

THE EVOLUTION OF SOCIAL HIERARCHY IN LEEWARD
KOHALA, ISLAND OF HAWAI‘I:
AN EVOLUTIONARY ECOLOGICAL APPROACH

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By

Robert J. DiNapoli

Thesis committee:

Terry L. Hunt (Chairperson)

Christian E. Peterson

Alexander E. Morrison

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Chapter 1: Introduction

“Any comprehensive explanation of human behavior requires evolutionary forces”

– Winterhalder and Smith (1992:4)

Among the prehistoric island societies of Polynesia, those of the Hawaiian Islands have long been singled out as a locus for the evolution of complex hierarchical polities (e.g., Johnson and Earle 2000; Kirch 1984; Sahlins 1958; Service 1971). At the time of European contact in 1778, Hawaiian society was divided into two distinct social ranks: a small hereditary elite and a large class of commoners (Ii 1959; Kamakau 1991; Malo 1987). This stratified social organization was characterized by marked differences between commoners and elites, especially in terms of elite control over land and resources. This hierarchical social organization was further differentiated within the elite class, with several ranks of chiefs (*ali‘i*), priests (*kahuna*), and land-managers (*konoiki*). Hawaiian social hierarchy was also mirrored in their tiered territorial land division (*ahupua‘a*) system and ritual architecture (*heiau*). In this way, Hawai‘i is distinct among ancient Polynesian societies (Kirch 2010; Hommon 2013).

The existence of this hierarchical social organization begs an important evolutionary question: why would such a large proportion of a social group accept such a marked lower status position in society? For prehistoric Hawai‘i, this specifically translates into questions surrounding what led to the evolution of multiple ranks of *ali‘i*, the existence of

the *konohiki* land-managers, and why such a large group of people, the *maka āinana* (commoners), would accept their subordinate role in society. Research on Hawaiian social organization has tended to emphasize the coercive powers of chiefs in bringing about social change (e.g., Earle 1997; Hommon 2013; Kirch 2010b). However, while not often appreciated in Hawaiian archaeology, such social hierarchies always involve a complicated interplay of both coercion, competition, and *cooperation* (Boone 1992; Bourke 2011). Because the level of social hierarchy seen in prehistoric Hawai‘i was unique in Polynesia, this leads us to ask – what environmental circumstances and evolutionary mechanisms led to the emergence of cooperative hierarchical groups in ancient Hawai‘i? Exploring answers to this question is the topic of this thesis.

Many scholars, anthropologists, and archaeologists have devoted much discussion and research to the topic of Hawaiian social evolution (e.g., Earle 1978, 1997; Hommon 1976, 2013; Kirch 1984, 2010b; Sahlins 1958; Service 1971). Studies of social evolution in prehistoric Hawai‘i have been predominantly focused on explaining the evolution of so-called “complex societies,” such as chiefdoms or states. These studies are often couched, whether explicitly or not, within the traditional cultural- or neo-evolutionary framework, typified by a social evolutionary trajectory from “simple” to “complex” social groups. Within this neo-evolutionary framework, Hawaiian society is often seen as transforming from a simple chiefdom-level society into to a complex chiefdom or an archaic state (e.g., Earle 1997; Field et al. 2011a; Hommon 1976, 2013; Kirch 1984, 2010b, 2012).

Despite its regularity of use and influence, the longstanding neo-evolutionary paradigm has failed to sufficiently explore the evolutionary ecological roots of social

hierarchy in prehistoric Hawai‘i. Explanations given for the emergence of complex chiefdoms or states in prehistoric Hawai‘i are wide ranging, but often focus on population growth and expansion, agricultural intensification, the political economy, warfare, surplus production, institutionalized ritual control, and, especially, the political agency of ambitious elites (e.g., Earle 1978, 1997; Hommon 1976, 2013; Kirch 1984, 2010b, 2012). These phenomena are seen as hallmarks of complex societies around the world and are often taken as important causes of their emergence. While inequality, leadership, and social hierarchy are almost always emphasized in discussions of increasing social complexity in Hawai‘i, these social phenomena are either assumed to already exist in an elaborated form or are taken for granted as a natural outcome of the previously listed hallmark characteristics of complex societies. Consequently, an explicit focus on the evolution of social hierarchy itself has been neglected.

This lack of explicit attention to the formation of social hierarchies in prehistoric Hawai‘i is problematic for several reasons. First, this present gap in our knowledge means that one of the most characteristic aspects of Hawaiian society, and that which distinguishes it among Polynesian groups, is not clearly understood. Second, and most importantly, Hawai‘i is often used as a model system for exploring the evolutionary and ecological influences on human societies (e.g., Kirch 2007, 2010a; Kirch et al. 2007; Kirch et al. 2012), but research on the formation of social hierarchies in Hawai‘i has mostly neglected the use of formal evolutionary ecological models of social evolution.

This thesis complements previous research by investigating the evolution of social hierarchy in prehistoric Hawai‘i using Darwinian evolutionary ecology (Davies et al. 2012; Nettle et al. 2013; Pianka 1999; Smith and Winterhalder 1992a; Winterhalder and

Smith 2000). Evolutionary ecology is the theoretical framework devoted to the study of adaptive phenotypic, especially behavioral, evolution under a variety of biotic and abiotic constraints (Pianka 1999). The foundational assumption used in evolutionary ecological analysis is that natural selection has favored individual phenotypes which respond in fitness optimizing ways in different environments. From an evolutionary ecological perspective, then, human social groups do not inherently progress towards greater and greater complexity, but those that do become more complex do so according to particular evolutionary mechanisms operating under certain environmental conditions (Barton 2013; Bernabeu Aubán et al. 2012:24). This tenet of evolutionary ecology allows for the construction of simple formalistic models which can then be used to measure change and derive predictions about the archaeological record (Bird and O'Connell 2006; Boone and Smith 1998; Broughton and O'Connell 1999; Shennan 2008). These models become a powerful tool in archaeological analysis because they are rooted in clearly stated formalized arguments that determine what set of processes likely explain the phenomena of interest (McElreath and Boyd 2007:6), whether it be human adaptation to the physical environment or strategic interaction in large hierarchical social groups.

Most simply, a social hierarchy is defined as a social structure composed of two or more ranked classes of individuals (Earley and Dugatkin 2010). The important evolutionary characteristics of human social hierarchies of interest here are their level of social inequality, multiple ranked classes (i.e., rank differentiation), and their level of cooperation. The first issue, social inequality, is often approached in evolutionary ecology with reference to *despotism*, which refers to a bias or skew in the control of resources and mates by a small number of individuals within a social group (Kennett

2005; Kennett et al. 2009; Summers 2005; Vehrencamp 1983b). Despotism often occurs in environments with persistent competition for unevenly distributed high-quality resources, resulting in a skew of resources toward those in control (Fretwell 1972; Fretwell and Lucas 1969; Sutherland 1996; Vehrencamp 1983b). Under certain environmental circumstances, such as in risky or uncertain environments, individuals in lower status positions would often do better to stay within the despotic group and accept their subordinate position rather than compete or attempt to emigrate (Boone 1992; Hamilton 2000; Krause and Ruxton 2002; Smith 1981; Vehrencamp 1983a). However, the maintenance of these large despotic groups, such as those seen in prehistoric Hawai‘i, requires cooperation on a large scale (Boyd and Richerson 1988), which often necessitates the evolution of ranking and special-interest leadership positions to enforce cooperation (Boone 1992; Boyd and Richerson 1992; Hooper et al. 2010; Smith and Choi 2007). The formation of these hierarchical groups is then exacerbated when there is a high degree of despotism and when the benefits to cooperation are large (Boone 1992; Hooper et al. 2010).

In the case of human social hierarchies, then, the evolutionary ecological mechanisms of greatest influence involve both competitive and cooperative behavioral strategies (Boone 1992; Bourke 2011). Following from this theoretical framework – the research objective of this study is to investigate the following question: what were the evolutionary ecological influences on the emergence of social hierarchy in prehistoric Hawai‘i?

Here, cooperative and competitive influences on social hierarchy formation are explored using both optimality models and evolutionary game theory, focusing on

individuals' strategic interaction with their environment and with other individuals (Krebs and McCleery 1984; Maynard Smith 1978, 1982; Maynard Smith and Price 1973; Smith and Winterhalder 1992b). Exploring the evolutionary and ecological conditions under which despotic groups form involves the investigation of the spatiotemporal patterning of resources, as these patterns greatly influence social organization and social inequality (Cashdan 1992). The argument put forth in this thesis is that despotism first evolved in Hawai'i as a result of an uneven distribution and control of high-quality economically defensible resources. Following the emergence of despotism, social hierarchy evolved as a form of population density-dependent cooperation resulting from an uneven spatial distribution between economically defensible and highly risk-prone and uncertain habitats (Boone 1992; Hooper et al. 2010).

Rather than approach the problem of Hawaiian social hierarchy on an archipelago wide-scale, the issue of social hierarchy formation in prehistoric Hawai'i is addressed using a specific case study. A single study area allows for the benefits of using a simple explanatory model, namely a clear set of predictions and criteria to evaluate them, as well as a manageable dataset. Here, the focus is on the Leeward Kohala Field System (LKFS), a large dryland agricultural complex in the North Kohala district in northwest Hawai'i Island (Figure 1.1.). The leeward Kohala area was settled relatively early in Hawaiian prehistory and the archaeological record of the region suggests continuous occupation until European contact in the 19th century (Ladefoged and Graves 2008; Rieth et al. 2011). This continuous occupation for nearly the whole of Hawaiian prehistory makes leeward Kohala an ideal place to evaluate long-term social change. In

addition to the archaeological record, leeward Kohala is notable for being home of some of the most hierarchical groups in Hawai'i (Ladefoged and Graves 2010).

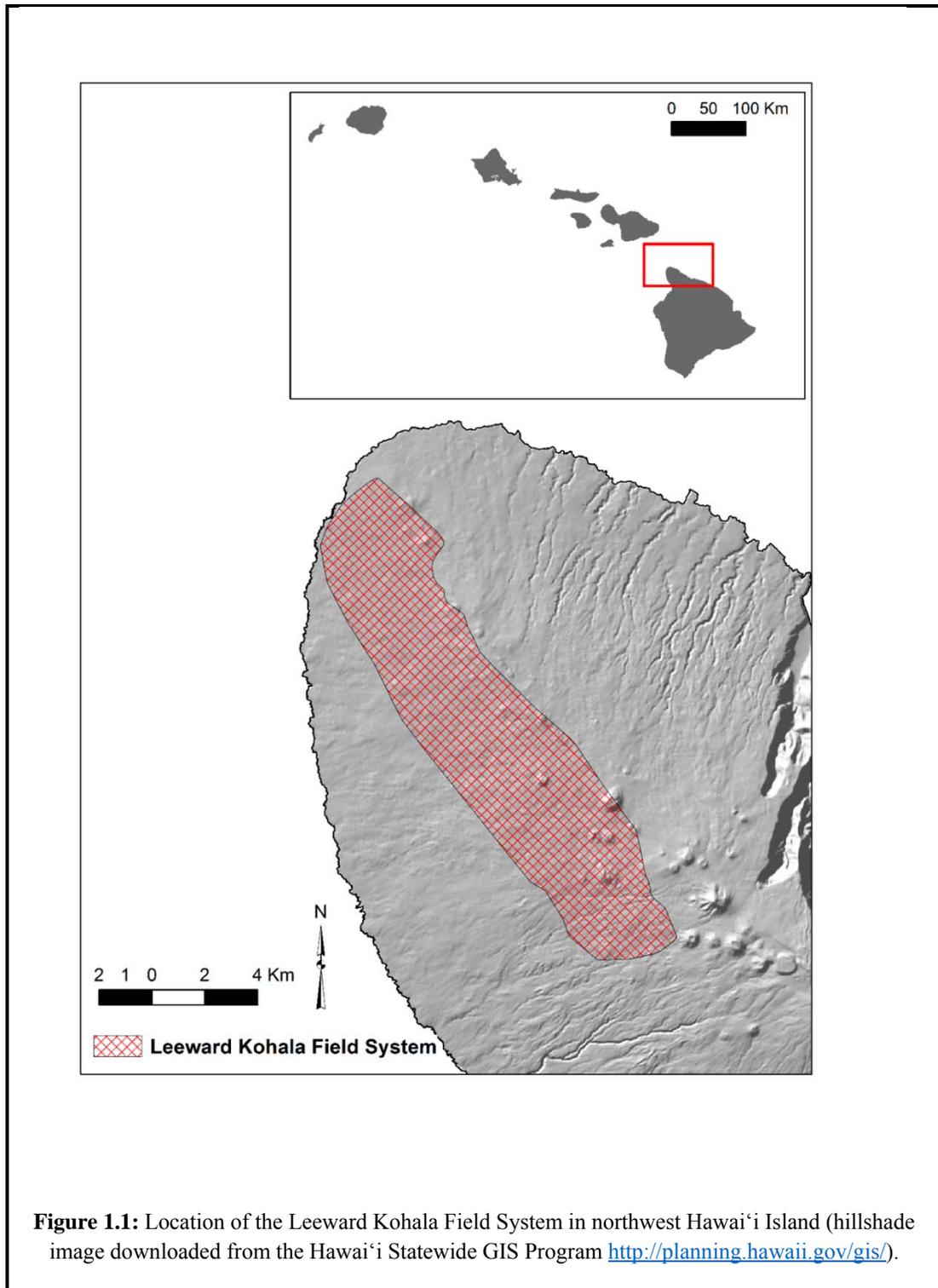


Figure 1.1: Location of the Leeward Kohala Field System in northwest Hawai'i Island (hillshade image downloaded from the Hawai'i Statewide GIS Program <http://planning.hawaii.gov/gis/>).

Over the past several decades, much archaeological research and analytical work has occurred in leeward Kohala (e.g., Field et al. 2010; Field et al. 2011a; Field et al. 2011b; Kirch 1984; Kirch et al. 2012; Ladefoged et al. 1996; Ladefoged and Graves 2000, 2008; Ladefoged et al. 2003; Ladefoged et al. 2008; Ladefoged et al. 2011; Rosendahl 1972, 1994). These previous studies provide a large source of data and information from which to build further explanations of social change in the area. Previous research has focused on establishing both relative and absolute chronologies for the region, patterns of field system expansion and intensification, the proliferation of religious complexes and habitations, and especially the dynamics of agriculture in the field system. This thesis builds on and complements this previous research through the reinterpretation of published data within an explicit evolutionary ecological model of social hierarchy formation and also the addition of new data and analyses on the risks and unpredictability of agriculture within the field system.

1.1. Organization of chapters

In Chapter 2, the nature of Hawaiian social organization at European contact is discussed. While a full treatment of Hawaiian society is beyond the scope of this chapter, a discussion of the nature of the social hierarchy is essential to understanding its evolution. Of particular interest is the nested hierarchical social organization of commoners, land-managers, and chiefs, and especially the marked differences in social

inequality and differences in resource control between these groups. Descriptions of Hawaiian society at European contact also portray a complex organizational hierarchy of land divisions mentioned previously. The information in this section of Chapter 2 is derived from the accounts of native Hawaiian ethnohistorians writing during the 19th century, namely Samuel Kamakau (1991, 1992a, 1992b), David Malo (1987), and John Papa I'i (1959).

Following this characterization of prehistoric Hawaiian social organization, the focus of Chapter 2 shifts to the ways that archaeologists and anthropologists have traditionally approached the issue of Hawaiian social complexity. The main ideas and arguments relating to the evolution of Hawaiian social complexity are reviewed. Rather than attempt a lengthy critique of these previous approaches, Chapter 2 concludes with a discussion of how an evolutionary ecological approach can greatly complement and improve upon previous research.

While the quantity of literature on Hawaiian social complexity is great, few explanations have been rooted in scientific evolutionary theory, and those that have been set in a Darwinian evolutionary framework have rarely laid out an explicit and complete model with clear predictions for the archaeological record (e.g., Cachola-Abad 2000; Graves et al. 2010; Ladefoged and Graves 2000). The present argument is not that the particular approach adopted here is an alternative to previous scholarship on Hawaiian social hierarchy – but rather that an evolutionary ecological model which explains the ultimate underlying influences in Hawaiian social evolution serves to complement existing neo-evolutionary explanations.

Chapter 3 presents a formal Darwinian model for the explanation of social hierarchy formation. Rather than attempt a comprehensive review of the evolution of hierarchical versus egalitarian societies, Chapter 3 presents a series of models that together account for the evolution and maintenance of social hierarchies. Following the explication of these models, a discrete set of archaeological predictions are made for the archaeological record of leeward Kohala.

Chapter 4 presents the case study where I evaluate the model – the Leeward Kohala Field System (LKFS) (Figure 1.1.). This chapter begins with brief review of relevant research on the LKFS. Using information from previous studies, the data for the LKFS are reevaluated in relation to the first set of predictions of the evolutionary ecological model presented in Chapter 3. As will be shown, the necessary components for the evaluation of whether leeward Kohala experienced marked spatial differences in risky and unpredictable resource shortages has not yet been sufficiently evaluated.

In Chapter 5 I evaluate whether the LKFS experienced risky and uncertainty temporal fluctuations in resources. While much archaeological modeling has been conducted on the LKFS (e.g., Lee et al. 2006; Ladefoged et al. 2008; Ladefoged et al. 2011), this research has mostly focused on variability in agricultural intensification and the ability of the field system to produce surplus. Little research has been devoted to characterizing the spatiotemporal occurrence of risky and uncertain drought events in leeward Kohala. Here, the topic of risk and uncertainty is explored using a geostatistical model of spatiotemporal rainfall variation with a particular focus on the occurrence of droughts. The geostatistical model is parameterized based on the critical annual rainfall requirements of sweet potato (*Ipomea batatas*), the primary crop grown in the field

system (Ladefoged and Graves 2010). Following the geostatistical modeling of risk from droughts, the topic of *uncertainty* is explored using time-series spectral analysis to determine whether rainfall variation in leeward Kohala would have been predictable on a human timescale, which would have important implications for various coping mechanisms and adaptive strategies.

Chapter 6 concludes with a brief summary and synthesis of the previous chapters, particularly the evolutionary ecology model of institutional social hierarchy formation and its predictions in light of the data presented in Chapters 4 and 5. Following this synthesis, the major weaknesses of this study are discussed and areas for future research are explored.

Chapter 2:

Hawaiian Social Organization at European Contact and Previous Explanations for the Emergence of Social Hierarchies

“The ma-ka-aina-na were the fixed residents of the land; the chiefs were the ones who moved about from place to place. It was the ma-ka-aina-na also who did all the work on the land; yet all they produced from the soil belonged to the chiefs; and the power to expel a man from the land and rob him of his possessions lay with the chief.”

– Malo (1987: 61)

2.1. Introduction

When the English explorer Captain James Cook made first European contact with the people of the Hawaiian Islands in 1778, he encountered a highly stratified and institutionalized hierarchal social system. Cook had been voyaging around the Pacific for some years and had observed many different peoples from across the Pacific. Many, especially the peoples of the Society Islands and Tonga, all lived in hierarchical social systems exhibiting a relatively high degree of inequality and social stratification. However, while the people of the Hawaiian Islands were undoubtedly very similar to other cultures of the Pacific, especially in relation to language, material culture, and religion, the social organization seen in Hawai‘i was markedly different than the rest of

Polynesia. In particular, prehistoric Hawaiian society exhibited a degree of hereditary inequality and rank differentiation unmatched in Oceania (Goldman 1970; Kirch 1984; Sahlins 1958).

The main social divisions in Hawaiian society were between the large commoner class, or *maka āinana*, and the relatively smaller rank of hereditary elite, or *aliʻi* (Malo 1987). The chiefly rank had several privileges according to their ranking within the social hierarchy. In addition to their privileges there were numerous laws and edicts (*kapu*) surrounding interactions with chiefs and their property, the violation of which was often punishable by death. Most importantly, at the time of European contact, the elite class in Hawaiʻi wielded a near complete monopoly of power and access to resources (Malo 1987; Kamakau 1992a). This class of elites was itself organized hierarchically, with a complex nested arrangement of chiefly classes based on heredity, including several different ranks of chiefs (*aliʻi*), priests (*kahuna*), and land managers (*konohiki*). Based on the ethnohistoric accounts of Kamakau (1991) and Malo (1987), in the 18th century there were upwards of twelve different ranks of high chiefs and several different categories of land managers and priests. There were very likely additional ranks of hereditary elites, but the ethnohistoric accounts differ on the exact number and names of different chiefs (see Ii 1983; Kamakau 1991, 1992; Malo 1987).

The purpose of this chapter is to succinctly describe the nature of prehistoric Hawaiʻi's social hierarchy and review the previous anthropological explanations for its evolution. The chapter begins with the accounts of native Hawaiian ethnohistorians

writing at the time of first European contacts in the 19th century and their descriptions of Hawaiian social organization. For the sake of brevity, the focus here is on the three most widely known and cited authors of Hawaiian ethnohistory, namely David Malo (1987), Samuel Kamakau (1991, 1992a, 1992b), and John Papa I'i (1959). The brief description of Hawaiian social organization in this chapter deals only with some important distinctions between elites and commoners and traditional territorial land division. To highlight the degree of social stratification, divisions of the land and the different rankings of elites are briefly outlined below.

Following the accounts of these ethnohistorians, the focus of the chapter switches to previous explanations by anthropologists and archaeologists regarding the evolution of Hawaiian social complexity, with a particular focus on the works of Earle (e.g., Earle 1978, 1997, 2012), Hommon (e.g., Hommon 1976, 1986, 2013), and Kirch (e.g., Kirch 1984, 1990b, 2010b). The chapter concludes with a discussion of some of the shortcomings of these scholar's explanations and how the present thesis attempts to improve upon these previous approaches.

