <- nndist(pare)
#mean nn
mean(pare_nn)
#median_nn
median(pare_nn)
```

```
#Perform L function test against 39 realizations of CSR with fixed number of points
set.seed(1234) #set random seed to get reproducible result
pare_L <- envelope(pare, fun=Lest,  fix.n=T,nsim=39)
#check it
plot(pare_L)
```

```
#Examine form of possible covariate effects using relative distribution (nonparametric regression (rhohat))
elev_rh <- rhohat(pare, elev, confidence = 0) #intensity as a function of elevation
ag_vis_rh <- rhohat(pare, ag_vis, confidence = 0) #intensity as a function of visibility from agricultural plots
tot_vis_rh <- rhohat(pare, tot_vis, confidence = 0) #intensity as a function of total visibility for the island
slope_rh <- rhohat(pare, slope, confidence = 0) #intensity as a function of slope
```

Modeling

```
# Beginning of point process models
#correction="none" so models do not calculate unobserved points outside the window.
ppm0 <- ppm(pare, ~1, correction = 'none')
ppm1 <- ppm(pare, ~elev, correction = 'none')
ppm2 <- ppm(pare, ~ag_vis, correction = 'none')
ppm3 <- ppm(pare, ~tot_vis, correction = 'none')
ppm4 <- ppm(pare, ~elev+ag_vis, correction = 'none')
ppm5 <- ppm(pare, ~elev+tot_vis, correction = 'none')
ppm6 <- ppm(pare, ~slope, correction= 'none')
ppm7 <- ppm(pare, ~slope+elev, correction= 'none')
ppm8 <- ppm(pare, ~slope+tot_vis, correction= 'none')
ppm9 <- ppm(pare, ~slope+elev+tot_vis, correction= 'none')
```

Multi-model selection and validation

```
# AICc model comparison
ppm_AICc <- model.sel(ppm0, ppm1, ppm2, ppm3, ppm4, ppm5, ppm6, ppm7,
ppm8, ppm9, rank=AICc)
ppm_AICc# Results
```

```
#print results of best fitting model
summary(ppm3)
```

```
# Compute Residual K-function to evaluate model fit in terms of second-order interaction
set.seed(1234)
K_sim <- envelope(ppm3, Kres, nsim=99, fix.n=T)
#check fit
plot(K_sim, lwd=3, legend='F')
```

Modeling with the Gibbs process

```
# Modeling with Gibbs hard-core process
ppm10 <- ppm(pare, ~ 1, Strauss(950), correction = 'none')
ppm11 <- ppm(pare, ~ tot_vis, Strauss(950), correction = 'none')
ppm12 <- ppm(pare, ~ elev, Strauss(950), correction = 'none')
ppm13 <- ppm(pare, ~ elev + tot_vis, Strauss(950), correction =
'none')
ppm14 <- ppm(pare, ~ ag_vis, Strauss(950), correction = 'none')
ppm15 <- ppm(pare, ~ elev + ag_vis, Strauss(950), correction = 'none')
ppm16 <- ppm(pare, ~ slope, Strauss(950), correction= 'none')
ppm17 <- ppm(pare, ~ slope+elev, Strauss(950), correction= 'none')
ppm18 <- ppm(pare, ~ slope+tot_vis, Strauss(950), correction= 'none')
ppm19 <- ppm(pare, ~ slope+elev+tot_vis, Strauss(950), correction=
'none')
```

Multi-model selection and validation

```
#compare Gibbs models
ppm_AICc2 <- model.sel(ppm10, ppm11, ppm12, ppm13, ppm14, ppm15,
ppm16, ppm17, ppm18, ppm19,rank=AICc)
ppm_AICc2
```

```
#print results of best fitting model
summary(ppm11)
```

```
#check residual K
set.seed(1234)
K_sim2 <- envelope(ppm11, Kres, nsim=99, fix.n=T)
#check fit
```

```
plot(K_sim2, lwd=3, legend='F')
```

```
#plot predicted first-order intensity of best-fitting model
plot(intensity.ppm(ppm11),
     col=gray.colors(10, start = 0.3, end = 0.9, gamma = 2.2, rev =
T),
     main="", riblab="Fitted intensity")
plot(pare, pch=16, col='red', cex=0.25, add=T)
```

```
#partial residual plot for elevation
par_res <- parres(ppm11, "tot_vis")

#check fit
plot(par_res)
```

Figures and plots

```
#Nearest neighbor and L function plot
jpeg(file=here('Figures','temporary','NN_and_Lfunction.jpeg'),width =
8, height = 4,units='in',res=300)
par(mfrow=c(1,2))
hist(pare_nn, xlab="meters", breaks=8, col="grey", xlim=c(0,1500),
ylim=c(0,5), main="") #creates histogram
mtext(side=3, line=1, at=-1, adj=0, cex=1, "a)")  # creates the
textline above the figure
plot(pare_L, lwd=3, xlab="r (meters)", main="", legend=F)
mtext(side=3, line=1, at=-1, adj=0, cex=1, "b)")
par(mfrow=c(1,1))
dev.off()
```

Code for Figure 3.4

```
#plot relative distributions
jpeg(file=here('Figures','temporary','relative_distributions.jpeg'),wi
dth = 8, height = 8,units='in',res=300)
par(mfrow=c(2,2))
plot(elev_rh, legend=F, xlab=("Elevation ASL"), main="",
xlim=c(0,500), lwd=3)
mtext(side=3, line=1, at=0, adj=0, cex=0.9, "a)")
plot(slope_rh, legend=F, xlab=("Slope (rad)"), main="", xlim=c(0,1.2),
lwd=3)
mtext(side=3, line=1, at=0, adj=0, cex=0.9, "b)")
plot(tot_vis_rh, legend=F, xlab=("Visibility"), main="", lwd=3)
mtext(side=3, line=1, at=2550, adj=0, cex=0.9, "c)")
plot(ag_vis_rh, legend=F, xlab=("Ag. Visibility"), main="", lwd=3)
mtext(side=3, line=1, at=0, adj=0, cex=0.9, "d)")
```

```
par(mfrow=c(1,1))
dev.off()
```

Code to create Figure 3.6

```
#residual diagnostic plots
jpeg(file=here('Figures','temporary','Residual_diagnostics.jpeg'),widt
h = 8, height = 8,units='in',res=300)
par(mfrow=c(2,2))
plot(K_sim, lwd=3, main='', legend=F, xlab="r (meters)") #model 3
mtext(side=3, line=1, at=0, adj=0, cex=1, "a)")
plot(K_sim2, lwd=3, main='', legend=F, xlab="r (meters)") #model 7
mtext(side=3, line=1, at=0, adj=0, cex=1, "b)")
plot(par_res, legend=F, main='', xlab="Visibility")
mtext(side=3, line=1, at=0, adj=0, cex=1, "c)")
par(mar=c(2.25,2.25,2.25,2.25))
plot(intensity.ppm(ppm11),
     col=gray.colors(10, start = 0.3, end = 0.9, gamma = 2.2, rev =
T),
     main="") #riblab="Fitted intensity")
plot(pare, pch=16, col='red', cex=0.5, add=T)
mtext(side=3, line=1, at=759002, adj=0, cex=1, "d)")
par(mfrow=c(1,1))
dev.off()
```

APPENDIX B

CODE FOR THE CHAPTER 4 POINT PROCESS ANALYSIS

Load the chosen packages in R