2.2. Hawaiian social organization at European contact

2.2.1 Divisions of the prehistoric Hawaiian landscape

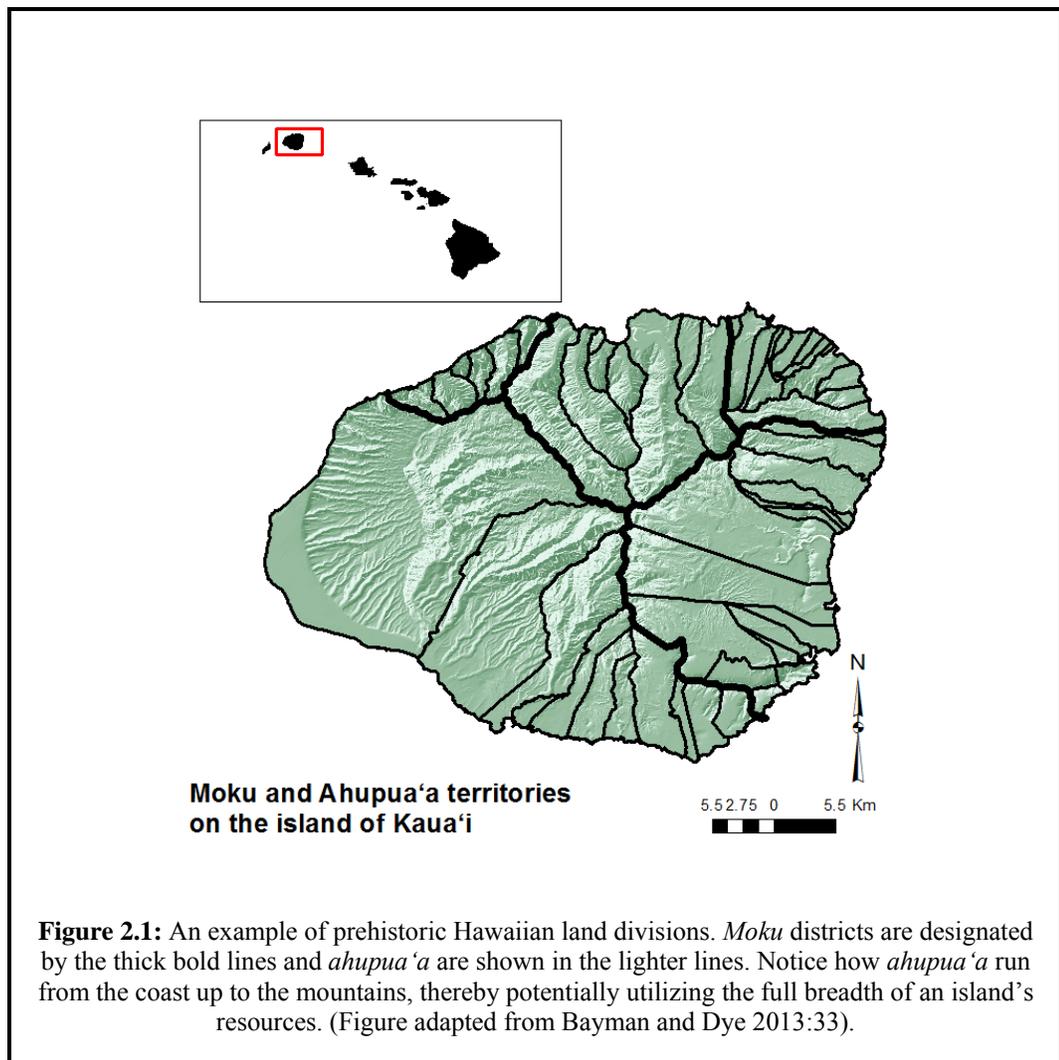
Before discussing the hierarchy of the different ranks of elites, it is first necessary to briefly describe the different territorial land divisions within traditional Hawaiian society, as the nature of the chiefly rankings largely mirrors, in many respects, the organization of the landscape.

At European contact the Hawaiian Islands were organized into a series of nested territorial divisions of the landscape, ranging from entire islands to individual farming plots. The largest territorial land division was the island, called a *mokupuni* (Kamakau 1992b:7; Malo 1987:16). Islands were then divided into many large districts, generally called *moku*, however, other terms such as *apana*, *moku-o-loko*, or *moku‘aina* are sometimes used (Kamakau 1992b:7; Malo 1987:16)¹. Each island district was further divided into several different nested categories. *Moku* were often divided into somewhat smaller sections variably termed *okana*, *kalana*, or *poko*. These district sections were then divided into the well-known *ahupua‘a* territories.

Ahupua‘a ranged in size and were “pie-shaped” divisions of the land usually encompassing an area from the coastal reefs up to a point near the inland mountains (Kamakau 1992b) (see Figure 2.1.). *Ahupua‘a* boundaries were often denoted by physical markers, “including walls, trails, and even sacrificial pig burials” (Ladefoged and Graves 2006:268). *Ahupua‘a* were administrated by particular ranks of chiefs and

¹ Here, for the sake of continuity, districts will either be referred to as simply districts or *moku*.

land-managers (see below) who collected taxes and tribute from the commoners who worked the land. The *ahupua'a* territories are the most frequently used community units in archaeological analysis, most likely as they provide delineated units reflecting human social, spatial, and economic organization. This aspect of *ahupua'a* will be utilized and elaborated upon the proceeding chapters.



Further dividing up the prehistoric Hawaiian landscape were the land sections within *ahupua'a* called *'ili* or *'ili'aina* (Kamakau 1992b; Malo 1987). Based on ethnohistoric accounts, *'ili* territories were often divided into several different varieties of smaller land divisions. These smaller land divisions were numerous and were often based on the kinds of crops grown or agricultural status of the land. The reader is directed to the works of Kamakau (1992b) and Malo (1987) for a full discussion of the smallest land divisions.

One of the smaller land divisions of importance here is the division within an *'ili* called a *ko'ele*. *Ko'ele* were lands which belonged to a chief or land-manger but which were worked by the commoners (Kamakau 1992b). Malo (1987:18) states that lands would often become *ko'ele* when a chief or land-manager seized land that was already under cultivation. Malo (1987:18) describes another pertinent land-division called a *haku-one*, which was a kind of *ko'ele* specifically for land-managers. Malo (1987) also mentions that chiefs and land-managers frequently seized the best or most productive lands for their *ko'ele*.

The ethnohistoric accounts briefly outlined above make it clear that in prehistoric Hawai'i the land was organized into a nested hierarchy of territorial divisions. Territories ranged from entire islands to single agricultural plots. As discussed below, each of these territories was administered by a particular land-manager or territorial chief, who in turn controlled the lands for the higher chiefs.

2.2.2. Divisions within Hawaiian society

At the top of the Hawaiian social hierarchy were the hereditary chiefs or *ali'i*, whom themselves were organized into a hierarchy, one where rank distinction was based on their genealogical distance from the highest ranked chief. The highest ranked chiefs were called *ali'i nui* (literally “big chiefs”) or *ali'i kapu* (“sacred chiefs”). This ranking of elite was the result of the union between two *ni'aupi'o* high chiefs of slightly lesser rank, usually close relatives such as brothers and sisters (Kamakau 1991; Malo 1987). Slightly below the *ali'i kapu* were the *ni'aupi'o* chiefs, which were of very high rank. Below these highest rankings in descending rank ordering were the *pi'o*, *naha*, *wohi*, *lo*, *papa*, *lokea*, *la'auli*, *kaukau*, *ali'i noanoa*, and *ali'i maka āinana* (See Kamakau 1991:4–6 for an in depth discussion of each of these ranks of chiefs). Each of these different ranks of chiefs retained different rights, privileges, and spiritual power (*kapu/mana*) over lesser chiefs, priests, land managers, and commoners, all characterized by differential rights and access to resources and power.

In addition to the several rankings of high chiefs, there were also a number of land-managers and administrative chiefs. Distinct administrative chiefs existed for each level of land division, such as *ali'i ai moku* (district chief) and *ali'i ai ahupua'a* (territory chief) (Malo 1987; Kamakau 1992). The lowest level of land managers were the *konohiki*. These lesser chiefs functioned within the society as administrative stewards who supervised many aspects of the prehistoric Hawaiian economy and the commoner class and also enforced the laws and the *kapu* system (Kamakau 1991, 1992a; Malo 1987).

Within traditional Hawaiian society there also existed a semi-separate ranked group of priests, or *kahuna*. According to Kamakau (1991:7), the *kahuna* priesthood were usually of *papa* ranking. However, within the priesthood there was also a ranking system of high priests (*kahuna nui*) and lesser chiefs and also multiple orders of priestly specialists and prophets (Kamakau 1991).

Separated from the ranks of hereditary elites was the large class of commoners, the *maka āinana*. The *maka āinana* made up the largest portion of Hawaiian society and were the ones who worked in the fields and harvested the sea; the *maka āinana* were forbidden to keep genealogies or own land, and instead lived and worked on land held by a chief (Malo 1987).

Below all classes of chiefs, land-managers, and commoners, were the *kauwa*. Sources differ on the exact definition of this class, but it is clear that they were akin to slaves or outcasts. As Kamakau (1991:8) describes, “*kauwa* were born outcasts from their ancestors’ time. They were a people much despised, and were called *kauwa kuapa ‘a*, [or] ‘load-carrying outcasts’...”. Table 2.1. summarizes the proto-historic Hawaiian social ranking system. This discussion of traditional Hawaiian social hierarchy is admittedly brief; however, it serves to illustrate the fact that Hawaiian society had become incredibly differentiated by the time of European contact.

Table 2.1: the different rankings within the ancient Hawaiian social hierarchy. Notice the number of hierarchical divisions within the social elite. (Table adapted from Kirch 2010:36).

The Hawaiian social hierarchy	
Ali'i (high chiefs)	
	ali'i kapu or ali'i nui
	nī'aupi'o
	pi'o
	naha
	wohi
	papa
	lōkea
	lā'au ali'i
	kaukau ali'i
	ali'i noanoa
Land-managers and territorial chiefs	
	ali'i 'ai moku
	ali'i 'ai ahupua'a
	konohiki
Commoners	
	maka'āinana
Outcasts or slaves	
	kauwā

2.2.3 Differences between commoners and elites

Based on the ethnohistoric accounts of Malo (1987), Kamakau (1991, 1992a; 1992b), and I'i (1959), it is clear that many important differences existed between commoners and elites in prehistoric Hawaiian society. Elite and commoner distinctions were institutionalized in the elaborate ritual and *kapu* system, which consisted of a series of laws, rules, and restrictions. One of the most frequently cited examples of *kapu*, likely because it effectively illustrates the level of social inequality, is the *kapu-moe*, the “prostrating taboo.” The *kapu-moe* required that all commoners and lower chiefs prostrate themselves in the presence of the high chiefs. Failure to adhere to the *kapu-moe* was punishable by death (Malo 1987). Elites had the right to institute *kapu* and as Malo (1987:56) explains, “the great chiefs were entirely exclusive, being hedged about with many tabus, and a large number of people were slain for breaking, or infringing upon, these tabus.” Examples of numerous *kapu* can be found in the ethnohistoric literature illustrating the inequality between ranks and the dominance of elites over the common people.

The ethnohistoric accounts make it clear that commoners and elites were distinguished by stark differential access to power and resources. The elites held the power to seize land, collect and institute taxes, and wage war. The institutionalization of elite taxation of the commoners can be seen in the elaborate ritual system, especially the yearly *makahiki* festival, which involved a month’s long religious ceremony of chiefly procession around an island collecting tribute payments (Malo, 1987:141-158).

Another major difference between elites and commoners was the fact that chiefs kept genealogies while commoners were forbidden from doing so (Malo, 1987). This was an important distinction, as the ability to recount one's genealogy established rights to lands and important resources (Kamakau 1991; Malo 1987). This can be seen as a possible way in which elites legitimized their monopoly of ownership of the lands of prehistoric Hawai'i (Kirch, 2010).

At European contact, the commoners seem to have been wholly responsible for food and craft production, while elites performed mostly political, managerial, or policing roles. As Malo (1987:61) describes, "it was from the common people...that the chiefs received their food and their apparel...also their houses and many other things." Elites were entitled to the best agricultural lands of their choosing, so called *ko'ele* lands, and wielded the right to seize these prime agricultural lands from commoners at any time. While some ethnohistoric sources make mention of chiefs participating in agricultural activities, these appear to have been mostly political or symbolic maneuvers (Malo 1987). Furthermore, the high chiefs themselves were not responsible for upholding these institutionalized differences, but instead appointed land-managers (*konoiki*) to enforce their rules.

The divisions of the land, institutionalized divisions within society, and differential access to power and resources make it clear that quite separate social ranks had established and diverged to a great degree over the course of Hawaiian prehistory. The recognition of the uniqueness of this outcome for the Pacific has prompted much research and discussion by archaeologists for more than four decades.

2.3. Anthropological approaches to Hawaiian social complexity

In this section the previous work of anthropologists dealing with the evolution of “social complexity” in prehistoric Hawai‘i is reviewed. This summary begins with the first major archaeological approaches to Hawaiian social complexity in the 1970’s following the comparative ethnographies of Sahlins (1958), Goldman (1970), and Service (1971). Although social complexity in Hawai‘i and Polynesia had been the focus much discussion in the social sciences before this time, the actual archaeological scholarship occurring post-1950 forms the backbone of late 20th century and early 21st century explanations for social change in prehistoric Hawai‘i². Because of this, the present review is mostly restricted to this influential post-1950’s scholarship, especially the works of Hommon (e.g., 1976, 2013), Earle (e.g., 1978, 1980, 1997), and Kirch (e.g., 1984, 1990b, 2010b). Following this brief review, the various strengths and weaknesses of these previous approaches are discussed, and a Darwinian approach is suggested which ameliorates previous explanatory drawbacks.

2.3.1. Previous explanations for social complexity in prehistoric Hawaiian society

The rise of social complexity has been an important and much discussed topic in Hawaiian archaeology since the 1950’s. Hawai‘i arguably first became an important locale for the study of cultural evolution with the designation of Hawai‘i as the typical

² The reader is directed toward Kirch (1984:8-13) for an excellent treatment of earlier discussions.

example of a “chiefdom-level” society by scholars like Sahlins (1958), Goldman (1970), and Service (1971) within their continuum of proposed stages of cultural evolution ranging from band, tribe, chiefdom, and state. For example, Service (1971:144–145) singles out Polynesia as the region where, “chiefdoms are the most typical and most highly developed” and that, “chiefdoms may ascend to the level of primitive states” and this is, “strikingly demonstrated in the cases of Tonga, Tahiti and Hawaii.” This approach, especially that of Sahlins (1958) and Service (1971), was largely informed by surveying Polynesian societies in the ethnographic present and ordering them along a spectrum of social complexity with Hawai‘i at the top. Following the placement of Hawai‘i at the apex of a Polynesian social ladder, it was concluded that Hawaiian society must have developed from a more egalitarian social structure like that seen elsewhere in Polynesia (Bayman and Dye 2013). Following Sahlins (1958), Goldman (1970), and Service (1971), archaeologists have attempted to look for evidence of Hawaiian cultural evolution in the ethnohistoric and archaeological record, focusing especially on population growth, agricultural intensification, the development of surplus, and warfare (Bayman and Dye 2013).

Hommon (1976) was one of the first archaeologists to tackle the problem of Hawaiian social complexity. His approach is firmly rooted in the neo-evolutionary anthropology of time, specifically the use of ethnographic analogy and the cultural evolutionism of Sahlins (1968) and Service (1971), focusing on how complex state-level societies develop from less complex “stateless” societies like chiefdoms. However, in contrast to Service and Sahlins, Hommon (1976) argues that Hawaiian society was not a chiefdom

but a “primitive state.” Hommon argues that contact-era Hawaiian society was characterized by several competing primitive states, which he sees as fundamental “evolutionary stage[s] or type[s]” (Hommon 1976:19). Hommon defines contact-era Hawaiian society as state-level based on the presence of two separate socioeconomic classes, a powerful and aggressive government, and sharp divisions between commoners and elites based on power and rank rather than kinship. Hommon (1976) attempts to explain the evolution of social inequality and hierarchy as a result of the disintegration of kinship ties, population growth and crowding, territoriality, and eventually conquest warfare.

Hommon’s (1976) model for the emergence of social hierarchy and “primitive states” focuses on the effects of population growth and limited land. Hommon (1976:230) draws upon Sahlins’ (1958) notion that following the colonization of Hawai‘i, Hawaiian polities were akin to the chiefdoms elsewhere in East Polynesia, organized around kinship ties with a relatively low level of social inequality. The existence of a higher-ranking class of chiefs is assumed, but they are thought to have been senior relatives with minimal power. As populations expanded, people moved from the coast inland and the *ahupua‘a* system developed to ensure everyone had access to the breadth of the island’s resources (Hommon 1976: 230). As the population of communities expanded and became organized at the *ahupua‘a* level, the kinship bonds within *ahupua‘a* and kinship bonds between these territorial groups were broken. Hommon (1976:14) argues that, “as the society as a whole becomes more complex” kinship ties inevitably weaken and that, “the links of kinship and attendant reciprocal obligations between the *ali‘i* and *maka‘ainana*

disintegrated as endogamous socio-economic classes formed” (1976:175). The disintegration of widespread community kinship bonds was followed by,

“a widening gap between chief and commoner as the concept of kinship centered increasingly within the local community. The practice of hypergamy for preservation of rank reinforcing endogamy within the *ali ‘i* as a social stratum also hastened the formation of socioeconomic classes...by 1600, the cleavage between commoners and chiefs had advanced to such an extent that the control exercised by the chiefs was no longer based on kinship, but rather on the demonstration of the monopoly of power. Thus, the formation of the *ali ‘i* and *maka ‘ainana* classes, and ultimately the development of *ahupua‘a* as a largely self-contained socioeconomic unit were necessary preconditions to the formation of the Hawaiian primitive state.” (Hommon 1976: 231).

For Hommon, population expansion led to the formation of the *ahupua ‘a* territories, which led to the breakdown of kinship, which in turn led to the development of inequality, social hierarchy, and eventually warfare. Territories in a primitive state are important for Hommon (1976:14) because they are “the area in which the monopoly of power legitimately operates”. The formation of territories is seen as being caused by elites, for elites, and territoriality, in turn, leads to warfare.

As the *ahupua ‘a* territories formed and social stratification emerged, Hommon (1976:141) argues that ambitious chiefs started to compete through conquest warfare which further increased the degree of social hierarchy. Hommon (1976:141) places a heavy focus on the importance of warfare in the emergence of social stratification,

“the evolutionary significance of conquest warfare is that the boundaries of the victorious political unit are expanded to include not only the new territory but the surviving residents of the annexed territory as well. Since the majority of the population of a primitive state society are lower class producers, successful conquest results in the capture of a producing unit complete with farmers, craftsmen and (in the Hawaiian case) fishermen...the net effect of conquest is the replacement of the control of one political hierarchy with that of another. Conquest warfare as described here is characteristic of state societies as opposed to stateless societies, since the membership and territory of the sociopolitical unit is augmented through the application of force rather than through the activation of kinship ties”.

Using the model outlined above, Hommon (1976) uses oral histories, ethnohistoric accounts, and archaeological data to track the change from approximately eight different political units or chiefdoms in the 1500's to approximately three primitive states at the time of European contact. In doing this, Hommon relies heavily on the political agency of influential and ambitious chiefs as forces of change in Hawaiian social evolution.

Over the years, Hommon has substantially expanded his ideas on social complexity in prehistoric Hawai'i (e.g., Hommon 1986, 1996, 2000, 2001, 2013). In particular, Hommon (1996, 2000, 2001, 2005) has drawn upon the field of complex adaptive systems (CAS) to shed light on the development of social complexity in prehistoric Hawai'i.

Briefly, CAS, or complex systems research more generally, is an interdisciplinary field focused on the explanation of emergent non-linear systems composed of relatively simple agents whose individually simple local interactions or behaviors produce non-simple and hard to predict non-local outcomes (Miller and Page 2007; Mitchell 2009). Complex systems theory has been widely applied to a range of fields, and commonly cited examples of complex systems are flocks of birds, schools of fish, and economic markets (Mitchell 2009).

Hommon (1996, 2000, 2001, 2005) suggests that the evolution of social complexity in prehistoric Hawai'i can best be explained through the lens of complex systems theory. Drawing on his previous (1976, 1986) model, Hommon (1996, 2000, 2001, 2005) argues that prehistoric Hawaiian social evolution is best explained as a CAS

because the individual *ahupua'a* territories and the individuals who occupied them formed in a non-centralized way through the actions of multiple simple individual agents resulting in an emergent complex community. This explanation is structured by his assumptions about the primary role of population growth in the evolution of social hierarchies. Drawing upon the “scalar-stress” models of Carneiro (1967) and Johnson (1982) on population growth and the evolution of leadership, Hommon (2000:138-139, 2001:145) hypothesizes that beyond a certain size, social groups cannot complete tasks effectively and therefore successful groups must “invent” leadership in order to handle the stress of information management in large groups. As populations grew in prehistoric Hawai‘i, complex hierarchical groups emerged from the interactions of individuals and individual *ahupua'a* then interact at another higher level of complexity to form an emergent “complex society.”

There are few problems with Hommon’s (1996, 2000, 2001, 2005) use of complex systems theory which must be addressed. First, Hommon offers up no explanatory mechanisms which influence individual interactions in the emergence of social complexity. He suggests self-organization as the guiding force in Hawaiian social evolution, but offers no mechanism for how individuals might become self-organized into what he calls Hawai‘i’s “complex society.” Furthermore, while Hommon (1996, 2000) does make many useful suggestions for how complex systems theory can be applied to Hawaiian prehistory, Hommon makes the common mistake of assuming the “complexity” in CAS is akin to how 20th century anthropologists have conceived of “social complexity” (Bernabeu Aubán et al. 2012). This is, again, somewhat misguided, as within complex systems theory all human social groups are considered complex

systems (Barton 2013). Hommon forsakes complex system theory's focus on non-linearity for his very linear perspective on how societies evolve.

In his recent book, *The Ancient Hawaiian State: Origins of a Political Society*, Hommon (2013) reworks his previous ideas regarding the evolution of social hierarchies in two important ways. The first is in what he terms “fission-fusion” processes, and the second major difference is in his “hard times hypothesis.” Seeming to eschew his past explicit use of complex systems theory, here Hommon (2013:225-226) draws upon what he terms “fission-fusion” processes in the development of complex social hierarchies in Hawai‘i. His fission-fusion hypothesis is based on what he explains as the “tendency” for human groups to fission as populations grow but also the tendency for groups to “draw together into a single unit in response to factors such as mutual self-interest, recognition of kinship ties, and coercion” (Hommon 2013:225). Hommon’s “fission-fusion” explanation is strikingly similar to his previous use of self-organization as the guiding force in the emergence of social hierarchies. Here, Hommon (2013) again offers no explanatory mechanisms which would structure individual interactions in a fission-fusion process, only that he sees this as a tendency in growing human populations. Nevertheless, this fission-fusion process is hypothesized to have led to the emergence of a nested organizational hierarchy in ancient Hawai‘i in response to stresses stemming from population pressure.