```
#load packages
library(maptools)
library(MuMIn)
library(raster)
library(rgdal)
library(rgeos)
library(sp)
library(spatstat)
library(here)
```

Load the data from the working directory

```
pare10_points <- readOGR('.', "Pare10")
pare20_points <- readOGR('.', "Pare20")
shore_line <- readOGR('.', "shore limit")
DTM <- raster("tingrid_Copy.tif")
path_distance <- raster("euc_pd_clip.tif") #path distance cost path calculations
based on tobler time
tot_vis <- raster("5m_tot_vis2_Copy.tif")
water_distance <- raster("euc_wtr_clip.tif")
```

Convert data into formats the R packages can read

```
#convert to spatstat format
shore <- as.owin(shore_line)
pare10 <- ppp(pare10_points$POINT_X, pare10_points$POINT_Y,
window=shore)
pare20 <- ppp(pare20_points$POINT_X, pare20_points$POINT_Y,
window=shore)
elev <- as.im(DTM) #convert DTM to a pixel image
pd_costpath <- as.im(path_distance)
tot_vis <- as.im(tot_vis)
water <- as.im(water_distance)
```

Exploratory data analysis

```
#Compute nearest neighbor distances for forts
pare10_nn <- nndist(pare10)
mean(pare10_nn)   #mean=1003
median(pare10_nn)    #median=1066.6
pare20_nn <- nndist(pare20)
mean(pare20_nn)      #mean=762.9
median(pare20_nn)    #median=723.4
```

```
#Perform L function test against 39 realizations of CSR with fixed number of points
set.seed(6789)
pare10_L <- envelope(pare10, fun=Lest,  fix.n=T,nsim=39)
plot(pare10_L)
```

```
set.seed(6789) #set random seed to get reproducible result
pare20_L <- envelope(pare20, fun=Lest,  fix.n=T,nsim=39)
plot(pare20_L)
```

```
#Examine form of possible covariate effects of the sample of 10 large pare using relative
distribution (nonparametric regression (rhohat)
elev_rh10 <- rhohat(pare10, elev, confidence = 0
pd_costpath_rh10 <- rhohat(pare10, pd_costpath, confidence = 0)
tot_vis_rh10 <- rhohat(pare10, tot_vis, confidence = 0)
water_rh10 <- rhohat(pare10, water, confidence = 0)
```

```
#Examine form of possible covariate effects of the sample of 10 large pare using relative
distribution (nonparametric regression (rhohat)
elev_rh20 <- rhohat(pare20, elev, confidence = 0)
pd_costpath_rh20 <- rhohat(pare20, pd_costpath, confidence = 0)
tot_vis_rh20 <- rhohat(pare20, tot_vis, confidence = 0)
water_rh20 <- rhohat(pare20, water, confidence = 0)
```

Models of the 10 pare

```
# Beginning of point process models for 10 forts
#correction="none" so models do not calculate unobserved points outside the window,

#Strauss. range of pairwise interaction determined by looking at Kr through mean(K_sim$r) =
942  and the mean of nearest neighbor = 1003
ppm100 <- ppm(pare10, ~ 1, Strauss(1000), correction = 'none')
```

```
ppm101 <- ppm(pare10, ~ pd_costpath, Strauss(1000), correction =
'none')
ppm102 <- ppm(pare10, ~ tot_vis, Strauss(1000), correction = 'none')
ppm103 <- ppm(pare10, ~ elev, Strauss(1000), correction = 'none')
ppm104 <- ppm(pare10, ~ water, Strauss(1000), correction = 'none')
ppm105 <- ppm(pare10, ~ pd_costpath+tot_vis, Strauss(1000),
correction= 'none')
ppm106 <- ppm(pare10, ~ pd_costpath+elev, Strauss(1000), correction=
'none')
ppm107 <- ppm(pare10, ~ pd_costpath+water, Strauss(1000), correction=
'none')
ppm108 <- ppm(pare10, ~ tot_vis+elev, Strauss(1000), correction=
'none')
ppm109 <- ppm(pare10, ~ tot_vis+water, Strauss(1000), correction=
'none')
ppm110 <- ppm(pare10, ~ elev+water, Strauss(1000), correction= 'none')
ppm111 <- ppm(pare10, ~ pd_costpath+tot_vis+elev, Strauss(1000),
correction= 'none')
ppm112 <- ppm(pare10, ~ pd_costpath+tot_vis+water, Strauss(1000),
correction= 'none')
ppm113 <- ppm(pare10, ~ pd_costpath+elev+water, Strauss(1000),
correction= 'none')
ppm114 <- ppm(pare10, ~ tot_vis+elev+water, Strauss(1000), correction=
'none')
ppm115 <- ppm(pare10, ~ pd_costpath+tot_vis+elev+water, Strauss(1000),
correction= 'none')
```

Multi-model selection and validation

```
#compare Gibbs models
ppm_AICc10 <- model.sel(ppm100, ppm101, ppm102, ppm103, ppm104,
ppm105, ppm106, ppm107, ppm108, ppm109, ppm110, ppm111, ppm112,
ppm113, ppm114, ppm115, rank=AICc)
ppm_AICc10
```

```
#print results of best fitting model
summary(ppm105)
```

```
#check residual K
set.seed(1234)
K_sim10 <- envelope(ppm105, Kres, nsim=99, fix.n=T)
#check fit
plot(K_sim10, lwd=3, legend='F')
```

```
#plot predicted first-order intensity of best-fitting model as a geographic map
```

```
plot(intensity.ppm(ppm105),
     col=gray.colors(10, start = 0.3, end = 0.9, gamma = 2.2, rev =
T),
     main="", riblab="Fitted intensity")
plot(pare10, pch=16, col='red', cex=0.25, add=T)
```

```
#partial residual plot for elevation
par_res_vis10 <- parres(ppm105, "tot_vis")
#check fit
plot(par_res_vis10)

#partial residual plot for paths
par_res_pd10 <- parres(ppm105, "pd_costpath")
#check fit
plot(par_res_pd10)
```

Models for the samples of 20 fortified sites

```
#HybridModel of Strauss and Area Interaction. Hybrids are good at modeling interaction at
multiple scales (i.e. the large pare and the small forts)  hybrid <- hybrid(Strauss(1000),
AreaInter(700))

hybrid20 <- Hybrid(Strauss(1000), AreaInter(740))

ppm200 <- ppm(pare20, ~ 1, hybrid20, correction = ‘none’)
ppm201 <- ppm(pare20, ~ pd_costpath, hybrid20, correction = ‘none’)
ppm202 <- ppm(pare20, ~ tot_vis, hybrid20, correction = ‘none’)
ppm203 <- ppm(pare20, ~ elev, hybrid20, correction = ‘none’)
ppm204 <- ppm(pare20, ~ water, hybrid20, correction = ‘none’)
ppm205 <- ppm(pare20, ~ pd_costpath+tot_vis, hybrid20, correction=
‘none’)
ppm206 <- ppm(pare20, ~ pd_costpath+elev, hybrid20, correction=
‘none’)
ppm207 <- ppm(pare20, ~ pd_costpath+water, hybrid20, correction=
‘none’)
ppm208 <- ppm(pare20, ~ tot_vis+elev, hybrid20, correction= ‘none’)
ppm209 <- ppm(pare20, ~ tot_vis+water, hybrid20, correction= ‘none’)
ppm210 <- ppm(pare20, ~ elev+water, hybrid20, correction= ‘none’)
ppm211 <- ppm(pare20, ~ pd_costpath+tot_vis+elev, hybrid20,
correction= ‘none’)
ppm212 <- ppm(pare20, ~ pd_costpath+tot_vis+water, hybrid20,
correction= ‘none’)
ppm213 <- ppm(pare20, ~ pd_costpath+elev+water, hybrid20, correction=
‘none’)
```

```
ppm214 <- ppm(pare20, ~ tot_vis+elev+water, hybrid20, correction=
‘none’)
ppm215 <- ppm(pare20, ~ pd_costpath+tot_vis+elev+water, hybrid20,
correction= ‘none’)
```

Multi-model selection and validation

```
#compare Gibbs models
ppm_AICc20 <- model.sel(ppm200, ppm201, ppm202, ppm203, ppm204,
ppm205, ppm206, ppm207, ppm208, ppm209, ppm210, ppm211, ppm212,
ppm213, ppm214, ppm215,rank=AICc)
ppm_AICc20
```

```
#print results of best fitting model
summary(ppm205)
```

```
#check residual K
set.seed(1234)
K_sim20 <- envelope(ppm205, Kres, nsim=99, fix.n=T)
#check fit
plot(K_sim20, lwd=3, legend='F')
```

```
#plot predicted first-order intensity of best-fitting model
plot(intensity.ppm(ppm205),
     col=gray.colors(10, start = 0.3, end = 0.9, gamma = 2.2, rev =
T),
     main="", riblab="Fitted intensity")
plot(pare20, pch=16, col='red', cex=0.25, add=T)
```

```
#partial residual plot for visibility
par_res_vis20 <- parres(ppm205, "tot_vis")
#check fit
plot(par_res_vis20)
```

```
#partial residual plot for paths
par_res_pd20 <- parres(ppm205, "pd_costpath")
#check fit
plot(par_res_pd20)
```

Figures and plots

Figure 4.3 and 4.4

```
#Nearest neighbor and L function plots
par(mfrow=c(1,2))
hist(pare10_nn, xlab=”meters”, breaks=8, col=”grey”, xlim=c(0,1500),
ylim=c(0,5), main=””) #creates histogram
mtext(side=3, line=1, at=-1, adj=0, cex=1, “a)”)  # creates the
textline above the figure
hist(pare20_nn, xlab=”meters”, breaks=10, col=”grey”, xlim=c(0,1500),
ylim=c(0,5), main=””) #creates histogram
mtext(side=3, line=1, at=-1, adj=0, cex=1, “b)”)  # creates the
textline above the figure
par(mfrow=c(1,1))
```

```
par(mfrow=c(1,2))
plot(pare10_L, lwd=3, xlab=”r (meters)”, main=””, legend=F)
mtext(side=3, line=1, at=-1, adj=0, cex=1, “a)”)
plot(pare20_L, lwd=3, xlab=”r (meters)”, main=””, legend=F)
mtext(side=3, line=1, at=-1, adj=0, cex=1, “b)”)
par(mfrow=c(1,1))
```

Figure 4.5 and 4.6

```
#plot relative distributions of pare10
par(mfrow=c(2,2))
plot(elev_rh10, legend=F, xlab=(“Elevation ASL”), main=””,
xlim=c(0,500), lwd=3)
mtext(side=3, line=1, at=0, adj=0, cex=0.9, “a)”)
plot(water_rh10, legend=F, xlab=(“Water”), main=””, lwd=3)
mtext(side=3, line=1, at=0, adj=-10, cex=0.9, “b)”)
plot(tot_vis_rh10, legend=F, xlab=(“Visibility”), main=””, lwd=3)
mtext(side=3, line=1, at=2550, adj=0, cex=0.9, “c)”)
plot(pd_costpath_rh10, legend=F, xlab=(“Cost Path”), main=””, lwd=3)
mtext(side=3, line=1, at=0, adj=-2.5, cex=0.9, “d)”)
par(mfrow=c(1,1))
```

```
#plot relative distributions of pare20
par(mfrow=c(2,2))
plot(elev_rh20, legend=F, xlab=(“Elevation ASL”), main=””,
xlim=c(0,500), lwd=3)
mtext(side=3, line=1, at=0, adj=0, cex=0.9, “a)”)
```

```
plot(water_rh20, legend=F, xlab=(“Water”), main=””, lwd=3)
mtext(side=3, line=1, at=0, adj=-9, cex=0.9, “b)”)
plot(tot_vis_rh20, legend=F, xlab=(“Visibility”), main=””, lwd=3)
mtext(side=3, line=1, at=2550, adj=0, cex=0.9, “c)”)
plot(pd_costpath_rh20, legend=F, xlab=(“Cost Path”), main=””, lwd=3)
mtext(side=3, line=1, at=0, adj=-1.5, cex=0.9, “d)”)
par(mfrow=c(1,1))
```

```
#residual diagnostic plots
par(mfrow=c(2,2))
plot(K_sim10, lwd=3, main=’’, legend=F, xlab=”r (meters)”)
mtext(side=3, line=1, at=0, adj=0, cex=1, “a)”)
plot(K_sim20, lwd=3, main=’’, legend=F, xlab=”r (meters)”)
mtext(side=3, line=1, at=0, adj=0, cex=1, “b)”)
par(mfrow=c(1,1))
```

Figure 4.8 and 4.9