Hommon (2013) also introduces the “hard times hypothesis.” The hard times hypothesis is largely based on the processes resulting from population growth and expansion outlined in Hommon’s (1976) dissertation, but with the additional emphasis on the role of population pressure on food stress. Hommon derives his model through a

survey of several Polynesian societies as they were in the ethnographic present and again orders them along a scale of increasing complexity with Hawai‘i at the top. One of these societies, the small Polynesian outlier of Tikopia, forms the basis for Hommon’s (2013:8) hard times hypothesis which is “modeled after Tikopia’s leaders’ adoption of coercive measures in reaction to a major food crisis after a severe hurricane” in the early 20th century.

Hommon (2013:233) attributes the stresses in his “hard times hypothesis” to a reduction in agricultural productivity resulting from agricultural intensification and population growth. Hommon (2013:252) sums up his model as follows,

“the model proposes that the hard times of increased labor burden for men and women, rapid growth that led to population doubling within a single lifetime, diminished productivity resulting from loss of soil fertility, and expansion of cropping to or beyond environmental and technological limits led to escalation by chiefs of coercive measures that encouraged the acquisition of managerial skills and political strategies required for the emergence of the state”.

In summary, Hommon (1976, 1986, 1996, 2000, 2001, 2013) has dealt extensively with the issue of social evolution in prehistoric Hawai‘i. His approach stems largely from the neo-evolutionary approach pioneered in Polynesia by Sahlins (1958), Goldman (1970), and Service (1971), which places Hawai‘i at the apex of a Polynesian cultural evolutionary ladder. Hommon’s work on this complicated subject has been predominantly focused on arguing for Hawai‘i’s membership in the select group of prehistoric societies commonly referred to as “primary-”, “primitive-”, or “archaic-states.” Within his focus on the development of state-level polities in Hawai‘i, Hommon has attempted to explain the evolution of social hierarchies in prehistoric Hawai‘i as the inevitable result of population growth and expansion (Hommon 1976, 1986), self-

organization by autonomous agents (Hommon 1996, 2000), and fission-fusion processes during hard-times (Hommon 2013).

Earle (e.g., 1978, 1980, 1997, 2012; Johnson and Earle 2000) has also greatly contributed to the topic of emergent social complexity in prehistoric Hawai‘i. As a student of Sahlins’, Earle also operates largely from the neo-evolutionary approach described previously, seeing societies as falling into a discrete number of categories ranging from simple bands to complex chiefdoms and archaic states. However, in contrast to the ideas of Hommon and later Kirch (see below) on Hawaiian “statehood,” Earle (1978, 1980, 1987a, 1987b, 1993, 1997, 1998, 2000, 2002) is primarily concerned with explaining what he sees as “complex chiefdoms” in prehistoric Hawai‘i. Earle (1978:2) describes “complex chiefdoms” as very complex and hierarchically organized societies transitional between simpler tribes/simple chiefdoms and the more complex governmental state-level societies.

Earle (1978) takes prehistoric Hawaiian society to be representative of a complex chiefdom on the way to becoming a state. Hawaiian society is described as having a well-developed level of stratification, whereby social roles within the elite class had become differentiated and power centralized. Earle (1978) attempts to evaluate three influential cultural evolutionary models for the evolution of the Hawaiian chiefdoms. Each of the models Earle (1978:4-5) evaluates are at their core based on population growth toward some critical density threshold in particular environments which “select for specific cultural adaptation which, in turn, require the centralization of decision

making for adequate control” and eventually the development of chiefdoms. The three models which derive from this core assumption are each based on possible leading factors in the evolution of social complexity: irrigation, warfare, and redistribution.

Earle (1978) first evaluates the applicability of Wittfogel’s (1957) “hydraulic hypothesis” for the evolution of social complexity and social hierarchy. In brief, Wittfogel’s (1957) model is founded on the proposition that as populations grow in agricultural societies practicing irrigation, the organizational complexity of these irrigation technologies necessitate the presence of a managerial class to stabilize production leading to the differentiation of social roles and the centralization of power. For prehistoric Hawai‘i, the development of social hierarchy occurs through the demands of the irrigation system’s construction, maintenance, and management; this managerial unit is the *konohiki* or one of the other administrative chiefly classes. Earle (1978) tests this irrigation hypothesis through an in depth analysis of the archaeology and irrigation systems of the Halele‘a district of Kaua‘i and compares them to similar types of irrigation in other cultures. Ultimately, Earle (1978) concludes that the complexity and scale of Hawaiian irrigation systems were not sufficient to necessitate the development of centralized management or the evolution of chiefdoms, and that other explanations must be sought.

Following the dismissal of Wittfogel’s (1957) hydraulic hypothesis, Earle (1978) evaluates the “ecological redistribution” model of Service (1971). As Earle (1978:5) recognizes, this model is quite similar to the hydraulic hypothesis in many ways: as population density increases in settlements located in diverse ecological zones, not all portions of the population will have access to all the resources they need. Centralized

authority emerges to facilitate smooth management of the redistribution of these different resources across ecological zones. This process eventually leads to complex social hierarchy and centralized power in the hands of a small number of elites (Earle 1978:159). Earle (1978:160) argues that this model cannot explain the evolution of Hawaiian chiefdoms because the “invention” of the *ahupua‘a* system effectively created a redundancy in resource availability, thereby cancelling out the possibility for ecological specialization between communities.

The third model explored by Earle (1978) derives from Carneiro’s (1970) “circumscription” explanation for the origins of state societies. This model focuses on the powerful influence that population growth and warfare have on the evolution of social complexity. As population density increases in “circumscribed” areas (those for which emigration is not an option), conflict erupts over access to limited resources; the successful group then comes to dominate the conquered, leading to the evolution of social hierarchy, chiefdoms, and eventually states (Earle 1978:5, 162-165; Carneiro 1970). Earle (1978: 162) sees Hawai‘i as an ideal place to test this idea given its record of endemic warfare in oral histories and the inherent circumscription of islands. However, Earle (1978: 164-166) concludes that because the Hawaiian Islands were not totally circumscribed at the time of contact (i.e., people had not settled every livable location), the fact that archaeological evidence for warfare (e.g., forts, etc.) is lacking, and that warfare seems to have occurred only between districts or whole islands (rather than between small communities), warfare is not a sufficient explanation for the evolution of social hierarchy and chiefdoms in prehistoric Hawai‘i.

After discarding these three influential models due to their simplicity and overt focus on ecological factors, Earle (1978) puts forth his own economic and political explanation. Earle (1978:168) describes Hawaiian society, like all other Polynesian societies, as characterized by a “dual economy – a subsistence economy and a political economy. A subsistence economy has a minimizing strategy for which the goal is to meet the needs of the household unit. In contrast, a political economy has a maximizing strategy for which the goal is to produce the greatest income possible to finance political aspirations.” In Hawai‘i, Earle sees this supposed pan-Polynesian social structure as present at the time the islands were colonized (i.e., some level of social differentiation is already established). With the replacement of a kinship-based local leader, a pan-Polynesian pattern, with the *konohiki*, a non-kin elite, the structure of the local communities in prehistoric Hawai‘i was broken and a high level of social hierarchy created (Earle 1978:169). Over time, the unstable political economy moves towards increased complexity as ambitious chiefs compete to finance their political objectives, such as conquest warfare, greater social ranking, and attainment of surplus and craft goods. The way in which the Hawaiian chiefs financed their political aspirations was through capital investment in the extraction of surplus from the highly productive irrigation agricultural systems.

Over the years Earle has written extensively on the evolution of chiefdoms and has consistently built on his original (1978) explanation, repeatedly using Hawai‘i as one of his prime examples (Earle 1980, 1987a, 1987b, 1993, 1997; 1998, 2000, 2002, 2012). In Earle’s (1997) book, *How Chiefs Come to Power*, he most clearly explicates and summarizes his thesis (1978) that complex chiefdoms and social inequality developed in

prehistoric Hawaiian society through the political agency of ambitious chiefs vying for economic, military, and religious power. Since his original treatment of Hawaiian social complexity, Earle's (2012) views have changed only in that he now agrees with Hommon (e.g., 1976, 1986) and Kirch (2010b see below) that prehistoric Hawaiian society was representative of a primitive State.

Kirch is perhaps the most influential and prolific scholar of Hawaiian social complexity. Kirch's published discussions of Hawaiian social complexity are extensive – only the most widely cited and programmatic works are reviewed in detail here (e.g., Kirch 1984, 1990b, 2005, 2010b, 2012). In sum, Kirch's publications on Hawaiian social complexity have been consistent over the years.

In his influential book, *The evolution of the Polynesian chiefdoms*, Kirch (1984) attempts to trace the origins of Hawaiian social complexity from early beginnings in what he terms “Ancestral Polynesian Society” (APS) (see also Kirch and Green 1987, 2001 for an in depth treatment of their reconstructions of ancestral Polynesian culture). Briefly, Kirch (1984; Kirch and Green 1987, 2001) surveys Polynesian cultures as they were at the time of European contact and then attempts to reconstruct their source in APS through a “phylogenetic triangulation method” using comparative ethnography, archaeology, and historical linguistics. This creates a “baseline” from which he traces the development of the Hawaiian chiefdoms (Kirch 1984:7).

Using his triangulation method, Kirch (1984:31-32) argues that APS was organized as a “conical clan,” an extensive kin-group tracing their origins to a single

common ancestor and ranked according to their genealogic distance from this ancestor. As Kirch (1984:34) explains, “the conical clan is, at every level, a ranked structure. Older and younger siblings, chiefs and commoners, higher and lesser ramares – all are positioned on a continuous scale with the fundamental criterion of seniority of descent.” Based on historical linguistics and comparative ethnography, Kirch (1984:63) asserts that APS had chiefs of some social ranking, however, the level of stratification is argued to be low, but “lexical data clearly indicate that APS had already developed the institution of hereditary chieftainship” (Kirch 1984:64).

Kirch (1984:65-66) also reconstructs APS social groupings, especially the corporate, landholding descent group, or **kainanga*, and the less inclusive **kainga* household descent group. **Kainanga* is seen as a basic territorial social group led by an APS chief, while the less inclusive **kainga* is seen as an extended household descent group which owned and cultivated land (Kirch 1984:66). Following colonization, this social organization would have created what Kirch (1984:71, 1985:285) calls a kind of cultural founder effect in Hawai‘i, whereby a small founding population with a relatively restricted level of cultural variation evolves into an elaborated culture derived from this original baseline.

Kirch’s (1984:201-202) basic model for the evolution of the Hawaiian chiefdoms is as follows: After the colonization of Hawai‘i the best ecological zones were settled first, especially windward valleys. As population size and density increases, agricultural expansion and intensification begins, and eventually groups begin to break off from these source populations into less-desirable leeward areas. Eventually the Hawaiian landscape becomes densely populated with people who continue to intensify agricultural

production. For Kirch (1984:161), like Earle (e.g., 1978), intensification of agriculture and production of surplus agricultural resources are intimately linked to the evolution of social hierarchy because surplus can be used to finance the political aspirations of chiefs. As Kirch (1984:164) explains, “the process of intensification, in short, results both from the increased demands for necessary consumption posed by a growing population, and the demands of the chiefs for surplus sufficient to underwrite their political actions and enhance their prestige.” This situation eventually leads to increased competition over territory and resources, which is exacerbated by natural disasters such as drought (Kirch 1984:201). This process of population growth, intensification of surplus production, and the politically motivated ambitions of chiefs eventually leads to conquest warfare whereby the successors form the top of the newly established social hierarchy (Kirch 1984: 201).

In summary, Kirch (1984: 281) argues that the APS that colonized the Hawaiian Islands was already hierarchically structured to some degree, with ambitious hereditary chiefs who demanded surplus to finance the political economy. Evidence for the beginnings of this transformation are seen in the archaeological evidence for the intensification of irrigation and dryland agriculture and in the florescence of monumental architecture (*heiau*). Building on Sahlins (1972), Kirch (1984:192) suggests that at the time of European contact Hawai‘i had likely reached the developmental endpoint of Polynesian society and Oceanic agricultural intensification. Over time, population growth in a land-limited area provided the context and opportunity for ambitious chiefs to intensify agricultural production to finance conquest warfare and in this process “we see the evolution of island chiefdoms” (Kirch 1984:216).

Kirch (1985:284–308) in *Feathered Gods and Fishhooks* places his model for the evolution of Hawaiian chiefdoms within his now orthodox sequence of culture historical phases, beginning with a Colonization Period (AD 300-600), Developmental Period (600-1100), Expansion Period (1100-1650), and a Proto-Historic Period (1650-1795)³. Kirch (1985) attempts to strengthen the evidence in favor of his (1984) model with new archaeological data. During the Colonization Period, Hawaiian social organization is argued to be much like APS, with differences between commoners and chiefs, but this stratification is thought to be relatively minor (Kirch 1985:302). During the Developmental Period, prehistoric Hawaiian society had greatly diverged from APS as populations grew rapidly and agriculture expanded and intensified; however, stratification was likely still low (Kirch 1985:303). With the onset of the Expansion Period, population density increased, and intensification of agriculture culminated in complex irrigation, dryland, and aquacultural systems. Following Hommon (1976), Kirch (1985:306) agrees that this rapid growth and expansion of populations led to the formation of the *ahupua'a* territories and a major sociopolitical change. This then set the foundation for politically ambitious chiefs to conduct ritually sanctioned and religiously legitimized territorial conquest warfare, transforming prehistoric Hawai'i into a complex chiefdom by the Proto-historic Period, as Kirch (1984) has argued.

Since laying out his model for the evolution of the Hawaiian chiefdoms within his proposed culture-historical periods, Kirch has written prolifically about the subject of

³ While the actual dates assigned to these period have changed greatly since this 1985 publication, specifically the estimates of the timing of colonization are much more recent (i.e., ~900-1250 AD), the basic periods and events have remained largely unchanged. The reader is directed to Kirch 2000:291-295 and Kirch 2010:128 for a history of “revised” culture-historical sequences.

Hawaiian social complexity (e.g., Kirch 1988, 1990b, 1990a, 1994, 2000, 2005, 2010b, 2010a, 2012, Kirch and Rallu 2007; Kirch and Sharp 2005; Kirch and Weisler 1994). Kirch's work on this subject has grown in a number of ways. For example, Kirch (1994) argues for the importance of aggressive and expansionist leeward chiefdoms in the evolution of social complexity. The logic behind his emphasis on leeward chiefdoms is that chiefs in the more marginal leeward areas come to need additional surplus, which their marginal lands cannot produce, so they aggressively expand into other areas, especially windward valleys, in the hopes of conquering these more fertile and productive areas (1994). The argument for aggressive leeward chiefdoms has been influential (e.g., Field et al. 2010; Field et al. 2011a; Ladefoged and Graves 2000, 2008; Ladefoged et al. 2003, see Chapter 4).

Kirch has also placed increased emphasis on the role of monumental architecture (e.g., Kirch 1990a; Kirch and Sharp 2005), arguing in that in Hawai'i, "the socio-political structure underwent a process of hierarchization, with the development of a stratified cadre of elite dominating a largely undifferentiated class of commoners... monumental architecture was utilized by these chiefly elite as symbols through which their dominance was continually reasserted" (Kirch 1990a:207). The political motivations of chiefs become legitimized through their growing religious authority. Monumental architecture, along with agriculture, serve as a method by which chiefs increase their status.

Overall, Kirch's arguments for the evolution of social hierarchy have remained remarkably consistent with the model put forth in *The evolution of the Polynesian chiefdoms*, with the relative importance attributed to chiefly agency, agricultural intensification, warfare, and rise of religious authority waxing and waning. One major

difference, however, is that in recent years Kirch has switched from referring to Hawai‘i as a complex chiefdom and instead now argues that prehistoric Hawaiian society evolved into an “archaic state” (e.g., Kirch 2005; 2010b; 2012).

In his recent publication, *How Chiefs Became Kings: Divine Kingship and the Rise of Archaic States in Ancient Hawai‘i*, Kirch (2010) restates his 1984 model for the evolution of social complexity. However, here he attempts to place prehistoric Hawaiian society in the select category of archaic states seen in places like China, the Middle East, and Mesoamerica. He places a renewed emphasis on the breakdown of the APS kinship and land-rights system in the evolution of Hawaiian social hierarchy, drawing on a detailed account of Hawaiian political history. Yet, his arguments for the evolution of social hierarchy remain essentially the same – social hierarchy simply develops through the political agency and rivalries of ambitious chiefs. Kirch (2010:204) argues that, “what begins as status rivalry between senior and junior siblings, or between two ranked lineages with an ancestral **mata-kainanga* group, ultimately plays out in Hawai‘i as the ranked differentiation of a chiefly class (itself highly graded internally) from the commoners.” For Kirch, the agency of individual actors in prehistory is “the real nexus of social change” (Kirch 2010:8). But the agency of actors is seen as the proximate explanation for Hawaiian social complexity, while the processes of population growth, agricultural intensification, surplus, and warfare are the “ultimate”, or “processual”, factors in the formation of Hawaiian archaic states (Kirch 2010:178-210).

However, because his “ultimate” factors for the development of archaic states do not provide any obvious ultimate mechanisms by which social hierarchy evolves, Kirch consistently falls back on his proximate reasons. His thoughts are best summed up in his

recent book, *A Shark Going Inland Is My Chief*, where he analyzes Hawaiian oral traditions to explain the evolution of social hierarchy following the stresses of population growth,

“Mā‘ilikūhāhi [a chief of O‘ahu] made the momentous decision to impose a new hierarchical order over the entire island. Rather than let the people work out their territorial rights according to ancestral claims based on membership in their *mata-āinanga* and *kāinga* groups, he would assign the land to the chiefs, lesser chiefs, and through them down to the common farmers and fishermen. This was a radical departure from the old Polynesian system, in which rights to land were tied to kinship. From this point on, the land tenure system became one of chiefly territories, in which the common people’s rights to land depended on their relationship with their chief. This new system would become fundamental to the economic and political order of the islands...” (Kirch 2012:139).

In the subsequent pages, Kirch (2012:139-142) describes how the high chief Mā‘ilikūhāhi further created all the territorial land divisions and managerial chiefs, such as the *konohiki* land-managers, and was responsible for the spread of this system throughout the archipelago and the breakdown of the APS kinship system.

Aside from the most influential ideas of the scholars reviewed above, several other anthropologists and archaeologists have written about the evolution of social complexity in Hawai‘i. While not as influential as the works of Hommon, Earle, and Kirch, these author scholars’ work are briefly mentioned here.

Cordy has written extensively about the evolution of complex chiefdoms in Hawai‘i for several decades (1974a, 1974b, 1981, 2000, Tainter and Cordy 1977), and his approach differs little from Hommon, Earle, or Kirch. Cordy (1974b) has mostly described the archaeological and ethnographic evidence for the development of complex chiefdoms and complex social ranking in Hawai‘i, such as the existence of large religious

temples and possible indicators of rank in settlements and prehistoric burials (Cordy 1981; Tainter and Cordy 1977). Echoing Carneiro (1970), Cordy (1974a, 1981) suggests that complex chiefly systems evolved in Hawai‘i through the pressures of population growth in a “full-land situation.” This primary factor of population growth is argued to have caused conquest warfare for limited land and led to major reorganization of the ancestral social structure and the evolution of social complexity.

Spriggs (1988) draws on Hommon’s (1976) ideas of rapid population growth and group fissioning and Kirch’s (1984) ideas of APS in an attempt to explain the development of complex social ranking in Hawai‘i. Spriggs’ (1988) ideas are essentially the same as those of Earle (1978), specifically that chiefly rivalries for power, especially those between junior and senior siblings, greatly influenced the development of social hierarchies. However, Spriggs places considerable weight on the possibility that diffusion of cultural traits from Tahiti may have had on the evolution of social complexity in Hawaiian prehistory, specifically diffusion of ideas relating to social inequality, chiefly ranking, and a new ritual order.

Cachola-Abad (2000) approaches the topic of Hawaiian sociopolitical evolution through an in depth analysis of native Hawaiian oral traditions within an evolutionary ecology framework. Cachola-Abad (2000) critiques the previous neo-evolutionary approaches of Kirch, Hommon, Earle, Spriggs, and Cordy in a number of ways. Specifically, Cachola-Abad (2000:7) argues that these previous neo-evolutionary approaches to Hawaiian social complexity have been overtly typological (e.g. focusing on stages such as chiefdoms or states) and this has led them to confuse descriptions of how Hawaiian society changed for explanations for why social evolution occurred.

Cachola-Abad (2000) argues that a Darwinian evolutionary ecology approach can make up for these shortcomings through its explicit focus on cultural variation and a dynamically and empirically sufficient explanatory framework.

Using Hawaiian oral histories, Cachola-Abad (2000) tracks fluctuations in the patterns of political integration, aggression, and number of chiefs over the 23 generations. Cachola-Abad's (2000) use of evolutionary theory in her analysis is devoted to explanations of how the change in political strategies can be seen as natural selection influencing the differential persistence of cultural variants and behavioral traits over time, such as "the frequency of *ali'i* marrying *ali'i* from neighboring islands...[and] warfare of the construction of monumental architecture" (Cachola-Abad 2000:15). Drawing on the evolutionary ecological model of Boone (1992, see Chapter 3), Cachola-Abad (2000:489) finds that chiefs portrayed in oral histories act in ways which promote and enforce the persistence of cooperative groups (especially in risky environments), and patron-client relationships, such as inter-polity marriage alliances. Cachola-Abad's (2000) research is later distilled and elaborated upon by Graves et al. (2010). While interesting applications of evolutionary ecological theory, the focus in Cachola-Abad (2000) and Graves et al. (2010) has been on how Hawaiian oral histories and ethnohistoric evidence fits within the end-points of evolutionary models of social hierarchy formation (e.g., Boone 1992), rather than completely fleshing out and interpreting these models' implications and predictions.