```
# Partial Residual plots for ridges and visibility
par(mfrow=c(1,2))
plot(par_res_pd10, lwd=3, xlab="r (meters)", main="", legend=F)
mtext(side=3, line=1, at=-1, adj=0, cex=1, "a)")
plot(par_res_vis10, lwd=3, xlab="r (meters)", main="", legend=F)
mtext(side=3, line=1, at=-1, adj=0, cex=1, "b)")
par(mfrow=c(1,1))


par(mfrow=c(1,2))
plot(par_res_pd20, lwd=3, xlab="r (meters)", main="", legend=F)
mtext(side=3, line=1, at=-1, adj=0, cex=1, "a)")
plot(par_res_vis20, lwd=3, xlab="r (meters)", main="", legend=F)
mtext(side=3, line=1, at=-1, adj=0, cex=1, "b)")
par(mfrow=c(1,1))
```

REFERENCES CITED

Adams, E. S., 2001. Approaches to the study of territory size and shape. *Annual Review of Ecology and Systematics*, 32(1): 277–303.

Addison, D. J., 2008. The changing role of irrigated *Colocasia esculenta* (taro) on Nuku Hiva, Marquesas Islands: From an essential element of colonization to an important risk-reduction strategy. *Asian Perspectives,* 47: 139–155.

Akaike, H., 1974. A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, 19(6): 716–723.

Allen, J., 1991. The role of agriculture in the evolution of the Pre-Contact Hawaiian state. *Asian Perspectives*, 30: 117–132.

Allen, M.S. and Kahn, J.G., 2010. Central East Polynesia: An introduction. *Archaeology in Oceania,* 45(2): 49-53.

Anderson, A., 2001. No meat on that beautiful shore: The prehistoric abandonment of subtropical Polynesian islands. *International Journal of Osteoarchaeology*, 11(1): 14–23.

Anderson, A., 2012a. Dwelling carelessly, quiet, and secure. In *Taking the High Ground*, pp. 25-46. Australian National University Press, Canberra.

Anderson, A., 2012b. The archaeology of coastal sites on Rapa Islands. In *Taking the High Ground*, pp. 47-76. Australian National University Press, Canberra.

Anderson, A, Conte, E., Smith, I., and Szabo, K., 2019. New excavations at Fa'ahia (Huahine, Society Islands) and chronologies of colonization in Central East Polynesia. *Journal of Pacific Archaeology,* 10(1): 1-14.

Anderson, A. and Kennett, D. (editors)., 2012. *Taking the High Ground: The Archaeology of Rapa, A Fortified Island in Remote East Polynesia*. Terra Australlis 37. Australian National University Press, Canberra.

Anderson, A., Kennett, D., and Conte, E., 2012a. The prehistory of Rapa Island. In *Taking the High Ground: The Archaeology of Rapa, a Fortified Island in Remote East Polynesia*, pp. 247–256. Terra Australis 37. Australian National University Press, Canberra.

Anderson, A., Kennett, D., and Conte, E., 2012b. Archaeological research on Rapa Island, French Polynesia. In *Taking the High Ground: The Archaeology of Rapa, a Fortified Island in Remote East Polynesia*, pp. 7–24. Terra Australis 37. Australia National University Press, Canberra.

Baddeley, A. E., and Turner, R. R., 2016. *Spatial Point Patterns: Methodology and Applications* with R. Chapman and Hall/CRC Press, London.

Balfour, F. R. S., 1945. ARCHIBALD MENZIES, 1754–1842, botanist, zoologist, medico and explorer. In *Proceedings of the Linnean Society of London*, 156: 170–183.

Bamforth, D. B., and Bleed, P., 1997. Technology, flaked stone technology, and risk. *Archeological Papers of the American Anthropological Association*, 7(1): 109–139.

Barton, K., 2020. MuMIn: Multi-Model Inference. R package version 1.43.17. https://CRAN.R-project.org/package=MuMIn

Bartruff, J., Kennett, D., and Winterhalder, B., 2012. Rapan agroecology and population estimates. In *Taking the High Ground: The Archaeology of Rapa, a Fortified Island in Remote East Polynesia*, pp. 235–246. Terra Australis 37. Australian National University Press, Canberra.

Bellwood, P., 1971. Fortifications and economy in prehistoric New Zealand. *Proceedings of the Prehistoric Society*, 37(1): 56–95.

Best, S., 1993. At the halls of the mountain kings. Fijian and Samoan fortifications: Comparison and analysis. *The Journal of the Polynesian Society*, 102(4): 385–447.

Bevan, A., Crema, E., Li, X., and Palmisano, A., 2013. Intensities, interactions and uncertainties: Some new approaches to archaeological distributions. In A. Bevan & M. Lake *Computational Approaches to Archaeological Spaces*, pp. 27-52, Left Coast Press.

Bivand, R., Keitt, T., Rowlingson, B., 2021. rgdal: Bindings for the 'Geospatial' Data Abstraction Library. R package version 1.5-23. https://CRAN.R-project.org/package=rgdal

Bivand, R., and Lewin-Koh, N., 2020. maptools: Tools for Handling Spatial Objects. R package version 1.0-2. https://CRAN.R-project.org/package=maptools

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

Bivand, R. and Rundel, C., 2020. rgeos: Interface to Geometry Engine - Open Source ('GEOS'). R package version 0.5-5. https://CRAN.R-project.org/package=rgeos

Bliege Bird, R. and Smith, E. A., 2005. Signaling theory, strategic interaction, and symbolic capital. *Current Anthropology*, 46: 221–248.

Boone, J. L., 1986. Parental investment and elite family structure in preindustrial states: A case study of Late Medieval-Early Modern Portuguese genealogies. *American Anthropologist*, 88(4): 859–878.

Boone, J. L., 1992. Conflict, competition and the emergence of hierarchies. *Evolutionary Ecology and Human Behavior,* pp. 301-337. Aldine de Gruyter, Hawthorne.

Boyd, R. and Richerson, P. J., 1991. Culture and cooperation. In, R.A. Hinde and J. Groebel (eds.), *Cooperation and Prosocial Behaviour*, pp. 27–48, Cambridge University Press, Cambridge.

Boyd, R., and Richerson, P. J., 2009. Culture and the evolution of human cooperation. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 364(1533): 3281–3288.

Brousse, R., and Gelugne, P., 1986. Géologie et Pétrologie de l'île de Rapa. In: Service Mixte de Contrôle Biologique (ed) *Rapa,* pp. 9–61. Direction des Centres d'Expérimentation Nucléaires, Moisdon La Riviere.

Brown, J. L., 1964. The evolution of diversity in avian territorial systems. *The Wilson Bulletin,* 76(2), 160–169.

Buck, Sir P., 1938. *Ethnology of Mangareva*. Bernice P. Bishop Museum, Honolulu.

Buck, Sir P., 1958. *Vikings of the Sunrise*. Whitcombe and Tombs Ltd., Christchurch.

Burnham, K. P., and Anderson, D. R., 2002. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*. 2nd ed. Springer, New York.