2.4. Discussion

The overwhelming majority of the studies reviewed above have focused on explaining the rise of particular societal types, such as complex chiefdoms and states, in prehistoric Hawai‘i. In these attempts, emphasis is placed on describing what are seen as hallmarks and important factors in the evolution of complex societies, such as the intensification of agriculture, the rise of monumentality and religious authority, conquest warfare, and especially the political agency of ambitious chiefs. In describing these supposed important factors in social change, scholars like Hommon, Earle, and Kirch have been influential in Hawaiian archaeology. However, their focus on large scale factors has also been their biggest shortcoming for the purposes of explaining the evolution of social hierarchy.

A lengthy critique of the influential neo-evolutionary approach so prevalent in Hawai‘i is not desired here (for compelling criticisms of this approach the reader is directed to Bettinger 1991; Dunnell 1980, 1989; Lyman and O’Brien 1997; and Shennan 2003); however, a few drawbacks of previous theorizing must be addressed. First, by concentrating on the evolution of complex chiefdoms and states and their supposed “hallmark characteristics,” previous studies have neglected to explain important factors and evolutionary mechanisms which might shed light on the evolution of social hierarchies themselves. A hierarchical group structure is either assumed to have been in place at the time of colonization, taken for granted as an inevitable outcome of linear cultural evolution, or as stemming from the agency of ambitious chiefs. Of the authors reviewed above, Hommon has come the closest in terms of offering up possible processes

by which social hierarchies emerged in Hawai‘i. However, while he has described a hypothetical process, specifically that as populations grow and “hard times” occur, groups *tend* to fission, hierarchically self-organize, and increasingly require leaders for efficient decision making, Hommon offers no causal mechanisms which ultimately influence these processes or explain their evolution.

Lacking a sufficient theoretical framework which might deal with hierarchical group formation, the vast majority of proposed explanations place considerable weight on the agency of individual chiefs in bringing about change. Considerable weight is also placed on agricultural intensification as an important factor in the evolution of Hawaiian social complexity, as intensification is argued to have led to the production of surplus which in turn was available for use by elites for their own political gain (e.g., Bayman and Dye 2013:95; Ladefoged and Graves 2008). While the agency of individuals may have importance to the unfolding of history, this approach lacks clear archaeological correlates and neglects important evolutionary ecological mechanisms which have considerable influence on the organization and structure of social groups.

This thesis is an attempt to complement these previous approaches by exploring the evolutionary and ecological influences on the evolution of social hierarchy in Hawai‘i. Evolutionary ecology provides a coherent body of internally consistent theoretical principles rooted in natural selection, from which testable prediction about the archaeological record can be derived.

Chapter 3

The Evolutionary Ecology of Social Hierarchy

“At the core of every society lies a conflict between cooperation and competition...”

– (Dávid-Barrett and Dunbar 2014:58)

3.1. Introduction

A *social hierarchy* is defined as a social structure consisting of two or more ranked classes of individuals (Earley and Dugatkin 2010). This stratified aspect of social hierarchies commonly manifests itself in differences in resource holding potential and/or reproductive success between the separate classes of individuals. Differences between classes in a social hierarchy are often top-heavy, or what is more correctly termed *despotic* – which describes a situation where the majority of resources are controlled by one or few individuals within the group (Earley and Dugatkin 2010; Summers 2005; Vehrencamp 1983b)⁴. However, while despotism is an important characteristic, and usually a prerequisite, for social hierarchy, there is a distinction to be made between social inequality resulting from despotism and a hierarchical social structure which has become fixed in a society. For instance, it is possible to have marked social inequality without the formation or maintenance of a social hierarchy. This is because social

⁴ However see Boehm (1999) for a discussion of social hierarchies which do not involve despotism.

inequality merely necessitates differences between individuals, whereas social hierarchies are fundamentally maintained through cooperation among group members; without cooperation the organizational structure of a hierarchy begins to break down (Bourke 2011). Consequently, the evolution of social inequality and despotism will here be treated as a prerequisite for the evolution of social hierarchy, and social hierarchy in turn will be addressed with reference to problems of cooperation and competition in risky and uncertain environments.

The analysis of the evolution of hierarchical social organization is profitably approached using evolutionary ecological models. A Darwinian evolutionary framework allows for the construction of simple models from which we can derive predictions that can be tested against the archaeological record, and can, consequently, help explain major influences on social change. In this chapter, a series of abstract models are presented which together provide an account of how and why social hierarchies might evolve under certain ecological circumstances. Rather than attempt a comprehensive review of Darwinian approaches to hierarchical versus egalitarian societies, this discussion is directed toward those models most relevant to the evolution of social hierarchy among human agriculturalists, such as those of the Hawaiian Islands. In particular, the aim of this chapter is to explain a selective process by which the formation of social hierarchies will be favored by individuals in particular environments.

The evolutionary ecological models used in this chapter include those focusing on resource distribution, habitat selection, group size, competition, and cooperation. The choice of models is influenced by previous applications of evolutionary theory to the archaeological analysis of human social hierarchies (e.g., Boone 1992, 2000; Kennett

2005; Kennett et al. 2009; Morrison 2012), but also builds on previous efforts with the addition of more recent theoretical work, in particular, models pertaining to group size, cooperation, and leadership.

This chapter begins with a brief introduction to the theoretical framework of evolutionary ecology. Following this introduction, I explore the evolutionary ecology of social inequality, in particular with reference to the degree of *despotism* in a social group. Despotism is defined as an unequal skew in the control of critical resources, such as mates or food, by one or a few individuals within a social group (Summers 2005; Vehrencamp 1983b). This inequality in the distribution of critical resources leads to social inequality, where one or a few individuals have higher resource holding potential (hence potentially higher reproductive fitness) than the rest of the social group (Boone 1992). Following the evolution of social inequality, the focus of the chapter shifts to explanations for the evolution and maintenance of social hierarchy in despotic groups. As explained above, the formation and maintenance of social hierarchies necessitates large-scale cooperation. In large-scale social groups where the benefits to cooperation are high, such as in environments where there is high spatial heterogeneity in risk and uncertainty, we should expect individuals to favor membership in stratified hierarchical groups composed of special interest groups, or “leaders,” which act to enforce and maintain cooperation (Boone 1992; Boyd and Richerson 1988, 1992; Hooper et al. 2010). Following the formulation of an evolutionary ecological model of social hierarchy formation, the chapter concludes with a series of testable predictions for the archaeological record of Hawai‘i.

3.1.1. *Evolutionary ecology*

The theoretical framework of evolutionary ecology (henceforth EE) is focused on explaining phenotypic evolution in a variety of biotic and abiotic ecological contexts (Pianka 1999)⁵. EE is founded on a number of foundational principles and organizing assumptions rooted in neo-Darwinian evolutionary theory. The principle assumption of EE is that natural selection has shaped individual phenotypes, including behavioral and cultural traits, to respond optimally to various environmental and social constraints. In regards to *Homo sapiens*, this means that evolutionary mechanisms have shaped both the capacity for adaptive cultural learning and behavioral plasticity in modern humans (Boyd and Richerson 1985; Dunnell 1980; Smith and Winterhalder 1992a)⁶. The optimality assumption of EE stems from the nature of evolution by natural selection, namely that natural selection acts to maximize reproductive fitness. The assumption of optimality, however, does not mean the “best conceivable,” but only that natural selection is expected to result in maximum fitness under specific environmental constraints (Krebs and McCleery 1984:92), even when those constraints change. Here, the environment is defined as “everything external to an organism that impinges upon its probability of survival and reproduction” (Winterhalder and Smith 1992:8).

⁵ There are a number of named subdisciplines of evolutionary ecology, such as behavioral ecology, which as its name suggests specifically focuses on the evolutionary ecology of behavioral traits, and human behavioral ecology which solely studies humans (and to some extent our primate relatives). However, because the models used in this chapter derive from several fields of evolutionary and ecological analysis, the theoretical approach used here is simply referred to as evolutionary ecology (EE). While these subfields have historically used different modeling techniques or approached different evolutionary topics, over the last several decades these subfields have more or less coalesced into a coherent framework (See Clutton-Brock et al. 2009 for a discussion and historical review)

⁶ While cultural transmission is not explicitly addressed in this chapter, it is nevertheless taken as an important aspect of human social evolution.

Two aspects of the environment are important in EE analysis – the *parametric* and the *strategic* environmental contexts (Winterhalder and Smith 1992). Strategic environmental contexts are those in which the optimal behavior is dependent on the frequency of other behaviors in the environment. Parametric environmental contexts, on the other hand, are not frequency dependent but generally consist of aspects of the physical environment. Stated another way, in a strategic context the optimal behavior of an individual both affects and is affected by the behavior of other individuals, whereas in parametric contexts there is an independent variable (the physical environment) which acts on individuals (Winterhalder and Smith 1992:8–9). Analysis of optimal behavioral responses to parametric and strategic environmental problems is approached through the use of simple context-specific models.

A defining quality of the field of EE is its emphasis on the use of formalistic models. EE problems are usually approached through the use of mathematical and graphical models, and increasingly through the use of computer simulations (Grimm and Railsback 2005; Otto and Day 2007). These models are necessarily simple. As the eminent biologist John Maynard Smith (1972:22) explains, “all good models in science leave out a lot. A model which included everything would be too complicated to analyse. The purpose of the model ... [is] not to give a complete picture, but to answer a particular problem.” EE models are based on the concept of *methodological individualism*, which holds that biological phenomena (including human social behavior) are mostly profitably analyzed with reference to mechanisms operating at the level of individuals (Smith and Winterhalder 1992b). Depending on the environmental context, modeling in EE analysis

is either approached through simple optimization models or evolutionary game theory (Krebs and McCleery 1984; Maynard Smith 1982).

3.1.1.1 Optimization and evolutionarily stable strategies

Simple optimization models are often used in parametric contexts as a method of explaining phenotypic responses under different ecological conditions (Maynard Smith 1978). A brief note about the logic behind the use of the optimality assumption is necessary. As mentioned previously, the assumption of optimality in EE models is not equivalent to claiming that natural selection always results in the best possible phenotypes in all situations (Krebs and McCleery 1984). One needs only cite the example of the human appendix to show that such a statement is clearly false (Maynard Smith 1978). However, the optimality assumption does provide a very useful assumption based in natural selection, which allows the formulation of testable models to explain some biological phenomenon. As Shennan (2003:25) explains, “this framework is not tautological. We are not saying that anything that exists must be optimal, but that given what we know about the specific context and behavior under study, we can predict what will be optimal... We can then see whether we find it or not.”

Following from the tenets of methodological individualism, optimization models focus on which out of a set of behavioral strategies an individual possesses will result in the optimal fitness under specified environmental constraints (Smith and Winterhalder 1992b:50). Because fitness itself is frequently difficult to measure directly, optimization models often focus on a proxy currency in which the costs and benefits of a given

behavioral strategy can be measured (Krebs and McCleery 1984; Maynard Smith 1978; Smith and Winterhalder 1992b). The most frequently used proxy currencies in human behavioral ecology are mating success, resource harvest rate, the net rate of energy capture, and risk avoidance (Cashdan 1990b; Smith and Winterhalder 1992b).

The prey and patch-choice models of foraging theory provide a prime example of optimization models (Stephens and Krebs 1986). In these models the potential caloric benefits of different habitat patches are used as proxy currencies for fitness. The various costs and benefits of an individual's potential foraging strategies are then calculated for each food resource and the optimal behaviors are predicted. These models often assume that individual foragers should seek to maximize their net acquisition rate of energy, but models incorporating risk minimization and stochasticity are also of importance (e.g., Cashdan 1990b; Smith 1988; Stephens 1990; Stephens and Charnov 1982; Winterhalder 1986). The use of optimal foraging models has been widely applied in human contexts, especially in relation to human hunter gatherers (e.g., Bettinger 1991; Kaplan and Hill 1992; Smith 1983a). Optimality modeling has also been widespread in archaeological applications of EE to prehistoric hunter-gathers and is increasingly being applied to the study of agrarian societies (e.g., Kennett and Winterhalder 2006). However, for the purposes of modeling optimal behavior in social contexts, such as in the formation of social hierarchies, such simple optimization models are unsatisfactory. To explore issues of human social organization we often must turn to the methods of evolutionary game theory (Maynard Smith 1982).

Game theory models are used in strategic environmental contexts where the optimal behavior depends on the actions of other individuals in the population, such as in

situations involving competition or cooperation (Maynard Smith and Price 1973; Maynard Smith 1974, 1982). In such strategic situations, the best strategy is usually *not* the one which *maximizes* an individual's fitness payoff, but one which will be *stable* over repeated interactions, especially when the strategy is played against itself (Maynard Smith 1974; Smith and Winterhalder 1992b). Such an *evolutionarily stable strategy* (ESS) is one that, if adopted by most members of a population, no alternative strategy can "invade" and do better (Maynard Smith and Price 1973). Often what is evolutionarily stable is to adopt a mixed rather than a pure strategy, such as "30% of the time use strategy *a*, 70% use *b*", or a mixed conditional strategy such as "if competitor *x* uses strategy *a*, use *b*" (Maynard Smith 1974, 1982).

A simple model known as the "Hawk/Dove game" illustrates the logic behind the ESS concept (Maynard Smith 1982:11–17; Maynard Smith and Price 1973). Consider a game in which there is competition for some resource and two alternative strategies exist, Hawk and Dove. There are three possible behaviors in this game: display, escalate, or retreat. A display will cause no injury, an escalation may cause injury, and a retreating individual abandons the resource. The Hawk strategy always escalates and either gets injured and retreats or causes a retreat. Dove first displays but immediately retreats if the opponent escalates. Which is the optimal behavioral strategy in this situation?

The Hawk/Dove game can be modeled through the use of a payoff matrix, a common tool in game theoretic models (Table 3.1.). If we assume that the resource being competed for has a gain to fitness value of V and injury has a fitness cost of C , then the payoff structure of the Hawk/Dove game is as follows (Table 3.1.): when a Hawk meets a Hawk, each

Table 3.1: The payoff matrix of the Hawk/Dove game from Maynard Smith (1982:12). As a convention, the payoff shown in each box is for the row player. The payoff is the change in fitness resulting from the contest

*Payoff Structure
of the Hawk/Dove game*

	<i>H</i>	<i>D</i>
<i>H</i>	$\frac{1}{2}(V - C)$	V
<i>D</i>	0	$V/2$

will always escalate to a fight and each has a 50% chance of either winning the resource, V , and a 50% chance of suffering the fitness cost of injury, C , or an average of $\frac{1}{2}(V - C)$. When a Hawk and Dove meet, the Hawk always escalates and the Dove immediately retreats, resulting in a gain of V to the Hawk but zero fitness change for the Dove. When a Dove meets a Dove both share the resource with fitness gain $V/2$ (Maynard Smith 1982:13).

In repeated iterations of such a game what will be the ESS? Clearly a population of all Doves results in the highest average payoffs in every iteration, but Dove is not evolutionarily stable, as a population composed of all Doves would easily be invaded and beaten every time by a Hawk (Maynard Smith 1982:14). Whether or not Hawk is a stable strategy depends on the actual fitness values assigned to the variables. For example, if the benefit from obtaining the resource is greater than the cost of injury ($V > C$), then it will pay to always play Hawk. However, if the inequality is switched and the

cost of fighting is greater than the benefit ($V < C$), then neither pure Hawk nor Dove is evolutionarily stable (Maynard Smith 1982:15). In this case Dove does best when played against other Doves but is not stable because Hawks always invade. Hawk is similarly unstable because the average payoff of Hawk/Hawk results in a negative fitness advantage. It turns out that in such a situation the optimal behavior is to play a mixed strategy whereby the average payoff from multiple interactions with Hawks and Doves is equal, i.e., play Hawk with probability V/C and play Dove with probability $1 - V/C$ (Hawkes 1992; Maynard Smith and Price 1973).

The Hawk/Dove model is useful here for two reasons. First, it simply and succinctly demonstrates methods and explanatory logic of the ESS. Second, and most importantly for the present purposes, the Hawk/Dove game illustrates that in an ecological context where either cooperation or competition is possible, the optimal behavioral strategy fundamentally depends on the payoff structure of critical resources. In the model presented below, the evolutionary ecological logic of optimization and evolutionary stability are used to model certain conditions favoring the evolution of social hierarchy in despotic, but cooperative, human groups.

3.2. An evolutionary ecological model

Here, a model is put forth which explains that hierarchical social organization will be an optimal and evolutionarily stable strategy in despotic situations wherein there are large benefits to cooperation between dominants and subordinates. Benefits to cooperation between dominants and subordinates will be high when each has something

to gain from continued interaction. One situation evaluated here in which this is the case, as it pertains to sedentary human populations, is when there are marked spatial differences in economic defendability and in the risks and uncertainty of critical resources.

3.2.1. The evolutionary ecology of social inequality: spatial habitat use, competition for resources, territoriality, despotism, and optimal group size

This section concerns the evolution of social inequality, measured by the degree of *despotism* in a social group. Despotism refers to an unequal distribution in the control of critical resources by one or a few individuals within in a group (Summers 2005; Vehrencamp 1983b). Here, a series of models are presented which together can account for the evolution of despotism. These models focus on the interrelated processes of spatial habitat use, competition for resources, territoriality, and evolutionarily stable group size formation, which together greatly influence selection for despotism. To begin, it is assumed that different kinds of resource distributions select for different kinds of competitive strategies (scramble versus competitive exclusion) which in turn affect despotism (Cashdan 1992; Fretwell 1972; Pianka 1999; Summers 2005).

When approached from an EE framework, the foundations of despotism reside in the responses of individuals to differences in the patterning of critical resources, such as mates, territory, or food. Following from the assumption that differences in habitat quality affect the fitness of the individuals utilizing them, it is necessary to explore

models of optimal spatial habitat use. Assuming that habitats differ in their quality, what is the optimal, or evolutionarily stable, strategy of habitat selection? The ESS in this situation will depend on the habitat in question and the behavior of other individuals. To address this issue, evolutionary ecologists have developed a series of models of habitat selection based on the *ideal-free distribution* (Fretwell 1972; Fretwell and Lucas 1969).

3.2.1.1. The ideal-free distribution

The quality of a habitat is determined by its net payoff in reproductive fitness, often measured by the density and predictability of available resources (Fretwell 1972).

Consider a population of individuals colonizing a new environment who are presented with a set of habitats that differ in their quality. What is the optimal choice for individuals to make in such a situation? Fretwell (1972; Fretwell and Lucas 1969) tackled this problem by introducing the *ideal-free distribution* (IFD) model.

Individuals colonizing a spatially heterogeneous environment are expected to settle and utilize the best available habitat (Fretwell 1972:82). The IFD predicts that individuals will scramble to settle the highest quality habitat available and that all individuals have equal success rates; stated another way – individuals are expected to have *ideal* habitat selection behaviors and that they are *free* to choose the highest quality habitats (Fretwell 1972:85). The IFD has the simplifying assumptions that all individuals are equal in their competitive abilities and that habitat quality decreases with population density. The proximate causes of decline in habitat quality are often *interference* and *depletion*. Depletion is the actual removal of resources from a patch, whereas

interference is “a short-term decline in intake rate due to the presence of others” (Sutherland 1996:9). In addition, habitat quality can also decline in value due to many other changes in the physical environment, such as climate change and tectonic events (Fitzhugh 1996, 2003). The ESS in the IFD is a function of the actions of other individuals in the environment (Fretwell 1972; Fretwell and Lucas 1969).

Suppose there are multiple habitats available for colonizers, A, B, C, \dots, n , and that each habitat varies in its quality such that $A > B > C \dots > n$. Upon settlement of the area, the IFD predicts that individuals will first settle habitat A . Because the IFD is density dependent and habitat quality decreases with population density, individuals are expected to settle habitat A up to a density where the quality of A now equals the quality of B . Incoming individuals should then be expected to settle habitat B until its quality matches that of habitat C , and so on until all habitats are of equal quality, determined by the density of individuals (Fretwell 1972:89) (see Figure 3.1.). In this way, in the IFD the ESS is to play a mixed strategy – settle the habitat A , however, if the interference or depletion of A exceeds some threshold, then settle B , and so on (Maynard Smith 1982; Sutherland 1996).

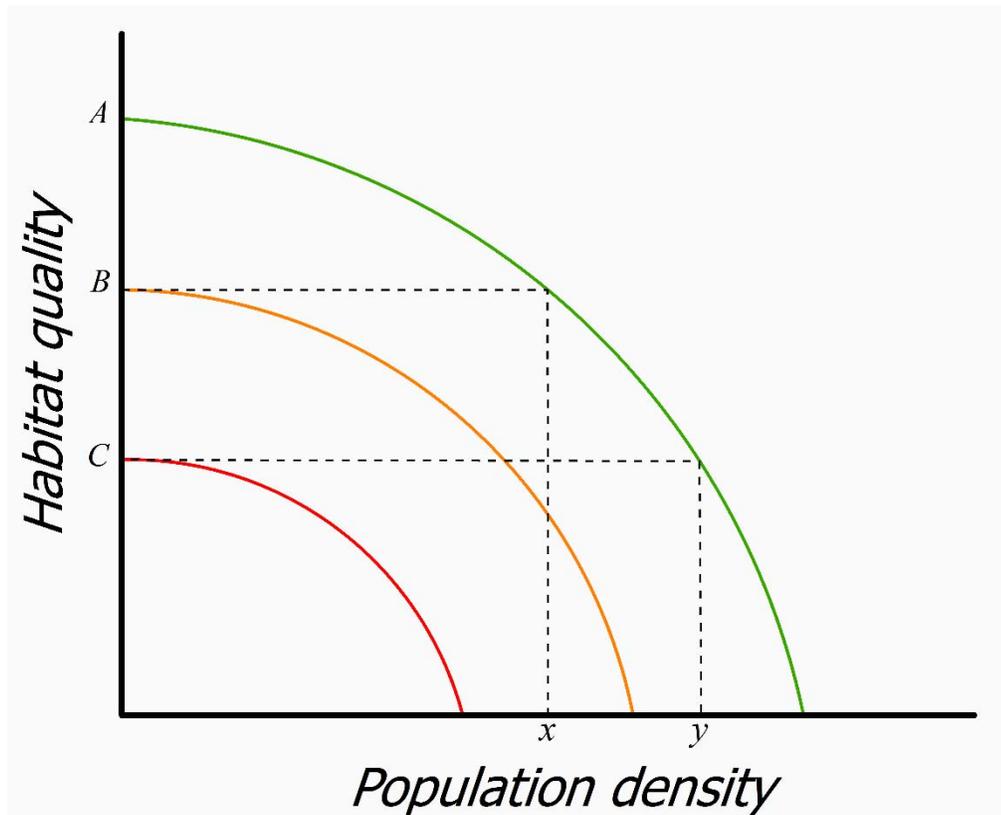


Figure 3.1: The Ideal-Free Distribution model for three ranked habitats $A > B > C$. Habitat quality (y-axis) declines with increasing population density (x-axis). Points x and y on the x-axis represent the population density at which habitat $A = B$ and $A = C$, respectively. Figure adapted from Davies et al. (2012) and Kennett et al. (2009).

The IFD occurs in tandem with *scramble competition*, which is non-aggressive but predicts that once the highest quality resource patches are occupied, individuals then move on to the next best patch (Pianka 1999). Under the conditions of the IFD, the distribution of individuals in the population stabilizes so that all habitats are of equal quality and that all individuals have equal fitness, determined by their equal access to resources. Therefore, in an IFD no inequality or despotism is possible.

To model the evolution of despotism we must relax some of the assumptions of the IFD. First, we must address models that do not assume that individuals are identical in their competitive abilities and in their ability to settle different habitats. Second, we must assume that individuals are capable of further altering their habitat selection strategies in different ecological circumstances, that is, we must assume greater phenotypic behavioral plasticity. If these assumptions are relaxed, it is possible to incorporate the effects of *contest*, or aggressive, competition and territoriality – critically important behaviors when considering the evolution of despotism (Fretwell 1972; Pianka 1999).

3.2.1.2. Economic defendability and territoriality

The evolution of despotism is contingent on the ability of an individual to exclude others from accessing high quality resources, which is often accomplished through territorial behaviors. Fretwell (1972:92) defines territorial behavior as “any site-dependent display behavior that results in *conspicuousness* and in *avoidance by other similarly behaving individuals*” (emphasis in original). Territorial behavior is any which deters individuals from encroaching on the other’s territory, be it signaling displays or actual physical aggression. A territory is defined as any area for which an individual controls exclusive access (Dyson-Hudson and Smith 1978). The evolution of territoriality is a broad and complex topic in EE (see Brown 1982; Davies and Houston 1984; Dyson-Hudson and Smith 1978; Fretwell and Lucas 1969; Hölldobler and

Lumsden 1980; Schoener 1983), so for the sake of brevity, only the ecological conditions selecting for human territoriality are explored here.

The selection for territorial behavior is dependent on the *economic defendability* of critical resources (Brown 1964). The economic defendability of a given resource is based on the relative costs and benefits of its defense – if there is competition for resources and the benefits of defense outweigh the costs, then the resource is said to be economically defendable (Brown 1964; Cashdan 1992; Davies et al. 2012). The costs of territoriality include the energetic costs of territory defense, risk of injury resulting from competitive exclusion, diversion of energy from other behaviors, and risks associated with a reliance on a limited habitat, whereas the chief benefit of territoriality is exclusive access to the resources of the territory (Cashdan 1992; Dyson-Hudson and Smith 1978:24). The relative costs and benefits of territoriality will vary in different ecological conditions.

Economic defendability is primarily determined by competition for high quality resources and the spatiotemporal patterning of resources (Cashdan 1992; Davies and Houston 1984; Dyson-Hudson and Smith 1978). Two characteristics in the spatiotemporal patterning of resources are important in determining economic defendability – density and predictability (Dyson-Hudson and Smith 1978). Resource density can be measured as the amount of a resource per unit area. Resource predictability is a more complicated concept; however, for the time being predictability can be thought of as the degree to which the availability of a resource is correlated over

different timespans (Cashdan 1992)⁷. When a resource is scarce and unpredictable its economic defendability is low and therefore territoriality will be costly (Dyson-Hudson and Smith 1978). However, in a situation where resources are both dense and predictable the economic defendability is high and territorial behavior will be optimal. This is because a high density of predictable resources allows for the low cost defense of a small area with the high benefits of relatively constant high-quality resources (Dyson-Hudson and Smith 1978:25).

One consequence of this economic defendability model is that differences in resource structure will also affect the range (i.e., territory size) needed to meet individual energetic requirements (Davies and Houston 1984:149). When resources are scarce and widely distributed we should expect an individual's range to similarly be widely disbursed. In the case of humans we should expect relatively fluid settlement systems, such as those seen in some foraging societies (Dyson-Hudson and Smith 1978; Kaplan et al. 2009). However, when resources are dense and predictable then we should expect territory size (or human settlements) to map onto this resource distribution and be relatively large, fixed, and clustered in these high quality areas (Cashdan 1992; Davies and Houston 1984:150; Hölldobler and Lumsden 1980).

The above explanation of the economic defendability of resources is necessarily simple, and it highlights the important point that territoriality is expected when resources are relatively dense and predictable over time and across space. The economic defendability model also has important implications for characteristics of settlement

⁷ The concept of (un)predictability will be given more complete treatment below.

structure and social organization. Indeed, in the case of humans, economic defendability is often argued to be a driving force in the evolution of despotic versus egalitarian societies (see Kaplan et al. 2009). It should be noted that there is a wide spectrum of territorial and non-territorial resource utilization strategies, and the reader is directed to the citations above for a more in depth treatment of this subject. However, for the present chapter it is important to emphasize that certain resource patterns greatly influence the selection for territoriality, which in turn is crucial for the emergence of despotism.

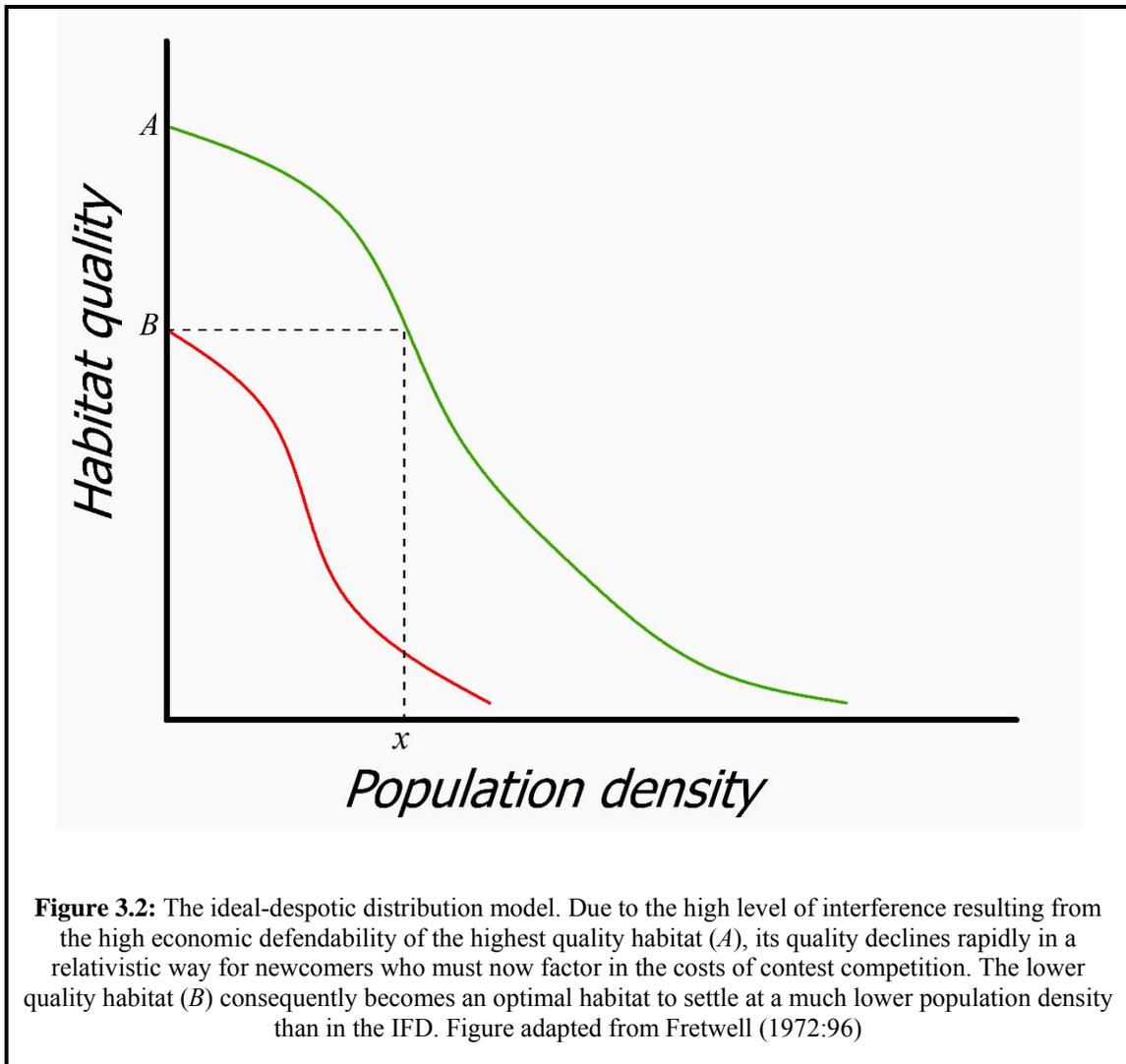
3.2.1.3. The ideal despotic distribution

Having discussed the IFD and the ecological conditions favoring the evolution of territoriality, it is now possible to model the evolution of despotism in social groups. As stated previously, despotism is heavily influenced by differences in the spatial patterning of resources. What will be the evolutionarily stable habitat selection strategy when individuals vary in their competitive abilities and exhibit territorial behavior? A variant of the IFD known as the *ideal despotic distribution* is ideally suited to explaining such a situation (Fretwell 1972; Fretwell and Lucas 1969).

Consider again the thought experiment presented above where a group of individuals colonize an environment characterized by a patchy resource distribution. If resources are economically defendable, then the assumptions and outcomes of the IFD change (Fretwell 1972:95). Like in the IFD, again it is expected that the first colonizers will exhibit *ideal* habitat selection behaviors and initially scramble to settle the highest quality habitats. However, if the territorial behavior of individuals (i.e., high

interference) is such that it is dangerous for incoming individuals to attempt to colonize habitats that have already been settled, then individuals are no longer *free* to settle all habitats (Tregenza 1995). When individuals vary in their competitive abilities and success in controlling high quality areas we should expect the initial colonizers or better competitors to eventually control a disproportionate amount of high quality resources, resulting in *despotism* (Fretwell 1972:92; Summers 2005). This leads to a different kind of habitat distribution termed the *ideal despotic distribution* (IDD) (Fretwell 1972).

The IDD differs from the IFD in that habitat quality is now determined by both depletion *and a higher degree of interference* in the form of competitive exclusion by resident individuals. The relative quality of the highest ranked habitats therefore declines much more rapidly for newcomers in the IDD (see Figure 3.2.). Incoming individuals are still expected to exhibit ideal habitat selection behaviors but must now adjust their strategies to factor in the fitness costs of contest competition or living in lower quality resource areas. In an IDD, lower-quality competitors will often accept a lower quality habitat because the cost from interference in the higher quality patch (which contains higher quality competitors) would be higher than the benefits. The ideal, or evolutionarily stable behavior is to accept the lower quality option (Sutherland 1996).



The fitness consequences of an IDD are clear. As identified by Fretwell (1972:98), one of the most important outcomes of the IDD is that, “if within an area some habitats are better than others, then the territorial restrictions...restrict newly settling individuals to the less good habitats.” This difference in the control of high quality resources between individuals results in reproductive skew, which is measured as the degree to which reproductive fitness within groups is biased toward a small number of individuals (Keller and Reeve 1994; Vehrencamp 1983b). In situations involving long-

term reproductive skew and despotism, those individuals controlling the disproportionate amount of the reproduction and high quality resources are termed *dominants*, while the lower status individuals are referred to as *subordinates* (Vehrencamp 1983b). In despotic situations characterized by marked reproductive skew, a subordinate, hypothetically, has the option of leaving the lower quality habitat in search of a better one or remain within the group. Despotic groups are expected to form when the benefits to being in the group are higher than being solitary and when the cost of leaving the group is high (Vehrencamp 1983a). This leads to issues involving the costs and benefits of group living.

Before proceeding into the important topic of evolutionarily stable group sizes, it is first necessary to discuss a variant of the two ideal distribution models presented above. Both the IFD and IDD assume that habitat quality always decreases as a function of population density, but this assumption does not hold in many situations, especially those involving beneficial group living. In many situations a population will not be reproductively stable at low population densities and therefore habitat suitability will initially increase with population growth. This is referred to as the *Allee effect* (Allee et al. 1949; Fretwell 1972). Allee effects also occur in situations where the benefits of social behavior or living in groups are high. There are often many benefits to group living, such as increased territory defense, more reproductive opportunities, and increased resource productivity (Krause and Ruxton 2002). However, ideal distributions with Allee effects are still density dependent, and after a certain point a continued increase in group size will begin to lower the suitability of an environment. For the present purposes it is

therefore necessary to incorporate optimal group size and the costs and benefits of group living into the model.

3.2.1.4. Optimal group size

In an IDD subordinates, in theory, have the choice of either remaining in the group and accepting their lower status position or leaving the group to be solitary (or join another group) (Boone 1992; Vehrencamp 1983a, 1983b). The outcome in such a situation depends on the various costs and benefits of group living (Krause and Ruxton 2002). Vehrencamp (1983b:676) argues that joining a group is only beneficial only when the per capita fitness benefit of grouping is higher than the cost of leaving the group and being solitary.

In a growing population characterized by a despotic distribution with Allee effects, both the costs and benefits of living within the group increase as group size increases. The increase in benefit is a decelerating function, meaning that the initial increase in group size results in a sharp increase in individual benefits which then begin to decline as group size grows. Conversely, the cost function of group size accelerates with each additional individual further reducing the net benefits to group members (Krause and Ruxton 2003:57). Therefore, groups are expected to reach a size where the costs peak and the benefits begin to decline. In theory, then, there should always be an optimal group size (Pulliam and Caraco 1984; Krause and Ruxton 2002) (see Figure 3.3.).

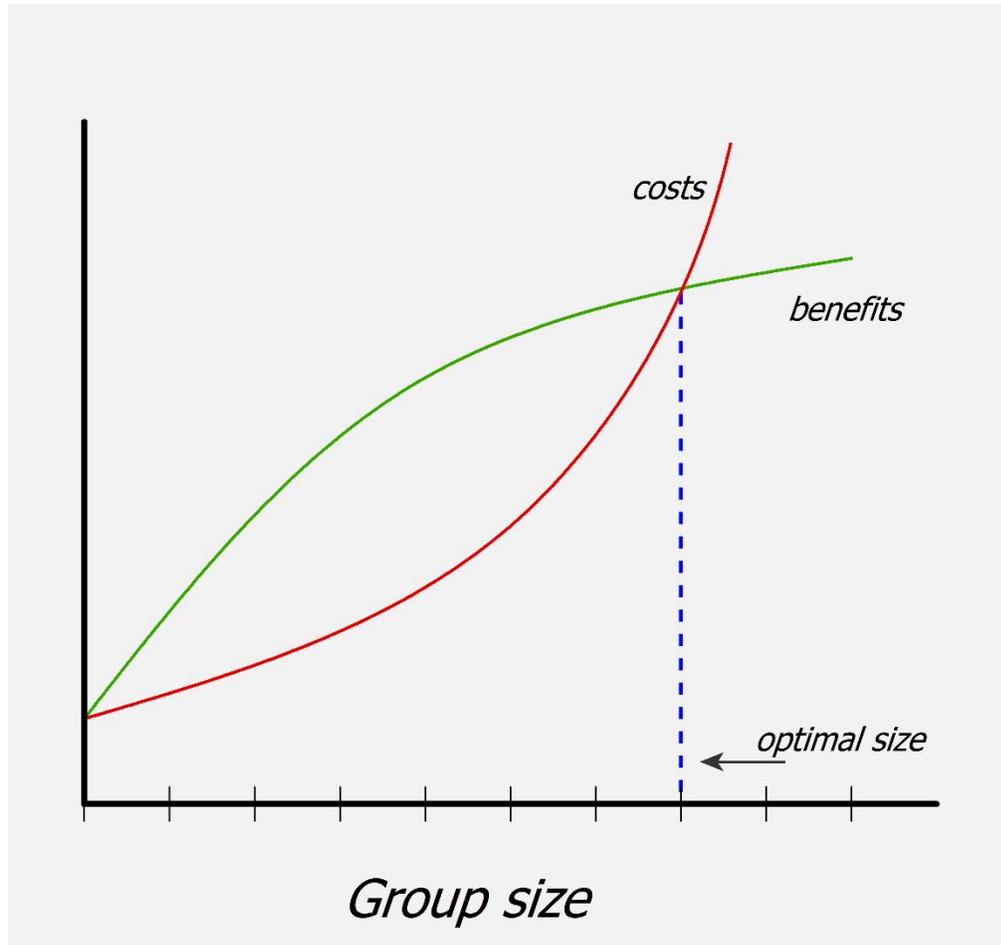


Figure 3.3: The theoretical optimal group size. Figure adapted from Krause and Ruxton (2002:57).

However, in reality the optimal group size will often be unstable in nature and groups will tend to be of sub-optimally large sizes (Sibly 1983). Suppose that there are large benefits but also some non-negligible costs to group membership. This cost-benefit ratio has an optimum threshold whereby the benefits to group membership are maximized

and the costs are minimum. Based on this simple model we should expect groups to be of optimum size. Sibly (1983) shows, however, that there is an optimal group size which maximizes the fitness benefits for everyone in the group, but that in actuality group size will be unstable and we should expect group size to be larger than optimal. Consider a simple example: suppose there exists an optimal group of size x_{op} which maximizes the fitness of all individuals in the group. Another individual comes along and joins the group becoming its $x_{op}+1$ member. This additional individual has now pushed the group size above optimum, but every group member still has a higher fitness advantage than they would on their own. Based on the model shown in Figure 3.4., we should expect group size to grow up to the point where the fitness advantages of group membership are just less than being solitary (Sibly 1983). This largest beneficial group size has come to be known as the *Sibly size* (Krause and Ruxton 2002).

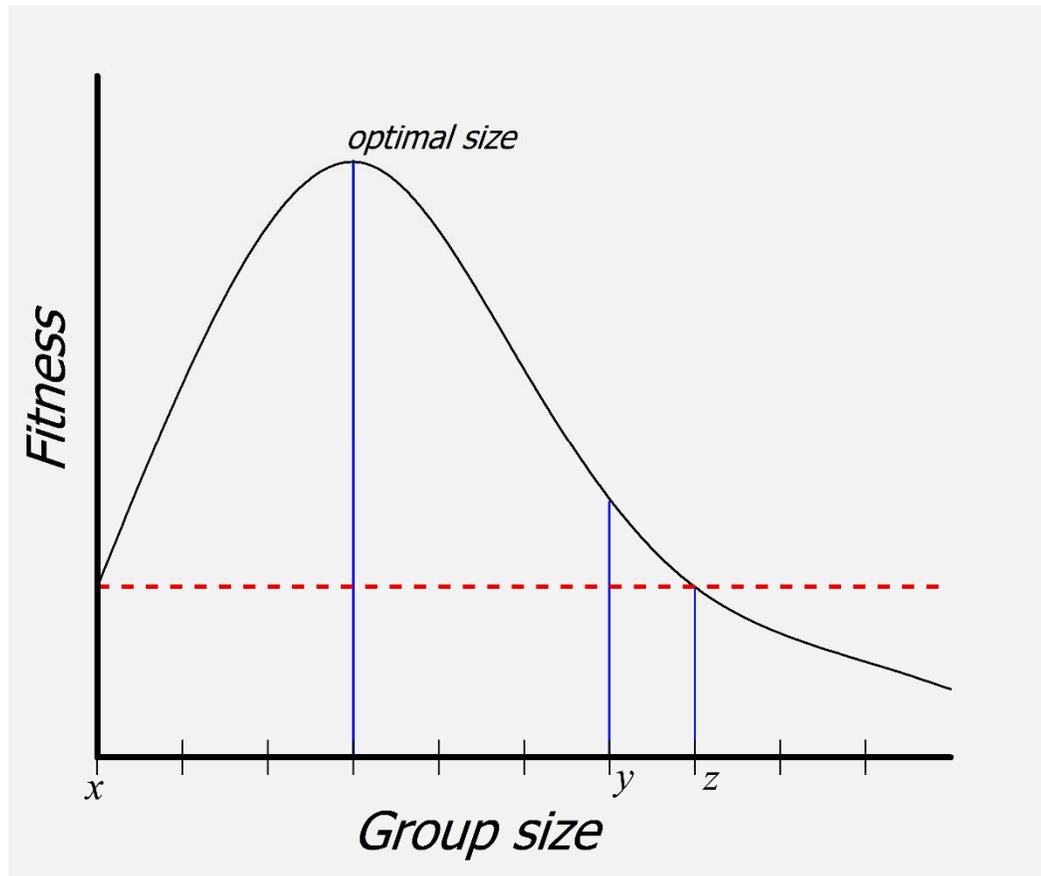


Figure 3.4: The theoretical optimal group size is unstable. x represents a group of size one, and the red dashed line shows the fitness of a solitary individual. z represents the point at which the group becomes so large that the net benefit to each individual is the same as being solitary. y shows the so-called Sibly size – the group size just less the point where the fitness advantages of group membership are just less than being solitary. Figure adapted from Sibly (1983) and Krause and Ruxton (2002:59).

To summarize, while we might predict the optimal group size, in fact individuals should only choose to be in a group as long as being in the group does not result in lower fitness than being solitary (Krause and Ruxton 2002:59). Once the group surpasses the optimal group size by a small amount, newcomers will experience a huge fitness gain by joining and present group members will only experience a small reduction in fitness. In

many cases this small reduction in fitness will be tolerated to a certain degree because the cost of excluding newcomers is often greater than the benefit; this is referred to as “tolerated theft” (see Blurton Jones 1984). As Krause and Ruxton (2002:59) explain, “the newcomer stands to gain more from joining than an existing group member can gain from excluding it. Hence exclusion of the newcomer is unlikely, and group size will increase.” Once the Sibly size is surpassed, the optimal choice for additional individuals is either live solitarily or to join other groups.