Caillot, A. C. E., 1932. *Histoire de l'isle Oparo ou Rapa*. Ernest Leroux., Paris.

Cameron, J., 2012. Cordage from Rapan archaeological sites. In *Taking the High Ground: The Archaeology of Rapa, a Fortified Island in Remote East Polynesia*, pp. 97–104. Terra Australis 37. Australian National University Press, Canberra.

Carneiro, R. L., 1970. A theory of the origin of the state. *Science,* 169: 733–738.

Carneiro, R. L., 1990. Chiefdom-level warfare as exemplified in Fiji and the Cauca Valley. In J. Hass (Ed.), *The Anthropology of War* (pp. 171–189). Cambridge University Press, Cambridge.

Carrero-Pazos, M., Bevan, A., and Lake, M. W., 2019. The spatial structure of Galician megalithic landscapes (NW iberia): A case study from the Monte Penide region. *Journal of Archaeological Science.* 108, 104968. https://doi.org/10.1016/j.jas.2019.05.004

Carrero-Pazos, M., Bustelo-Abuín, J., Barbeito-Pose, V., and Rodríguez-Rellán, C., 2020. Locational preferences and spatial arrangement in the barrow landscape of Serra do Barbanza (North-western Iberia). *Journal of Archaeological Science: Reports* 31, 102351. https://doi.org/10.1016/j.jasrep.2020.102351

Cashdan, E., 1992. Spatial organization and habitat use. In E. A. Smith and B. Winterhalder (eds.), *Evolutionary Ecology and Human Behavior,* pp. 237-266. Routledge, New York.

Cashdan, E., Barnard, A., Bicchieri, M.C., Bishop, C. A., Blundell, V., Ehrenreich, J., Guenther, M., Hamilton, A., Harpending, H. C., and Howell, N., 1983. Territoriality among human foragers: Ecological models and an application to four Bushman groups [and Comments and Reply]. *Current Anthropology*, 24(1): 47–66.

Chubb, L. J., 1927. The geology of the Austral or Tubuai Islands (southern Pacific). *Quarterly Journal of the Geological Society*, 83: 291–316.

Choi, J. K., and Bowles, S., 2007. The coevolution of parochial altruism and war. *Science,* 318: 636–640.

Davidson, J., 1987. The Paa Maaori revisited. *The Journal of the Polynesian Society*, 96(1): 7-26.

Davies, N. B. and Houston, A. I., 1981. Owners and satellites: The economics of territory defense in the pied wagtail, Motacilla alba. *The Journal of Animal Ecology*, 1981: 157–180.

Davis, D. S., DiNapoli, R. J., Sanger, M. C., and Lipo, C. P., 2020. The integration of Lidar and legacy datasets provides improved explanations for the spatial patterning of shell rings in the American southeast. *Advances in Archaeological Practice*, 8(4): 361-375.

DiNapoli, R. J., Lipo, C. P., Brosnan, T., Hunt, T. L., Hixon, S., Morrison, A. E., and Becker, M., 2019. Rapa Nui (Easter Island) monument (ahu) locations explained by freshwater sources. *PloS One,* 14(1): e0210409. https://doi.org/:10.1371/journal.pone.0210409

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

DiNapoli, R. J., Morrison, A. E., Lipo, C. P., Hunt, T. L., and 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.

Dolfini, A., Crellin, R. J., Horn, C., and Uckelmann, M., 2018. *Prehistoric Warfare and Violence: Quantitative and qualitative approaches*. Springer, New York.

Dungan, K. A., White, D., Déderix, S., Mills, B. J., and Safi, K., 2018. A total viewshed approach to local visibility in the Chaco World. *Antiquity,* 92(364): 905–921.

Durham, W. H., 1976. Resource competition and human aggression, part I: A review of primitive war. *Quarterly Review of Biology,* 51(3): 385-415.

Dyson-Hudson, R. and Smith, E. A., 1978. Human territoriality: An ecological reassessment. *American Anthropologist*, 80(1): 21–41.

Earle, T., 1978. Economic and social organization of a complex chiefdom: The Halelea district, Kaua'i, Hawaii. Anthropological Papers No. 63. University of Michigan Museum of Anthropology, Ann Arbor.

Earle, T., 1980. Prehistoric irrigation in the Hawaiian Islands: An evaluation of evolutionary significance. A*rchaeology and Physical Anthropology in Oceania*, 15: 1–28.

Edwards, E., 2003. *Archaeological survey of Ra'ivavae*. Los Osos: Easter Island Foundation.

ESRI., 2018. ArcGIS. Environmental Systems Research Institute, Redlands.

Eve, S. J. and 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.

Ferdon, E. N., 1965a. A reconnaissance survey of three fortified hilltop villages. In *Reports of the Norwegian Archaeological Expedition to Easter island and the East Pacific*. Monographs of the School of American Research and the Kon Tiki Museum, Vol. 2, pp. 9-21.

Ferdon, E. N.,1965b. A summary of Rapa Iti fortified villages. In *Reports of the Norwegian Archaeological Expedition to Easter Island and the East Pacific.* Monographs of the School of American Research and the Kon Tiki Museum, Vol. 2, pp. 69–75.

Field, J. S., 1998. Natural and constructed defenses in Fijian fortifications. *Asian Perspectives,* 37(1): 32-58.

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(1): 79–99.

Field, J. S., 2008. Explaining fortifications in Indo-Pacific prehistory. *Archaeology in Oceania,* 43(1): 1–10.

Field, J. S. and Lape, P. V., 2010. Paleoclimates and the emergence of fortifications in the tropical Pacific Islands. *Journal of Anthropological Archaeology,* 29(1): 113–124.

Fitzhugh, B. and Hunt, T. L., 1997. Introduction: Islands as laboratories: Archaeological research in comparative perspective. *Human Ecology,* 25(3): 379–383.

Fitzpatrick, S. M., Erlandson, J. M., Anderson, A., and Kirch, P. V., 2007. Straw boats and the proverbial sea: A response to “Island Archaeology: In search of a new horizon.” *Island Studies Journal,* 2(2): 229–238.

Fretwell, S.D. and Lucas, Jr. H.L., 1969. On territorial behavior and other factors influencing habitat distribution in birds. *Acta Biotheoretica*, 19: 16–36.

Giovas, C.M., Lambrides, A.B.J., Fitzpatrick, S.M., and Kataoka, O., 2017. Reconstructing prehistoric fishing zones in Palau, Micronesia using fish remains: A blind test of inter-analust correspondence. *Archaeology in Oceania*, 52(1): 45-61.

Giovas, C. M. and 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.

Glowacki, L., Wilson, M., and Wrangham, R., 2017. The evolutionary anthropology of war. *Journal of Economic Behavior & Organization*, 178: 963–982.

Gomez, J. M., Verdu, M., Gonzalez-Megias, A., and Mendez, M., 2016. The phylogenetic roots of human lethal violence. *Nature,* 538: 233–237.

Handy, E. S. C. and Handy, E. G., 1972. *Native Planters in Old Hawaii*. Bernice P. Bishop Museum, Honolulu.

Handy, E. S. C., 1923. *The Native Culture in the Marquesas*. Bernice P. Bishop Museum, Honolulu.

Handy, E. S. C., 1940. T*he Hawaiian Planter-Volume I, His Plants, Methods and Areas of Cultivation*. Bernice P. Bishop Museum, Honolulu.

Hanson, F. A., 1970. *Rapan Lifeways: Society and history on a Polynesian island*. Little, Brown and Company, Boston.

Hijmans, R. J., 2020. raster: Geographic data analysis and modeling. R package version 3.4-5. https://CRAN.R-project.org/package=raster

Hinsch, M. and Komdeur, J., 2010. Defense, intrusion and the evolutionary stability of territoriality. *Journal of Theoretical Biology,* 266(4): 606–613.

Jazwa, C. S., Kennett, D. J., and Winterhalder, B., 2016. A test of ideal free distribution predictions using targeted survey and excavation on California’s Northern Channel Islands. *Journal of Archaeological Method and Theory.* 23: 1242-1284

Keeley, L. H., 1996. *War Before Civilization: The Myth of the Peaceful Savage*. Oxford University Press, Oxford.

Keeley, L. H., Fontana, M., and Quick, R., 2007. Baffles and bastions: The universal features of fortifications. *Journal of Archaeological Research,* 15(1), 55–95.

Kennett, D., Anderson, A., Prebble, M., Conte, E., and Southon, J., 2006. Prehistoric human impacts on Rapa, French Polynesia. *Antiquity,* 80(308): 340-354.

Kennett, D., Culleton, B. J., Anderson, A., and Southon, J., 2012. A Bayesian AMS 14C chronology for the colonization and fortification of Rapa Island. In *Taking the High Ground: The archaeology of Rapa, a fortified island in remote East Polynesia,* pp. 189–202. Terra Australis 37. Australian National University Press, Canberra.

Kennett, D., Anderson, A., and Winterhalder, B., 2006. The ideal free distribution, food production, and the colonization of Oceania. In D. J. Kennet and B. Winterhalder (eds), *Behavioral Ecology and the Transition to Agriculture*, pp. 265–288, University of California Press, Berkeley.

Kennett, D. and McClure, S. B., 2012. The archaeology of Rapan fortifications. In *Taking the High Ground: The archaeology of Rapa, a fortified island in remote East Polynesia*, pp. 203–234. Terra Australis 37. Australian National University Press, Canberra.

Kennett, D. J. and Kennett, J. P., 2000. Competitive and cooperative responses to climatic instability in coastal Southern California. *American Antiquity,* 65(2): 379–395.

Kennett, D. J. and Winterhalder, B., 2008. Demographic expansion, despotism and the colonization of East and South Polynesia. In G. Clark, F. Leach, and S. O'Connor (eds.) *Islands of Inquiry: Colonisation, Seafaring and the Archaeology of Maritime Landscapes,* pp. 87-96, Australia National University Press, Canberra.

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., and Zeder, M. A., 2014. Grand challenges for archaeology. *American Antiquity,* 79: 5–24.

Kirch, P. V., 1977. Valley agricultural systems in prehistoric Hawaii: An archaeological consideration. *Asian Perspectives,* 20: 246–280.

Kirch, P. V., 1989. *The Evolution of the Polynesian Chiefdoms*. Cambridge University Press, Cambridge.

Kirch, P. V., 1994. *The Wet and The Dry: Irrigation and Agricultural Intensification in Polynesia*. The University of Chicago Press, Chicago.

Kirch, P. V., 1997. Microcosmic histories: Island perspectives on "global" change. *American Anthropologist,* 99: 30–42.

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.

Kirch, P. V., 2010. *How Chiefs Became Kings: Divine Kingship and the Rise of Archaic States in Ancient Hawai'i.* University of California Press, Berkeley.

Kolb, M. J. and Dixon, B., 2002. Landscapes of war: Rules and conventions of conflict in ancient Hawai'i (and elsewhere). *American Antiquity*, 67(3): 514–534.

Kurashima, N. and Kirch, P. V., 2011. Geospatial modeling of pre-contact Hawaiian production systems on Moloka'i island, Hawaiian Islands. *Journal of Archaeological Science*, 38(12): 3662–3674.

Ladefoged, T. N., Graves, M. W., and McCoy, M. D., 2003. Archaeological evidence for agricultural development in Kohala, island of Hawai'i. *Journal of Archaeological Science,* 30(7): 923–940.

Ladefoged, T. N., Kirch, P.V., Gon III, S.M., Chadwick, O.A., Hartshorn, A.S., and Vitousek, P.M., 2009. Opportunities and constraints for intensive agriculture in the Hawaiian Archipelago prior to European contact. *Journal of Archaeological Science,* 36(10): 2374–2383.

Lane, B. G., 2017. Geospatial modelling for predicting the ideal free settlement of Rapa. *Archaeology in Oceania*, 52(1): 13–21.

Lane, B. and DiNapoli, R., 2015. *The view from Rapa: Behavioral ecology and fortifications in Polynesia*. Paper presented at the annual Society for American Archaeology meeting, San Francisco.

Lape, P. V., 2006. Chronology of fortified settlements in East Timor. *The Journal of Island and Coastal Archaeology*, 1(2): 285-297.

Levins, R., 1966. The strategy of model building in population biology. *American Scientist,* 54: 421-431.

Llobera, M., 2003. Extending GIS-based visual analysis: The concept of visualscapes. *International Journal of Geographical Information Science,* 17(1): 25–48.

Make, A., Ghasarian, C., and Tematahotoa-Oitokaia, R., 2008. *Légendes de Rapa iti*. Au vent des îles.

Map Aspects., 2009. Cost-Distance 2009: Cost-Distance Analysis. http://mapaspects.org/node/3744/ , accessed March 12, 2021.

Martindale, A. and Supernant, K., 2009. Quantifying the defensiveness of defended sites on the Northwest Coast of North America. *Journal of Anthropological Archaeology*, 28(2): 191-204.

McCoy, M. D., 2017. Geospatial big data and archaeology: Prospects and problems too great to ignore. *Journal of Archaeological Science,* 84: 74-94.

McCoy, M. D. and 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*:* 101-113.

McCoy, M. D., Ladefoged, T. N., Codlin, M., and Sutton, D. G., 2014. Does Carneiro's circumscription theory help us understand Maori history? An analysis of the obsidian assemblage from Pouerua Pa, New Zealand (Aotearoa). *Journal of Archaeological Science*, 42: 467-475.