This same line of reasoning presented above for the evolution of group size has been independently addressed by evolutionary anthropologists. Smith (1981) argues that group foraging will only be optimal up to a certain point beyond which foraging efficiency begins to decline. Individuals should therefore only join foraging groups when doing so does not lower the per capita net rate of energy capture for the whole group (Smith 1981; 1983b). Independent of Sibly (1983), Boone (1992) recognized that in the formation of sedentary groups there will be a conflict between preexisting members and joiners such that joiners should attempt to join groups when doing so increases their own fitness, even if joining lowers the overall net fitness of other individuals in the group. Boone (1992:302) has formally modeled this issue of evolutionarily stable group size for sedentary populations (such as human agriculturalists). Under optimal conditions, an individual should seek to join a group as long as,

$$R_n > R_1$$

Where R_n is the per capita energy return rate for groups of a given size n , and R_1 is a solitary individual. This is referred to as the "joiner's rule" (Boone 1992:303). Groups should favor the addition of more members as long as,

$$R_n > R_{n-1}$$

A conflict will emerge when the benefits to an individual of being in a group are greater than the groups benefit of allowing the individual to join, or,

$$R_{n-1} > R_n > R_1$$

If the group in question is characterized by a high degree of sociality and despotism, then the models of evolutionarily stable group size presented above have important implications. In such a situation it is predicted that dominants will skew resources and reproductive benefits in their favor up to a point just less than the threshold where subordinates would do better on their own (i.e., Sibly size) (Boone 1992; Higashi and Yamamura 1993; Krause and Ruxton 2002; Vehrencamp 1983a). This leads to two important predictions. First, if the benefits to group living are high and solitary living is costly or unviable, then subordinates will tend to accept marked lower status and an unequal portion of critical resources (Hamilton 2000:684; Vehrencamp 1983a). Second, dominants are expected to "recruit" subordinates into their group such that the dominant's fitness is maximized and the group size is stable enough to discourage emigration (Hamilton 2000).

The two predictions of this stable group size model in a despotic distribution have important consequences for the evolution of social inequality and hierarchy. First, the model predicts that social inequality will be marked in areas with high spatial

heterogeneity in resource quality and where there are large benefits to group membership. Second, the model also predicts that in certain situations subordinates and dominants will both benefit from a despotic social arrangement. This second point assumes cooperation between dominants and subordinates (Hamilton 2000), which is a crucial prerequisite for the evolution of social hierarchies (Bourke 2011). The problem of the evolution of cooperation is discussed in the following section.

3.2.1.5. Summary

The evolution of social inequality is dependent on the distribution of critical resources in the environment (Cashdan 1992). Upon initial settlement of a habitat individuals are expected to exhibit habitat selection behaviors resulting in an ideal-free distribution whereby they are free to choose the best habitats (Fretwell 1972; Fretwell and Lucas 1969). As population density increases so does competition for the highest quality habitats, and if resources are economically defendable, then territoriality will become an ESS (Cashdan 1992; Davies and Houston 1984; Dyson-Hudson and Smith 1978). If individuals display territorial behaviors and attempt to exclude others from certain high-quality resource patches, then the conditions of the ideal-free distribution no longer hold (Fretwell 1972; Fretwell and Lucas 1969; Tregenza 1995), and competition for the highest quality resource patches results in some individuals controlling a disproportionate amount of high quality resources, or an ideal-despotic distribution (Fretwell 1972; Sutherland 1996). Such a situation leads to a high degree of despotism and reproductive skew with marked dominant and subordinate status positions (Summers

2005; Vehrencamp 1983a, 1983b). If the social situation involves Allee effects, whereby the addition of more individuals in a habitat increases the net benefit for group members, then group size is expected to increase up to the Sibly size (Allee et al. 1949; Fretwell 1972; Krause and Ruxton 2002; Pulliam and Caraco 1984; Sibly 1983). Subordinate individuals in a despotic social arrangement are then faced with the choice to leave the group or remain and accept their lower status position (Vehrencamp 1983a, 1983b). In situations where solitary living is costly or unviable, such as in a spatially limited environment, subordinates are expected to stay within despotic groups. The size of despotic groups will tend to be sub-optimally large but evolutionarily stable such that dominants maximize their own fitness while maintaining groups above the Sibly size threshold (Hamilton 2000). In such a situation of prolonged reproductive skew and despotism the evolution of evolutionarily stable social inequality is expected.

While despotism has often been argued to adequately account for the evolution of social hierarchy in human groups (e.g., Kennett 2005; Kennett et al. 2009; Summers 2005), models of despotism themselves are insufficient to explain the evolution of institutionalized social hierarchies seen in many human groups. There are two important reasons for this. First, despotism only explains how subordinate and dominant statuses arise from differences in resource holding potential; despotism in itself is insufficient to account for the evolution of leadership or special interest groups (discussed below) (Boone 1992; Hooper et al. 2010). Second, models of despotism assume stable cooperation between subordinates and dominants, a phenomenon which itself requires explanation and is dependent on certain ecological circumstances. While despotism is indeed an important prerequisite for social hierarchy, the evolution of stable social

hierarchies with multiple ranked classes requires the evolution of leadership roles and, most importantly, large-scale cooperation, an issue not often addressed in Hawaiian and Pacific archaeology (However, see Carballo [2013] and Carballo et al. [2014] for recent theoretical and substantive work on cooperation and collective action in other geographic regions).

3.2.2. The evolution of cooperation, special interest groups, and social hierarchy in a risky and uncertain environment

The previous section detailed the conditions favoring the evolution of despotism – a large skew in the distribution of critical resources among ranked individuals. Models of despotism, however, while sufficient to explain the evolution of social inequality (i.e., dominant and subordinate rankings), fail to explain the evolution of leadership and multi-tiered hierarchies seen in some human groups, such as in ancient Hawai‘i. Furthermore, sustained despotism assumes that there is continued cooperation between dominants and subordinates, but cooperation itself requires explanation and is only predicted in certain environmental contexts (Axelrod 2006; Davies et al. 2012). Cooperation will be the ESS when costs incurred by not cooperating are great, particularly in risky and unpredictable environments. As will be shown, the problem of cooperation in the face of risk and unpredictability provides the impetus for the evolution of leadership and special interest groups, resulting in evolutionarily stable social hierarchies (Boone 1992, 2000; Diehl 2000; Hooper et al. 2010).

3.2.2.1. The evolution of cooperation, special interest groups, and social hierarchy

Cooperation is defined as any behavior which provides a benefit to another recipient individual, possibly at a cost to the actor, and which has partly been selected for because of the beneficial effect on the recipient (West et al. 2007:416). In any social hierarchy cooperation between individuals is critical (Bourke 2011; Maynard Smith and Szathmáry 1997). This is because hierarchy is contingent on the suppression of within-group conflict; “if the level of internal conflict is too great, the higher level of organization either fails to emerge or is unstable and collapses” (Bourke 2011:3). Therefore, the existence of social hierarchies in both human and animal societies presents an interesting evolutionary problem. Social hierarchies are characterized by differential access to resources and mates, and therefore result in fitness differences between dominants and subordinates (Bourke 2011). This presents a problem because natural selection predicts that individuals will seek to maximize their own fitness (Davies et al. 2012), but social hierarchies by definition result in large numbers of individuals accepting lower reproductive success than they might have if they emigrated from the hierarchical society. For many non-human hierarchies, such as the insect societies (e.g., Hölldobler and Wilson 2008), this problem is explained through Hamilton’s rule of inclusive fitness, which explains how subordinate societal roles are maintained by a high

degree of relatedness between individuals (Bourke 2011; Hamilton 1964)⁸. Inclusive fitness theory, however, is not sufficient to explain cooperation between non-kin, a widespread phenomenon in nature (Clutton-Brock 2009; Axelrod and Hamilton 1981). This problem is even more salient when considering the evolution of most human social hierarchies, which are often composed of very large numbers of unrelated individuals.

Initially, the issue of cooperation among unrelated individuals was approached with reference to reciprocity (Trivers 1971). There are both costs and benefits to cooperation – the costs accrue because behavior which benefits another individual consequently redirects valuable energy away from activities which could benefit yourself. However, if unrelated individuals interact more than once, the costs of cooperation can be offset by reciprocity. Whatever cost one incurs from cooperating will be paid back when the favor is returned. There is, however, a problem with this so-called “reciprocal altruism” model.

The problem of reciprocal cooperation among non-kin is simple. Consider a situation where individuals can either cooperate or defect. An individual on the receiving end of cooperation receives some fitness benefit; however, the act of cooperation itself is costly and therefore it pays to exploit the situation and defect (thus incurring no cost) and still receive all the benefit. It is easy to see that cheaters would quickly invade a population of pure cooperators. All individuals would do best if all cooperated, but reciprocity is not guaranteed. It therefore pays to always defect. This is the logic of

⁸ While inclusive fitness theory is still widely accepted in biology, recently there have been a number of detractors claiming that we discard inclusive fitness theory in favor of a revamped group selection. The reader is directed to Nowak et al. (2010) for a discussion of the controversy.

many evolutionary games and collective action problems, such as the well known “Prisoner’s dilemma” (Axelrod and Hamilton 1981; Rapoport and Chammah 1965) and the “tragedy of the commons” (Hardin 1968).

The solution to this problem of reciprocal cooperation, or the *iterated Prisoner’s dilemma*, is to employ a mixed conditional strategy. In a series of computer simulation experiments, Axelrod and Hamilton (Axelrod and Hamilton 1981; Axelrod 2006) show that the best strategy for an individual to play in an iterated Prisoner’s dilemma is always cooperate in the first interaction and then copy the opponent’s strategy in all repeated interactions. The logic is simple: cooperate with cooperators and defect when interacting with cheaters. This “tit-for-tat” strategy is evolutionarily stable when played against itself and can easily invade a population of individuals playing a multitude of different strategies. Even in a population composed of all cheaters, a small group of individuals employing the tit-for-tat strategy can invade (Axelrod 2006:68). Indeed, based on this strategy, “cooperation based on reciprocity can thrive and be evolutionarily stable in a population with no relatedness at all” (Axelrod and Hamilton 1981:1394). However, cooperation based on conditional reciprocity is only evolutionarily stable if there is a high probability of continued interaction between individuals (Axelrod and Hamilton 1981:1393). This presents a problem when dealing with large populations composed of individuals who likely do not interact on a daily basis, such as many sedentary human groups (Boyd and Richerson 1988).

Conditional reciprocity likely accounts for cooperation in small human social groups, such as those that characterized most of our evolutionary history (Boyd and Richerson 2005; Kaplan et al. 2009). This is because in small social groups pairs of

individuals are likely to interact repeatedly over their lifetimes. This is not the case, however, in large-scale human groups where an individual interacts with multiple others on a daily basis, some of whom they are likely to never interact with again. In such situations “free-riders,” individuals who do not pay the cost of cooperation but reap its benefits, have higher payoffs than conditional cooperators. As group size increases, cooperation based purely on conditional reciprocity begins to break down because the cost of frequent non-reciprocation makes defection the optimal strategy (Boyd and Richerson 1988). Unless some mechanism exists to monitor and deter free-riding, group sizes are expected to remain small.

For cooperation to be evolutionarily stable in large groups, the costs of defection must be sufficiently great that they deter free-riding. One strategy that will be successful is if free-riders are punished for non-reciprocation (Boyd and Richerson 1992). Punishment can take a variety of forms, such as withholding future cooperation, violence, or gossip, but what is important is that the punishment is sufficiently costly to free-riders such that they would do better to cooperate in the future. If the cost to non-cooperators from punishment is not sufficiently severe, they will still outcompete cooperators (Smith and Choi 2007). Like in the previous model, however, this situation becomes problematic as group size increases because monitoring group members and punishment becomes costly to the punisher, whereas the benefits of the punishment (enforced cooperation) are experienced by the rest of the group at no extra cost. Natural selection, therefore, should favor the invasion of the group by non-punishing cooperators; this situation is known as the *second-order* cooperation problem (Boyd and Richerson 1992).

The second-order problem can be avoided if punishers receive benefits in addition to cooperation (i.e., a “fee” or “tax”) which cancels out the cost of punishing (Boyd and Richerson 1992; Boyd et al. 2010; Henrich and Boyd 2001). When cooperation is sufficiently beneficial and punishment is coordinated, punishers can assume special benefits or social status (Boyd et al. 2010). In despotic groups, Boone (1992:309) refers such cooperation enforcers as a “special interest group” (SIG), which consists of leadership or policing social roles, for instance chiefs or land-managers. As group sizes become large in ecological conditions favoring despotism (e.g., limited habitat, patchy resources) *and* the need for cooperation (e.g., risk and uncertainty, see Section 3.2.2. below), individuals are expected to favor a stratified group structure consisting of dominants, subordinates, and SIGs, in other words – a social hierarchy (Boone 1992).

Recently, Boone’s (1992) model of social hierarchy formation has been formally modeled by Smith and Choi (2007) and Hooper et al. (2010). Using an agent-based simulation model, Smith and Choi (2007) show that SIGs will be favored when groups sizes are large enough that the costs to cooperators of paying the additional benefits needed by the SIG are not too high; that is, when the costs of maintaining a special interest group can be shared by many individuals. However, Smith and Choi (2007:116) also suggest that SIGs are expected to raise their “fee” to highest possible value but without surpassing the threshold beyond which it no longer pays for dominants and subordinates to cooperate. This is a similar prediction as those of the optimal despotic group size model presented in Section 3.1.4. In this situation we should further expect to see a high degree of despotism between subordinates and SIGs, as dominants are expected to be able to pay the SIG fee at low cost to themselves (Hooper et al. 2010),

whereas the SIG is expected to raise their fee to highest possible value that a subordinate will tolerate (Smith and Choi 2007).

Using mathematical game theory, Hooper et al. (2010) formally model the hypothesis that individuals should favor a SIG to sustain cooperation in large despotic social groups. Individuals in cooperative despotic groups who are willing to pay a “tax” to SIGs, such as a share of the group’s productivity that offsets the leader’s cost of punishment, outcompete those who are not. Hooper et al. (2010) determine that individual strategies favoring cooperation in a social hierarchy are more evolutionarily stable than those without SIG, and this outcome is significantly increased when groups become very large, when groups are despotic, and *when the benefits to cooperating are great*⁹.

3.2.2.2. Environmental risk and uncertainty as selective mechanisms for hierarchical cooperation

One particularly strong selective force in the evolution of hierarchical cooperation addressed here is environmental risk and uncertainty, specifically in situations where the effects of risk accrue unevenly among individuals in a population. Before advancing to an explanation of how risk and uncertainty select for hierarchical cooperation under certain environmental conditions, it is important to define exactly what these terms refer to in EE.

⁹ The reader is directed to Kohler et al. (2012) for an application of the Hooper et al. (2010) model of the evolution of cooperative leadership and social hierarchy using an agent-based simulation of prehistoric Puebloan society.

While both involve problems associated with stochastic environments, the concepts of risk and uncertainty have distinct meanings (Stephens and Charnov 1982; Stephens 1990). *Risk* refers to the degree of stochastic variation in the outcome of some strategy, whereas *uncertainty* refers to an individual's lack of complete information about the outcome (Smith 1988:231). Distinguishing between risk and uncertainty is important for analytical purposes, as risk does not necessarily involve uncertainty. For example, an individual that has perfect information about the outcomes of different strategies (i.e., no uncertainty) will still have to deal with the variation (i.e., risk) (Smith 1988:231). For example, if the temporal frequency of food shortages in a given habitat is risky but totally predictable (i.e., no uncertainty), then individuals can respond by not relying on those areas when shortages are likely (Low 1990). However, this is unlikely when the level of uncertainty is high.

Individuals are expected to pursue strategies which, in most situations, minimize risk and always seek to minimize uncertainty (Smith 1988; Stephens and Charnov 1982; Stephens 1990; Winterhalder 1986, 1990)¹⁰. In situations where an individual should prefer less risk, they are expected to pursue strategies which average, or smooth out, the variation in the outcomes of their strategies (Cashdan 1992; Smith 1988). While problems of risk are relatively simple (e.g., extreme variation in decision outcomes), uncertainty is more nuanced. For analytical purposes, uncertainty can best be thought of as involving problems of resource (un)predictability (Colwell 1974; Low 1990).

Predictability is associated to two related concepts of measurement – *constancy* and

¹⁰ In certain situations an individual would do best to choose risky foraging strategies. For example, in situations with one constant (i.e., low risk) but inadequate resource and one highly variable (i.e. risky) resource, an individual is expected to choose the riskier resource (Stephens 1990).

contingency (Cashdan 1992; Colwell 1974; Low 1990). If a resource shows very low variation over time, then it is predictable because of its constancy; if the resource exhibits large amounts of variation but does so depending on the occurrence of some other event, then it is predictable because of contingency (Cashdan 1992: 238). When the risk associated with relying on some critical resource is unpredictable, then individuals are expected to pursue a range of different coping strategies which average out spatiotemporal variation, such as mobility, reciprocal resource exchange, information sharing, increasing diet breadth, or storage (Cashdan 1990a, 1992; Halstead and O'Shea 1989; Kaplan et al. 1990; Smith 1988; Smith and Boyd 1990; Winterhalder 1990). The optimal risk minimization strategy will vary depending on the environmental circumstances.

In despotic situations where mobility is unviable and resources are dense and predictable in certain areas and low-quality, risky, and uncertain in others, those in the resource poor areas (potential subordinates) will be much more affected by risk than those in the high-quality areas (potential dominants). Having established that both dominants and subordinates benefit by cooperating, the risk minimization strategy expected in such a situation is often reciprocal exchange. For example, in the event of a severe resource shortage (possibly due to a drought or other natural disaster), those in the lower-quality resource patches will be severely affected, but those in the highest-quality resource areas will likely not suffer as great a resource loss. In this situation there is the possibility for the evolution of "patron-client relationships" (Boone 1992), whereby dominants exchange excess resources with subordinates for some kind of reciprocated fitness benefit later on, or what Diehl (2000:21) refers to as "social debt." In human

populations this often involves reciprocation of resources, labor, or territorial defense. Such “magnanimous” resource sharing by dominants will likely be relatively low cost and may actually have the added benefit of signaling their own fitness quality to other individuals (Boone 1998, 2000). However, the models presented in Section 3.2.1. predict that subordinates will attempt to cheat and not reciprocate if possible, and therefore the evolution of a hierarchical social structure involving SIGs who enforce cooperation is expected.

If this pattern of unevenly experienced risk and uncertainty in reciprocal despotic situations persists in large populations, it is expected that individuals will favor the evolution of stable hierarchical cooperation involving dominants and subordinates (i.e., patron-client relationships), along with leadership in the form of SIGs which enforce cooperation. It is in these patchy, risky, and unpredictable environments where the benefits to cooperation are large that we will likely see strong selection for the evolution of social hierarchies.

3.3. Model predictions for the Hawaiian archaeological record

The evolutionary ecological model presented above provides a selective process by which individuals should favor membership in a social hierarchy under certain environmental constraints. Given what we know about Hawaiian social organization at European contact and the evolutionary ecological model presented above, the following predictions are derived for archaeological record of Hawai‘i:

1. A despotic distribution

- 1.1. Agricultural resources should be unevenly distributed (i.e., patchy) such that some areas are economically defensible and others are relatively lower quality, risky and uncertain, which would select for a despotic distribution and territoriality.
- 1.2. Archaeological evidence for change in spatial habitat use over time, which approximates the expectations of the IDD. Individuals are expected to settle the highest quality habitats first and then with declining order of their quality.
- 1.3. Evidence for territoriality, first in the highest quality habitats and then in relatively lower quality areas as habitat densities increase.
- 1.4. Evidence for group fissioning as the Sibly size is surpassed.

2. Evidence for environmental conditions favoring cooperation between dominants and subordinates (i.e., evidence for frequent environmental crises/resource shortages/downfalls).

- 2.1. Uneven distribution of risk and uncertainty stemming from resource shortages. As the case study of interest involves populations relying on rain-fed agriculture, this prediction will be evaluated by quantifying and analyzing the spatiotemporal patterns droughts (risk) and the predictability of these drought events (uncertainty).

This set of EE predictions will be evaluated in the following chapter by reanalyzing previously published archaeological data and new geostatistical and time-series analyses on the leeward Kohala region of Hawai'i Island, an area with an occupation record spanning the larger portion of Hawaiian prehistory, a central location for dryland agriculture, and an important locus for the emergence of hierarchical groups.

Chapter 4

Results: Testing the predictions of the evolutionary ecological model:

The Leeward Kohala Field System

4.1. Introduction

In this chapter, the results of testing the evolutionary ecological (EE) model predictions 1.1. – 1.4 against the Hawaiian archaeological record are presented. To reiterate, model predictions 1.1. – 1.4 are as follows:

- 1.1. Agricultural resources will be unevenly distributed (i.e., patchy) such that some areas are economically defendable and others are relatively lower quality, risky and uncertain, which would select for a despotic distribution and territoriality?
- 1.2. Archaeological evidence for change in spatial habitat use over time which approximates the expectations of an ideal despotic distribution. Individuals are expected to settle the highest quality habitats first and then expand into less optimal locations with declining order of their quality
- 1.3. Evidence for territoriality, first in the highest quality habitats and then in relatively lower quality areas as habitat densities increase
- 1.4. Evidence for group fissioning as the Sibly size is surpassed

An ideal place to test these predictions is the leeward Kohala region of northwest Hawai'i Island, location of the Leeward Kohala Field System (LKFS), a large (~60 km²) prehistoric dryland agricultural complex (Figure 4.1.). Several reasons make the leeward Kohala region a prime candidate for preliminary investigations of the EE model for Hawai'i: (1) the area has a long temporal record of continuous habitation which allows

for the examination of evolutionary processes (Ladefoged and Graves 2008); (2) the amount of archaeological and interdisciplinary research that has been conducted in Kohala in recent years (e.g., Field et al. 2010; Field et al. 2011a; Hartshorn et al. 2006; Kirch 2010a; Ladefoged and Graves 2000, 2006, 2008, 2010; Ladefoged et al. 2005; Ladefoged et al. 2008; Ladefoged et al. 2003; Meyer et al. 2007; Tuggle and Tomonari-Tuggle 1980; Vitousek et al. 2004) has yielded a rich dataset to work with; (3) the agricultural resources upon which the prehistoric inhabitants of this region relied were dependent on rainfall; therefore, the potential for risk from climatically induced resource shortages was great; and (4) some of the most hierarchical social groups in the Hawaiian Islands originated in leeward Kohala, including those who eventually conquered and united the rest of the Hawaiian Islands (Ladefoged and Graves 2010:110).