McElroy, W. K., 2007. The Development of Irrigated Agriculture in Wailau Valley, Moloka’i Island, Hawai’i. Unpublished PhD thesis, University of Hawaii, Honolulu.

Moss, M. L. & Erlandson, J. M., 1992. Forts, refuge rocks, and defensive sites: The antiquity of warfare along the North Pacific Coast of North America. *Arctic Anthropology*, 29(2): 73-90.

Müller, J. G., Ogneva-Himmelberger, Y., Lloyd, S., and Reed, J. M., 2010. Predicting prehistoric taro (*Colocasia esculenta* var. *antiquorum*) lo’i distribution in Hawaii. *Economic botany,* 64(1): 22–33.

Müller, K., 2020. here: A simpler way to find your files. R package version 1.0.1. https://CRAN.R-project.org/package=here

Mulloy, W., 1965. The fortified village of Morongo Uta. *Reports of the Norwegian Archaeological Expedition to Easter Island and the East Pacific* Monographs of the School of American Research and the Kon Tiki Museum, Vol. 2, pp. 23-61.

Newbury, C. W., 2011. *History of the Tahitian Mission, 1799-1830, Written by John Davies, Missionary to the South Sea Islands*. Hakluyt Society, London.

Neiman, F., 1997. Conspicuous Consumption as Wasteful Advertising: A Darwinian Perspective on Spatial Patterns in Classic Maya Terminal Monument Dates. *Archaeological Papers of the American Anthropological Association,* 7(1): 267–290.

O'Connor, J. T., White, F. J., and Hunt, T. L., 2017. Fishhook variability and cultural transmission in East Polynesia. *Archaeology in Oceania*, 52(1):32-44.

O'Connor, S., McWilliam, A., Brockwell, S. (Eds.)., 2020. F*orts and Fortification in Wallacea: Archaeological and Ethnohistoric Investigations*. Terra Australis Vol. 53. Australia National University Press, Canberra.

O'Sullivan, D. and Perry, G. L., 2013. *Spatial Simulation: Exploring Pattern and Process*. Wiley-Blackwell, USA.

Onwueme, I., 1999. *Taro Cultivation in Asia and the Pacific*. Food and Agriculture Organization of the United Nations Regional office for Asian and the Pacific, Bangkok.

Palmer, M. A., Graves, M., Ladefoged, T. N., Chadwick, O. A., Ka'eo Duarte, T., Porder, S., and Vitousek, P. M., 2009. Sources of nutrients to windward agricultural systems in pre-contact Hawai'i. *Ecological Applications,* 19: 1444–1453.

Parkinson, W. A. and Duffy, P. R., 2007. Fortifications and enclosures in European prehistory: A cross-cultural perspective. *Journal of Archaeological Research,* 15(2): 97-141.

Pebesma, E. J. and Bivand, R. S., 2005. Classes and methods for spatial data in R. R News 5 (2), https://cran.r-project.org/doc/Rnews/.

Prebble, M., 2008. No fruit on that beautiful shore: What plants were introduced to the subtropical Polynesian islands prior to European contact? In G. Clark, F. Leach, and S. O'Connor (eds.) *Islands of inquiry: Colonisation, seafaring and the archaeology of maritime landscapes,* pp. 227-251. Australia National University Press, Canberra.

Prebble, M., Anderson, A., and Kennett, D., 2013. Forest clearance and agricultural expansion on Rapa, Austral Archipelago, French Polynesia. *The Holocene,* 23(2): 179-196

Prebble, M. and Anderson, A., 2012a. The Archaeobotany of Rapan Rockshelter Deposits. In *Taking the High Ground: The archaeology of Rapa, a fortified island in remote East Polynesia,* pp. 77–96. Terra Australis 37. Australian National University Press, Canberra.

Prebble, M. and Anderson, A., 2012b. Palaeobotany and the Early Development of Agriculture on Rapa Island. In *Taking the High Ground: The archaeology of Rapa, a fortified island in remote East Polynesia*, pp. 167–188. Australian National University Press, Canberra.

Prebble, M., Anderson, A., Augustinus, P., Emmitt, J., Fallon, S. J., Furey, L. L., Holdaway, S. J., Jorgensen, A., Ladefoged, T. N., Matthews, P. J., Meyer, J., Phillipps, R., Wallace, R., and Porch, N., 2019. Early tropical crop production in marginal subtropical and temperate Polynesia. *Proceedings of the National Academy of Science*, 116(18): 8824-8833.

R Core Team, 2020. R: A language and environment for statistical computing. R Foundation for statistical computing, Vienna, Austria. https://www.R-project.org/.

Rieth, T. M. and Morrison, A. E., 2017. Pre-contact fish choice and foraging efficiency at Tula, American Samoa. *Archaeology in Oceania*, 52(1): 22-31.

Rieth, T. M., Morrison, A. E., and Addison, D. J., 2008. The temporal and spatial patterning of the initial settlement of Sāmoa. *The Journal of Island and Coastal Archaeology,* 3(2): 214–239.

Riris, P., 2020. Spatial structure among the geometric earthworks of western Amazonia (Acre, Brazil). *Journal of Anthropological Archaeology,* 59: 101177. https://doi.org/10.1016/j.jaa.2020.101177

Roscoe, P., 2008. Settlement fortification in village and 'tribal' society: Evidence from contact-era New Guinea**,** *Journal of Anthropological Archaeology*, 27: 507-519.

Routledge, S. and Routledge, K., 1921. Notes on some archaeological remains in the society and Austral Islands. *The Journal of the Royal Anthropological Institute of Great Britain and Ireland,* 51: 438–455.

Scarborough, V. L., 2003. *The Flow of Power: Ancient Water Systems and Landscapes*. School of American Research, Santa Fe.

Scherer, A. K. and Golden, C., 2009. Tecolote, Guatemala: Archaeological evidence for a fortified Late Classic Maya political border. *Journal of Field Archaeology,* 34: 285-305.

Shineberg, D., 1986. Archibald Menzies' account of the visit of the Discovery to Rapa and Tahiti, 22 December 1791-25 January 1792. *Pacific Studies*, 9(2): 59–102.

Smith, C. S., 1965a. Test excavations and surveys of miscellaneous sites on the island of Rapa Iti. *Reports of the Norwegian Archaeological Expedition to Easter Island and the East Pacific*. Monographs of the School of American Research and the Kon-Tiki Museum, Vol 2, pp. 77-87.

Smith, C. S., 1965b. The burial complex on the island of Rapa Iti. *Reports of the Norwegian Archaeological Expedition to Easter Island and the East Pacific.* Monographs of the School of American Research and the Kon-Tiki Museum, Vol. 2, pp. 89–95.

Smith, C. and Cochrane, E. E., 2011. How is visibility important for defense? A GIS analysis of sites in the western Fijian Islands. *Archaeology in Oceania,* 46(2): 76–84.