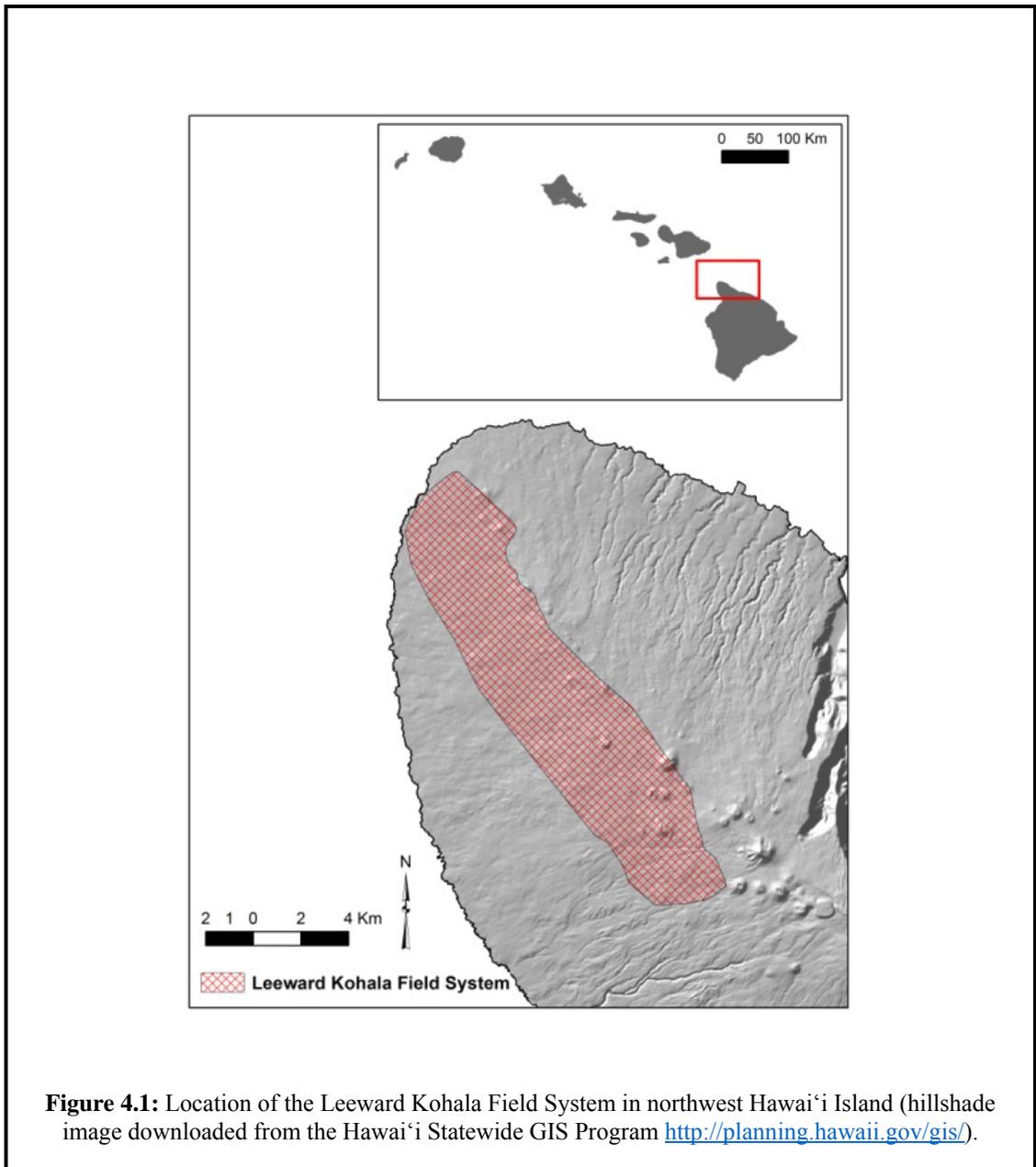


Figure 4.1: Location of the Leeward Kohala Field System in northwest Hawai'i Island (hillshade image downloaded from the Hawai'i Statewide GIS Program <http://planning.hawaii.gov/gis/>).

Following a brief review of the prehistory of leeward Kohala and the archaeological research on the LKFS, the EE model predictions are evaluated. While not set within the EE framework presented here, previous research and published data exists with which to test model predictions relating to the evolution of despotism. Although there is often much discussion of the potential risks and uncertainty involved in Hawaiian

dryland agriculture, the patterns of agricultural risk and unpredictability of food shortages has not been satisfactorily evaluated or quantified. To address this deficiency, and to test model prediction 2.1, the spatiotemporal patterns of drought in the LKFS are investigated in Chapter 5 through the use of both geostatistical models and time-series analysis.

4.2. Background: Hawaiian dryland agriculture and the Leeward Kohala Field System

Prehistoric agriculture in Hawai‘i is typically divided into two contrasting systems of wetland and dryland agriculture (Kirch 1994). The wet agriculture systems are those which exploit permanent or semi-permanent water sources in the construction of raised-bed, pond-field, or irrigated systems (Kirch 1977; Kirch and Lepofsky 1993). These wetland agricultural systems provided a high and consistent crop-yield, and were therefore predicable and relatively low in risk. Dryland agricultural strategies, in contrast, were almost completely dependent on rainfall and have been described as labor intensive and highly variable (Allen 2004; Kirch 1994; Lee et al. 2006). Despite these disadvantages, dryland agriculture is thought to have been an important factor in the political economy and evolution of social complexity in Hawai‘i (Kirch 1984; Ladefoged and Graves 2000, 2008). The dynamic relationship between society and dryland subsistence practices has been especially important topic in the Hawaiian Archipelago, specifically in relation to the large dryland agricultural systems of Maui, Moloka‘i, and Hawai‘i Island (Kirch 2007, 2010a; Kirch et al. 2004; Kirch et al. 2007; Kirch et al. 2012; Vitousek et al. 2004).

The large dryland field systems of the Hawaiian Islands are typically located on “sweet spots” of rainfall and soil fertility on the islands’ leeward volcanic slopes (Ladefoged et al. 2009; Vitousek et al. 2004). In comparison to wetland irrigated agriculture in the Hawaiian Islands, these dryland field systems are generally characterized as having lower average yields, requiring more labor input, and being more prone to risk from droughts (Lee et al. 2006; Malo 1987:204; Kamakau 1992b). Despite these drawbacks, dryland agriculture was widely practiced and depended upon in Hawaiian prehistory and often argued to have been an important force in complex sociopolitical patterns late in Hawaiian prehistory (e.g., Graves et al. 2010; Kirch 1984; Kirch 1994; Kirch 2010a, Kirch 2010b, Kirch 2012; Ladefoged and Graves 2000, 2008). Of the large Hawaiian dryland field systems, the LKFS has been the most intensively studied and offers unique opportunities to explore the evolutionary and ecological influences on social organization.

4.2.1. The Leeward Kohala Field System

The LKFS is a large (3 km x 20 km) rain-dependent dryland agricultural field system situated on the leeward slopes of the Kohala Mountains in the North Kohala district of Hawai‘i Island (Figure 4.1.). The field system consists of an intricate grid of agricultural alignments (garden plot “walls”), animal enclosures, religious and domestic structures, and a large network of trails (Ladefoged and Graves 2010; Mills 2002; Mulrooney and Ladefoged 2005; Field et al. 2010; Field et al. 2011a) (see Figure 4.2.). Relative and absolute dating of archaeological features suggests human occupation and agricultural activity shortly following the colonization of Hawai‘i Island in the 13th

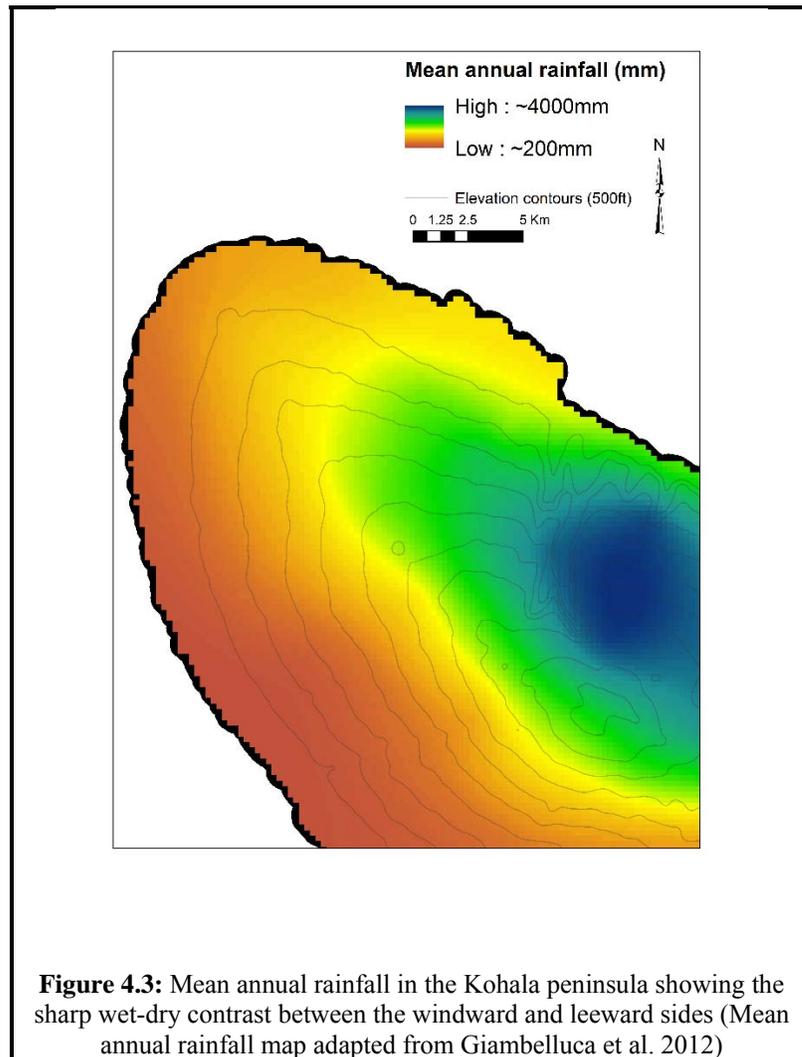
century AD, beginning with long-fallow swidden agriculture, followed by expansion, intensification, and segmentation of the field system continuing in a series of phases until its abandonment in the 19th century (Ladefoged and Graves 2008; Ladefoged et al. 2005; Ladefoged et al. 2011; Rieth et al. 2011).



Figure 4.2: Google Earth image showing a portion of the LKFS and the intricate grid of embankments (vertically oriented “walls”) and trails (horizontal features), which together form the boundaries of the agricultural plots. The embankments are thought to serve as territorial boundary markers, wind-breaks, and erosion/run-off reducing features, while the trails likely facilitated mobility between communities and served as territorial boundaries.

The spatial extent of the field system is constrained by the nutrient and water requirements of Hawaiian crops, with the upper elevations of the LKFS constrained by base saturation and phosphorous levels, while the lower boundary is mostly inhibited by rainfall around the 750 mm mean annual rainfall isohyet (see Figure 4.3.) (Ladefoged et

al. 1996; Vitousek et al. 2004). This difference in soil nutrients is partially due to the geology of the Kohala region, which consists of two basaltic lava formations, the younger, more nutrient rich, Hawi Formation (~150,000 years old) and the older Pololu Formation (~400,000 years old), that comprise the Kohala mountains rising from the coast up to ca. 1,600m above sea level (Ladefoged and Graves 2010:92).



Sweet potato (*Ipomoea batatas*) was the primary crop grown in the LKFS, although other crops, such as dryland taro (*Colocasia esculenta*), sugarcane (*Saccharum officinarum*), yams (*Dioscorea alata*), ti (*Cordyline fruticosum*), and banana (*Musa* sp.) were also cultivated (Handy and Handy 1991; Kirch et al. 2012; Ladefoged and Graves 2010; Yen 1974). Sweet potato is an ideal crop for Hawaiian dryland agriculture: it is well adapted to a range of environments, can be grown in a variety of soil types, and it is moderately resistant to drought, requiring a minimum of 750 mm of rainfall per year (Lebot 2008; Onwueme 1978).

4.3. Investigating model prediction 1.1 – 1.4: despotism and territoriality

Due to the wealth of previous research in leeward Kohala, much of the requisite archaeological data needed to evaluate the model predictions already exists. Using the available data, model predictions 1.1. through 1.4. are evaluated below.

4.3.1. Prediction 1.1.: The spatial distribution of resources in the LKFS

The evolution of despotism and territoriality is contingent on an uneven distribution of dense and predictable resources (Brown 1964; Dyson-Hudson and Smith 1978; Fretwell 1972). Several recent attempts at modeling the productive agricultural capabilities of the leeward Kohala area have demonstrated high spatial heterogeneity in agricultural productivity (e.g., Kirch et al. 2012; Ladefoged et al. 2008; Ladefoged et al. 2009; Ladefoged et al. 2011; Lee et al. 2006; Lee and Tuljapurkar 2010; Vitousek et al.

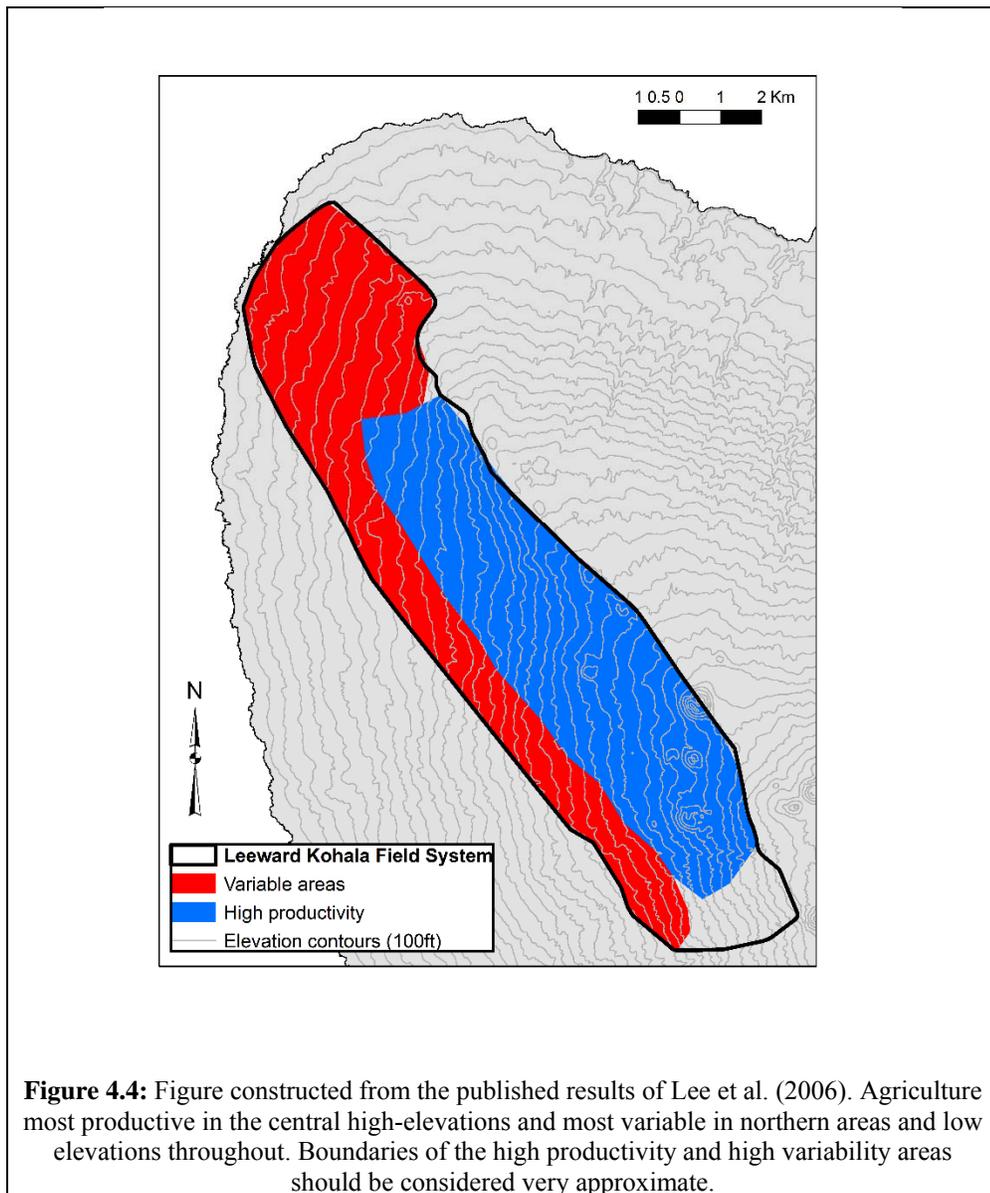
2004). The most relevant studies are briefly reviewed here, as they provide a positive affirmation of the expectation of unevenly distributed resources.

Variation in LKFS agricultural production is simulated by Lee et al. (2006), who use Hawaiian climate data and a variation of the CENTURY model (see Parton et al. 1987) to explore the coupled dynamics of rainfall, temperature, soil nutrient cycling, plant growth, cropping activity and their combined effect on agricultural crop yield in the LKFS. Lee et al. (2006) study three discrete locations in the leeward Kohala area in detail and then employ stochastic rainfall simulations at ten points along four transects within the LKFS. The four transects in their rainfall simulation are spread out along a north-south gradient and utilize 60 years of monthly rainfall measurements from three reference sites within leeward Kohala¹¹. Lee et al. (2006) parameterize their ecosystem model and simulations for sweet potato and demonstrate that agricultural yield and surplus varies greatly both spatially and temporally within the field system. For example, their model and simulations indicate that sweet potato yields are generally more variable in the northern areas and in low elevations throughout the field system. Their results also indicate that sweet potato yields are, on average, greater and less variable in higher elevations “due to a combination of increased rainfall, increased N input, and decreased variability” (Lee et al. 2006:757) (Figure 4.4.).

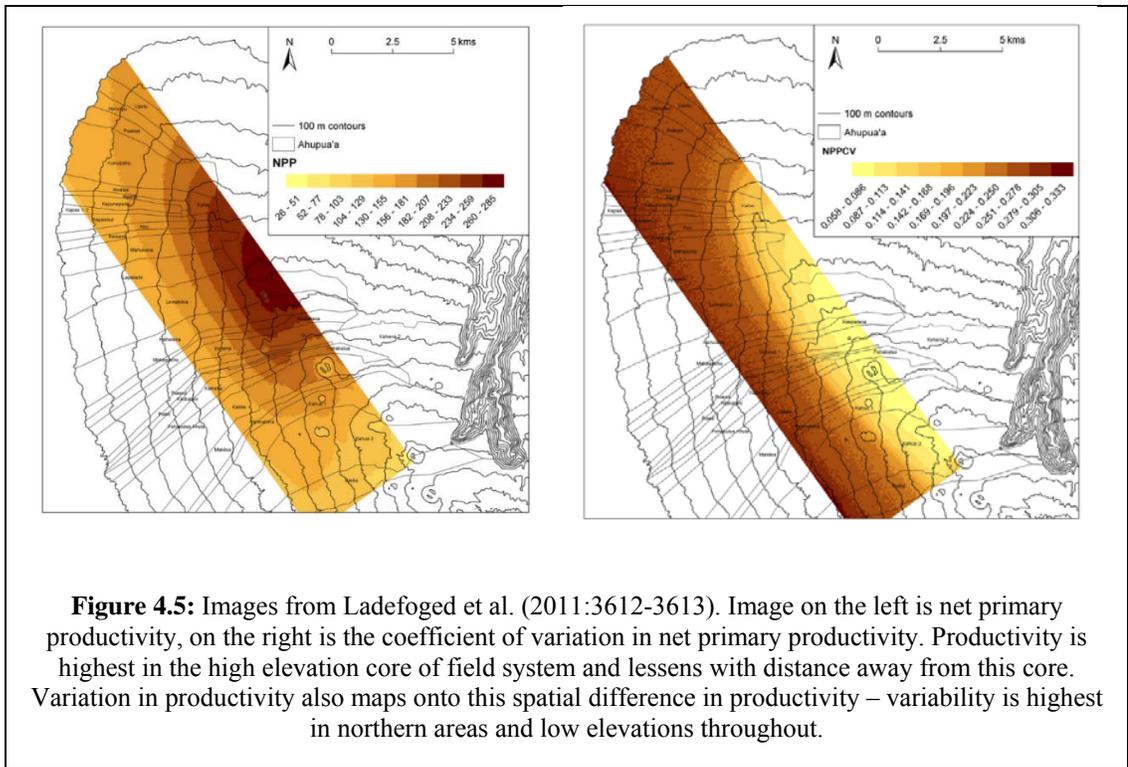
Lee et al.’s (2006) results are later corroborated and reproduced in similar productivity modeling by Ladefoged et al. (2008) in an attempt to address the relationship between territoriality, agricultural surplus, and life expectancy (discussed below). Like

¹¹ One of Lee et al.’s (2006) data points is located well outside the south-west boundary of the field system.

Lee et al. (2006), they utilize a small set of rainfall measurements to simulate climatic variation and its effect on agricultural production for the entire LKFS. Ladefoged et al.'s (2008) results largely corroborate those of Lee et al. (2006) and suggest that large variations in agricultural surplus production across the LKFS would have been high (Ladefoged et al. 2008:104).



Similarly, through an analysis of LIDAR imagery in combination with a similar agricultural productivity model from Ladefoged et al.(2008), Ladefoged et al. (2011) investigate spatiotemporal trends in agricultural potential in the LKFS. In their productivity modeling, Ladefoged et al. (2011) use two measures of agricultural potential, potential net primary productivity and the coefficient of variation in net primary productivity. Their model results indicate that net primary productivity is highest in the central high elevation areas of the field system and that net primary productivity declines with increased distance from this central area, while the coefficient of variation in productivity is lowest in central and southern high elevation areas and highest in low elevations throughout the field system (Ladefoged et al. 2011:3612–3613). Ladefoged et al. (2011:3615) also suggest that variation in net primary productivity may be correlated with variation in rainfall. The results of Ladefoged et al.'s (2011) productivity modeling are shown in Figure 4.5., below.