Spencer, C. S. and Redmond, E. M., 2001. Multilevel selection and political evolution in the valley of Oaxaca, 500–100 BC. *Journal of Anthropological Archaeology,* 20(2): 195–229.

Spriggs, M., 1984. Taro irrigation techniques in the Pacific. In S. Chandra (ed) *Edible Aroids*, pp. 123-135. Clarendon, Oxford.

Spriggs, M., 1990. Why irrigation matters in Pacific prehistory. In: D. Yen and J. M. J. Mummery (eds.) *Pacific Production Systems*, pp. 174–189. Australia National University Press, Canberra.

Stokes, J. F. G., n.d. *Ethnology of Rapa Island*. Manuscript on file at the Bishop Museum, Honolulu.

Stokes, J. F. G., 2021. *Ethnologie de l'ile de Rapa 1921* (C. Ghasarian, Trans.). Api Tahiti, Papeete.

Suggs, R. C., 1961. The archaeology of Nuku Hiva, Marquesas Islands, French Polynesia. *Anthropological Papers of the American Museum of Natural History,* Vol 49, Part 1.

Surface-Evans, S. L. and White, D. A., 2012. An introduction to the least cost analysis of social landscapes. *Least Cost Analysis of Social Landscape: Archaeological Case Studies.* pp. 1-7, The University of Utah Press, Salt Lake City.

Sutherland, W. J., 1983. Aggregation and the ideal free distribution. *Journal of Animal Ecology*, 52: 821–828.

Sutherland, W. J., 1985. Distribution of unequal competitors. In R. M. Sibly and R. H. Smith (eds.) *Behavioral Ecology: Ecological Consequences of Adaptive Behavior*, pp. 255-274. Blackwell Scientific, Oxford.

Sutherland, W. J., 1996. *From Individual Behavior to Population Ecology.* Oxford Series in Ecology and Evolution from Individual Behavior to Population Ecology. Oxford University press, Oxford.

Szabo, K. A. and Anderson, A., 2012. The Tangarutu invertebrate fauna. In *Taking the High Ground: The archaeology of Rapa, a fortified island in remote East Polynesia*, pp. 135–144. Terra Australis 37. Australian National University Press, Canberra.

Szabo, K. A., Vogel, Y., and Anderson, A., 2012. Marine Resource Exploitation on Rapa Island: Archaeology, material culture and ethnography. In *Taking the High Ground: The archaeology of Rapa, a fortified island in remote East Polynesia,* pp. 145–166. Terra Australis 37. Australian National University Press, Canberra.

Tennyson, A. J. D. and Anderson, A., 2012. Bird, reptile, and mammal remains from archaeological sites on Rapa Island. In *Taking the High Ground: The archaeology of Rapa, a fortified island in remote East Polynesia,* pp. 105–114. Terra Australis 37. Australian National University Press, Canberra.

Trichet, J., Jamet, R., and Gautheyrou, J., 1986. Reconnaissance des sols et des altérations de L'Ile de Rapa. In: Service Mixte de Contrôle Biologique (ed) *Rapa*, pp. 75-101. Direction des Centres d'Expérimentation Nucléaires, Moisdon La Riviere.

Turchin, P., Currie, T. E., Turner, E. A. L., and Gavrilets, S., 2013. War, space, and the evolution of Old World complex societies. *Proceedings of the National Academy of Science*, 110: 16384–16389.

Vancouver, G., 1798. *Voyage of discovery to the North Pacific Ocean and round the world*. J. Vancouver (ed). Vol. 1. G. G. and J. Robinson, London.

Vogel, Y. and Anderson, A., 2012. Prehistoric fishing on Rapa Island. In *Taking the High Ground: The archaeology of Rapa, a fortified island in remote East Polynesia*, pp. 115–134. Terra Australis 37. Australian National University Press, Canberra.

Walczak, J., 2003a. *Le peuplement de la Polynésie orientale. Une tentative d'approche historique par les exemples de Tahiti et de Rapa (Polynésie francaise)* [Unpublished PhD Dissertation]. Universite Paris I-Pantheon Sorbonne.

Walczak, J.,2003b. Presentation des données actuelles sur la préhistoire de Rapa Iti (archiple des Australes-Polynésie Française). In *Archeologie en Oceanie Insulaire: Peuplement, Societes et Paysages*, pp. 28–45. Editions Artcom, Paris.

Walworth, M., 2015. *The Language of Rapa Iti: Description of a Language in Change*. Unpublished PhD Dissertation. University of Hawai'i at Manoa.

Walworth, M., 2017. Classifying old Rapa: Linguistic evidence for contact networks in Southeast Polynesia. *Issues in Austronesian Historical Linguistics, Special publication 1*, pp.102–122.

Wheatley, D., 1995. Cumulative viewshed analysis: A GIS-based method for investigating intervisibility, and its archaeological application. In G. R. Lock and Z. Stancic (eds.) *Archaeology and Geographical Information Systems: A European Perspective*, pp. 171–185. Taylor and Francis, London.

White, D. A., 2015. The basics of least cost analysis for archaeological applications. *Advances in Archaeological Practice*, 3(4): 407–414.

Willems, E. P. and van Schaik, C. P., 2015. Collective action and the intensity of between-group competition in nonhuman primates. *Behavioral Ecology*, 26(2): 625–631.

Wilmshurst, J. M., Hunt, T. L., Lipo, C. P., and Anderson, A. J., 2011. High-precision radiocarbon dating shows recent and rapid initial human colonization of East Polynesia. *Proceedings of the National Academy of Sciences*, 108(5): 1815–1820.

Wilson, D. S. and Sober, E., 1994. Reintroducing group selection to the human behavioral sciences. *Behavioral and Brain Sciences* 17(4): 585–607.

Wilson, D. S. and Wilson, E. O., 2007. Rethinking the theoretical foundation of sociobiology. *The Quarterly Review of Biology,* 82(4): 327–348.

Winterhalder, B., Kennett, D., Grote, M., and Bartruff, J., 2010. Ideal free settlement of California's Northern Channel Islands. *Journal of Anthropological Archaeology,* 29: 469–490.

Winterhalder, B. and Smith, E.A., 1992. Evolutionary ecology and the social sciences. In E.A. Smith and B. Winterhalder (eds.) *Evolutionary Ecology and Human Behavior*, pp. 3-24. Aldine De Gruyter, New York.

Winterhalder, B. and Smith, E.A., 2000. Analyzing adaptive strategies: Human behavioral ecology at twenty-five. *Evolutionary Anthropology,* 9: 51-72.

Zahavi, A. and Zahavi, A., 1997. *The Handicap Principle: A missing Piece of Darwin's Puzzle*. Oxford University Press, Oxford.

Zefferman, M.R. and Mathew, S., 2015. An evolutionary theory of large-scale human warfare: Group-structured cultural selection. *Evolutionary Anthropology*, 24: 50–61.