Overall, these models suggest that agricultural yield and surplus would have been most productive in the central core of the LKFS (Kirch et al. 2012:22). Resources are high-quality, dense, and predictable in the central core of the field system – high quality and dense because of their ability to support productive agriculture and seemingly predictable because of their constancy, as measured by the low coefficient of variation in net primary productivity. The low variation apparent in these agricultural models suggests that the central high elevation areas would have been the most economically defensible, with economic defensibility decreasing with distance from this core area. Based on the predictions of the ideal-despotic distribution, we should expect to see early evidence of habitation in this core area, along with territoriality and a despotic pattern of land use, with habitat use expanding over time into the less desirable areas.

4.3.2. Predictions 1.2. – 1.4: Evidence for despotism: an ideal-despotic expansion and intensification of agricultural features and territoriality

To test the predictions of the ideal-despotic distribution (IDD) model, it is necessary to investigate the archaeological evidence for patterns of habitat use and settlement over time. The model of despotism presented in Chapter 3 predicts that we should see initial resource utilization and agricultural activity in the highest quality habitats, such as the central-core areas of the LKFS. Because these high quality habitats have a high potential for economically defensible agricultural resources, we should expect to see the evolution of territoriality whereby this high ranked habitat and its resources are secured against additional settlement, interference, or theft. The IDD predicts that economically defensible areas will be settled first and newcomers, whether new immigrants or later generations, will be forced to utilize the lower quality resource patches. Over time as population continues to grow, groups that surpass the Sibly size are expected to fission and/or further exclude newcomers and some individuals will further be forced into the lower quality areas. With a decline in the amount of unsettled viable habitat and differences in economic defensibility, the costs of competition between individuals in high and low quality areas differs such that the costs of competition are greater for those in the low quality areas, and their best strategy is to accept their lower quality position, resulting in despotism.

4.3.2.1. Patterns of land use in the LKFS

Over the past 30+ years there has been increasing development of relative and absolute chronologies for changes in habitat use in the LKFS. While these data provide the requisite information to evaluate the IDD model of interest here, they have not yet been explained within this EE framework. The evidence for patterns and changes in landscape use is discussed and then placed within the context of the EE predictions.

Much research in the LKFS has attempted to differentiate between the first establishment of agriculture, agricultural expansion, and intensification (e.g., Kirch 1984; 1994; Ladefoged and Graves 2000, 2008; Ladefoged et al. 1996; Ladefoged et al. 2003; Ladefoged et al. 2011). The establishment of agriculture simply refers to the initial cultivation of a particular area. Following the establishment of cultivation, expansion refers to the movement of agriculture into areas that were previously not under production. In contrast to expansion, intensification is an increase in the amount of labor put into a specific area already under production (Brookfield 1972; Leach 1999). In terms of the archaeological correlates of these concepts within the LKFS, the addition of new agricultural features or trails in previously unused areas is taken as evidence of expansion, while the addition of more features to an area with preexisting agricultural infrastructure is usually taken as evidence of intensification. The segmentation of an area by a new trail is considered to be evidence of community fissioning (e.g., Field et al. 2011a; 2011b; Ladefoged et al. 2011). Intensification of agricultural land is most visible in the archaeological record through the remains of infrastructural improvements like

increased density of walls, but also likely involved other increased work put into a given plot, such as mulching or weeding (Ladefoged and Graves 2008:773). The authors cited above frequently refer to expansion and intensification in the LKFS as different “pathways to agricultural development,” and have developed both relative and absolute chronologies to track these phenomena.

The earliest absolute dates for human activity in leeward Kohala come from C₁₄ age determinations on sweet potato fragments suggesting earliest human occupation and agricultural activity in the range of ca. 1290 AD – 1430 AD, shortly following the colonization of Hawai‘i Island (Ladefoged and Graves 2008:784; Ladefoged et al. 2005; Rieth et al. 2011). This oldest sample (KRC 16) was excavated near the low elevation boundary of the LKFS in Kahua 1 *ahupua‘a* in the southern portion of the field system (Ladefoged and Graves 2008; Ladefoged et al. 2005) (see Figure 4.6. below).

Based on a method originally suggested by Rosendahl (1972, 1994) and elaborated upon by Kirch (1984), a relative chronology of several “phases” of agricultural expansion, intensification, and trail construction is now well established for the LKFS (Ladefoged and Graves 2000, 2008; Ladefoged et al. 2003; see also Dye 2011)¹². This relative dating method is based on deconstructing the field system by matching and mismatching patterns of trail and wall interconnections. The trails run from the coast inland and branch off from each other in a dendritic fashion, and the field walls run north-south. Because the field border walls and trails often intersect, it is

¹² Because the northern portion of the field system has been disturbed by modern agricultural activities (e.g. sugarcane and pineapple plantations), most relative chronology building has focused on the area from the *Kapaanui ahupua‘a* southward (Ladefoged and Graves 2000: 432)

possible to develop a chronology of construction sequences based on the pattern of interconnections. For example, “when a wall extends continuously across a trail, the wall’s construction is earlier than the trail. When a wall terminated at a trail, forming an offset with surrounding walls, it was built later than, or at the same time, as the trail” (Ladefoged and Graves 2000:431). In general shorter walls and trails are considered older than longer ones (Ladefoged and Graves 2000). Walls that intersect trails are assumed to be older than walls that abut them. The rationale behind this assumption is that trails serve as territorial or social boundary markers which are not usually crossed, so once a trail is established all walls that abut them must have come later (Ladefoged and Graves 2006). The oldest walls are the ones that intersect trails with the highest ratio of abutting to intersecting walls (Ladefoged et al. 2003:929). Several other rules are used: multiple walls abutting the same trail are assumed to be of the same temporal unit, trails are assigned to the temporal unit of their oldest abutting wall, and branching trails are younger than the trails they diverge from (Ladefoged et al. 2003:931).

Using this relative chronological method, upwards of five “phases” are now proposed for field system expansion and intensification (Field et al. 2011a; Ladefoged and Graves 2008)¹³. Recent radiocarbon dates have yielded absolute age estimates for the field system construction sequences (Ladefoged and Graves 2008), with the first phase in the range of 1290 AD – 1420 AD), the middle of the sequence from 1420 AD – 1650 AD, and the furthest extent of the field system from 1650 AD – 1800’s. However,

¹³ Following Rosendahl (1972), Kirch (1984) suggests three phases of development the *Lapakahi ahupua’a*. Ladefoged and Graves (2000) later corroborate Kirch’s (1984) phases for the entire field system using a GIS model and aerial photography. Later, Ladefoged et al. (2003) identify four phases in a detailed GPS survey of three sections of the field system, and recently Ladefoged and Graves (2008c) and Field et al. (2011) suggest five phases.

because the majority of these radiocarbon dates were excavated from underneath the field system features, they provide a *terminus ante quim* for field system construction rather than exact estimates (Dye 2011; Ladefoged and Graves 2008). Nonetheless, they still provide valuable chronological evidence of patterns of land-use over time.

Initial wall construction occurs in the central high-elevation core of the LKFS, an area with enough average rainfall and soil nutrients to support optimal crop growth (Ladefoged and Graves 2000). Detailed examination of the particular sections of the LKFS by Ladefoged et al. (2003) indicate that agriculture in the *Lapakahi ahupua 'a* was established early and was also a location of rapid expansion and later intensification. As these high quality areas of the field system are further intensified, field system construction begins to expand from this core area into more marginal areas north, south, and to lower elevations (Ladefoged and Graves 2000, 2008). For example, expansion occurs somewhat later in the *Makeanehu* and *Kaupalaoa ahupua 'a*, and intensification does not begin until towards the end of the middle of the sequence (Ladefoged et al. 2003). Expansion and intensification of these areas continues throughout the sequence, especially in the area from *Lapakahi* to *Kehena 1* (Ladefoged et al. 2011). Towards the later phases of the relative chronology, construction spreads to the most marginal southern portions of the LKFS, with areas like *Kahua 1-2* and *Ki'ioikalani* exhibiting evidence of relatively late expansion and very little intensification (Ladefoged and Graves 2000, 2008; Ladefoged et al. 2003; Ladefoged et al. 2011). While not securely anchored within the relative chronology, most agriculture in the northern *ahupua 'a*, such as *Kapunapuna*, *Kapa 'a 1-2*, *Kamano*, *Mahukona*, and *Kaiholena*, appears to be characteristic of expansion with little intensification (Ladefoged et al. 2011). Aside from

expansion and intensification, recent analyses suggest that segmentation of preexisting agricultural plots was also prominent in the area from *Kapunapuna* to *Lamaloloa*, and in *Kahua 1* (Ladefoged et al. 2011). The pattern of changes in land-use in the LKFS is summarized in Figure 4.6.

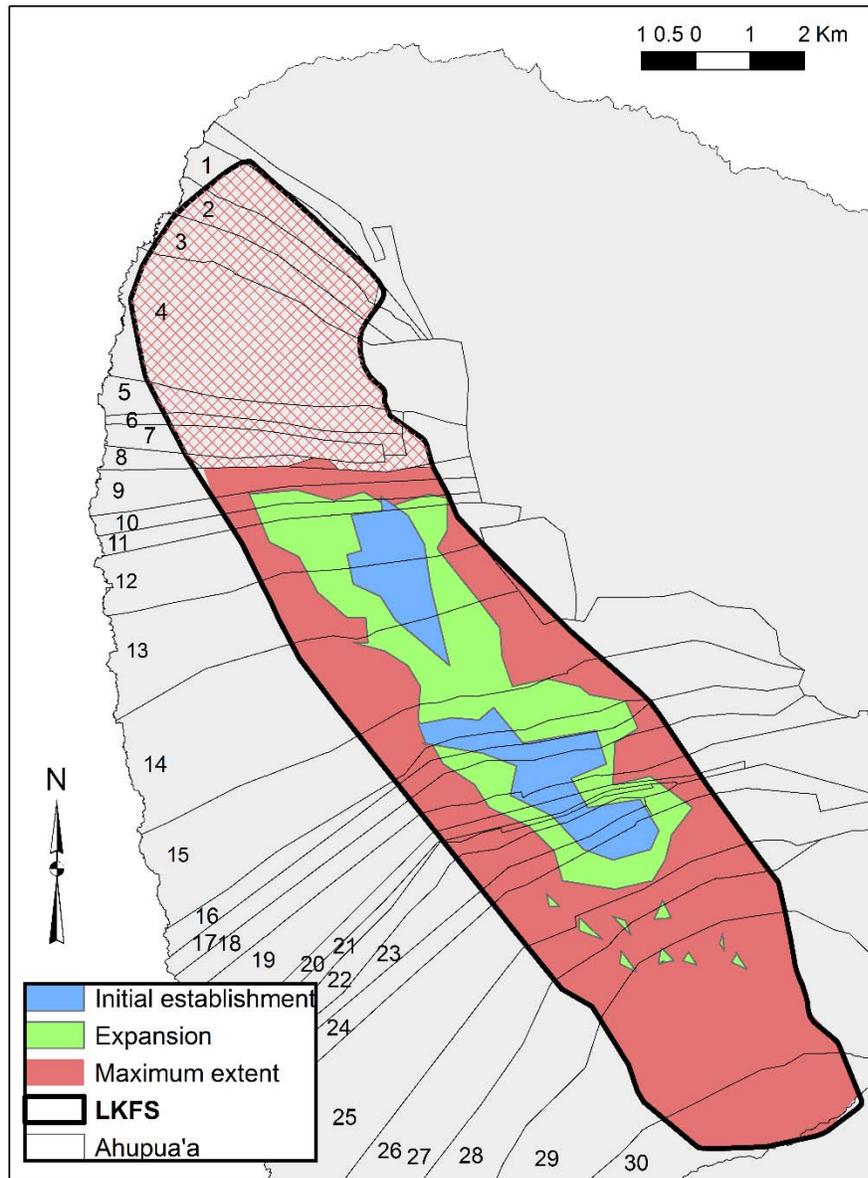


Figure 4.6: Visual summary of the relative chronology of LKFS expansion from Ladefoged and Graves (2000;2008); Ladefoged et al. (2003), and Ladefoged et al. (2011). Exact locations of the phases of field system expansion are approximate.

Ahupua'a number key: 1- Upolu, 2 – Honoipu, 3 – Puakea, 4 –Kukuipahu, 5 – Awalua, 6- Haena, 7- Kapunapuna, 8- Kappa'a 1-2, 9 - Kappa'anui, 10 – Kou, 11 – Kamano, 12- Mahukona, 13- Lapakahi, 14 – Lamaloloa, 15 – Kaiholena, 16 – Makeanehu, 17 – Kaupalaoa, 18 - Kahena 1, 19 - Kahena 2, 20 – Puanui, 21 – Puaili, 22 – Kiokalani, 23 - Kauho'oa, 24 - Pohakulua ahula, 25 – Kalala, 26 – Makiloa, 27 – Pahinahina, 28 - Kahua 1, 29 - Kahua 2, 30 - Waika

Relative and absolute chronologies of residential features within leeward Kohala also indicate that an increase in household expansion occurred simultaneously with field system construction (Field et al. 2010; 2011a; 2011b). This research shows that the population of the LKFS increased in size and density as agriculture intensified and expanded. Analysis of midden deposits indicates that exchange of subsistence resources between inland and coastal residences also increased over time (Field et al. 2010). For example, marine mollusks increasingly occur in inland deposits later in prehistory, and there is an increase in pig and dog bones in coastal middens (Field et al. 2011b). This pattern is argued to represent stable exchange between communities in different ecological zones within *ahupua'a*. As the field system and human population increased, there was also a concomitant increase in the construction of monumental architecture (*heiau*) and territoriality in leeward Kohala (Ladefoged and Graves 2006; Mulrooney and Ladefoged 2005).

At European contact there were 35 separate named *ahupua'a* territories in leeward Kohala. Using a relative chronology of territory formation, Ladefoged and Graves (2006) suggest up to six episodes of increased territoriality in the LKFS. The “ideal” *ahupua'a* is one which extends from the coast to the summit of the nearest mountain, allowing community access to the full breadth an island’s resources. Ladefoged and Graves’ (2006) method of *ahupua'a* chronology is based on the assumption that the earliest *ahupua'a* would have been ideal in this way. Therefore, if an *ahupua'a* does not reach the summit of a nearby peak or end at the coast, then it is assumed to be younger than adjacent *ahupua'a* that do. For example, if one of two

adjacent *ahupua'a* does not extend to the traditional inland border, then it was originally included within the other. Also, if two or more *ahupua'a* share a common name, such as *Kahua 1* and *Kahua 2*, then these are assumed to have once been the same *ahupua'a*. Ladefoged and Graves (2006:269) use this method to show that nine relatively large *ahupua'a* got subdivided into consecutively smaller territorial units over the course of Hawaiian prehistory, with 35 recorded in the mid-19th century, and these patterns of increased territoriality match up well with the sequence of wall and trail construction.

Using the agricultural productivity model developed by Lee et al. (2006) and an age-structured demographic model (Lee and Tuljapurkar 2008), Ladefoged et al. (2008) model life expectancy at birth and surplus production in leeward Kohala *ahupua'a* in each of the six proposed territory configurations. They simulate agricultural production at a series of points within each *ahupua'a* and its associated population size. Their model assumes that every year all *ahupua'a* residents pool their resources, “so the locations within each territory that are more productive in a given year effectively subsidize the less productive locations within each territory” (Ladefoged et al. 2008:96). The result of the model’s design is that all *ahupua'a* residents experience the same effects of environmental variability, whether food surplus or food shortage. They assume that when a given territory does not produce a surplus, this is because the extra resources harvested from the more productive areas go to support the residents in the less productive habitats (Ladefoged et al. 2008:99). Later in time as territory number increases and territories become smaller and smaller, some territories become much better off in terms of the surplus they produce, while others are much worse. Again, Ladefoged et al (2008) assume that in these instances those in the more productive

territories may share their resources with those in the less productive areas; however, now the resources must pass through the control of a chief (Ladefoged et al. 2008:99). Based on several iterations of their model, Ladefoged et al. (2008) find that the 14 territory configuration results in the highest per person life expectancy at birth values for leeward Kohala. However, this per capita optimal configuration is not maintained, and over the remaining course of Hawaiian prehistory territories continue to subdivide in leeward Kohala up to 35 *ahupua'a*. This further subdivision results in high spatial heterogeneity across territories, with the central *ahupua'a* generally having higher surpluses and life expectancy at birth than more northern or southern areas (Ladefoged et al. 2008).

These patterns of land use and social organization in the LKFS have been approached from two major perspectives. First, Ladefoged and Graves (2000) attempt to interpret changes in the LKFS within an EE framework by suggesting that selection acted over time to produce adaptive agricultural technologies and land-use behaviors. For example, field walls have a selective value because they increase agricultural productivity through decreased evapotranspiration and decreased erosion, which reduce risk and optimize surplus production (Ladefoged and Graves 2000, 2008, Ladefoged et al. 2003). They also argue that a standardization in agricultural plot morphology later in time from more rectangular to more square shapes served to increase surface area for crop production. This is argued to be the result of selection acting on variability in agricultural strategies (Ladefoged and Graves 2000:440). However, aside from the selective benefits of agricultural technologies, the explanation for the processes of expansion and intensification, household increase, and increased territoriality are generally attributed to

the agency and coercive powers of chiefs and their land managers in pursuit of additional surplus (e.g., Ladefoged and Graves 2000:443, 2006: 269; Ladefoged et al. 2003:937; Ladefoged et al. 2008:106). For example, Ladefoged and Graves (2008:785) suggest that powerful elites “deployed” commoner populations into more marginal areas, such as the southern portions of the field system, to fund their needs for surplus.

While the recent studies discussed in the previous section have been very successful at documenting the changes in the LKFS over time, the evidence has not been explicitly placed within an evolutionary framework which can explain the causal linkages between the different lines of evidence in a dynamically sufficient way. Emphasis in these previous studies is overwhelmingly placed on the agency of powerful elites in shaping patterns of land-use and social change for their own benefit. While not incorrect, these processes in prehistory are profitably explained using explicit evolutionary ecological models which might shed light on their underlying influences. Here, the existing evidence of land use and territoriality is reinterpreted using the EE model outlined in Chapter 3.

4.3.2.3. An evolutionary ecological explanation

Archaeological evidence suggests that the field system was initially established in the central high elevation core of the field system and in other disbursed regions in high elevations sometime between the 13th and 15th centuries AD¹⁴ (see Figure 4.6). When

¹⁴ The spatial location of this earliest C14 date in the relatively low quality area of Kahua 1 (based on Ladefoged et al.'s (2011) productivity modeling) is contrary to the expectation of an optimal settlement model (e.g. IFD or IDD) which predicts that individuals should exploit the highest quality areas first. If this date does indeed represent some of the earliest agricultural activities in Kohala, then it may be an

compared with the results of the agricultural productivity modeling of Ladefoged et al. (2011) (Figure 4.5.), this roughly meets the IDD prediction 1.2. that individuals should seek to settle the highest quality habitats first (Fretwell 1972; Fretwell and Lucas 1969). Following initial establishment, construction of the field system occurs rapidly through expansion and intensification within the central core. Later, agriculture begins to expand into more marginal areas. Over time, these central areas continue to expand and intensify, and eventually agriculture begins to expand into the most marginal southern and northern *ahupua'a* (Figure 4.6.). Again, this is the pattern of habitat use expected by the IDD – as the highest-quality economically defensible habitats in the central core of LKFS are settled, individuals within these areas prevent further settlement and newcomers are forced to utilize and settle the less desirable areas of the field system. Over time with further increases in population density, newcomers are further forced to settle even the most marginal areas of the northern and southern areas of the LKFS. Over many generations this uneven pattern of landscape use likely resulted in a high degree of despotism among the residents of leeward Kohala, with those utilizing the high quality core areas of the field system assuming dominant social roles and those in the low quality areas assuming subordinate status stemming from marked differences in resource holding potential.

Increased territoriality in the most economically defensible habitats of the LKFS is also likely related to differential intensification within the field system. Ladefoged et

indication of experimentation with sweet potato productivity in different spatial locations. However, it is not possible to make any significant statements with such a low sample size of early dates.

al. (2011:3613) show that agricultural intensification was dominant in the mid-elevation¹⁵ core of LKFS ranging from *Lapakahi* to *Kehena 1*. Most northern (e.g. *Kapunapuna*, *Kapa'a 1-2*, *Kamano*, *Mahukona*, *Kauholena*) and southern (*Ki'iokalani* to *Kahua 2*) *ahupua'a* almost exclusively show evidence of expansion. This is a further confirmation of the IDD and economic defendability model, which expects territory sizes to be relatively large, fixed, and clustered in these habitats where resources are dense and predictable (Cashdan 1992; Davies and Houston 1984:150). This prediction (model prediction 1.3) is met in the LKFS with the archaeological correlates of fixed, intensive, and relatively large agricultural activity zones in the most economically defendable areas.

Intensification (additional labor input into a particular unit of agricultural land [Brookfield 1972; Leach 1999]), can also be seen as a side-effect of economic defendability, as it is the kind of behavioral strategy expected when an individual's resident habitat comprises dense and predictable high-quality resources. Intensification can be viewed as an increase in territoriality as individuals put more work into a given high quality area – i.e., it pays to invest more in a high quality economically defendable resource area. That is, these high quality areas are economically defendable, so individuals should defend them with the consequence being an intensification of work invested into that particular area. In contrast, in the less economically defendable areas of the northern and southern *ahupua'a*, the archaeological evidence indicates that land-use was less intensive, as is expected when resources are more scarce and unpredictable.

¹⁵ Ladefoged et al. (2011:3616) suggest that the reason why intensification is not most prominent in the central high-elevation core (i.e. the highest quality area based on their productivity model) is a result of a flaw in their model, namely that the model only accounts for nitrogen, not phosphorus or other nutrients.

This ideal-despotic pattern of habitat use occurred simultaneously with settlement expansion and increasing subdivision of territories (Ladefoged and Graves 2006). Based on the evidence of initial field system establishment, the first territories were likely established in the most economically defensible core areas of the LKFS (Figure 4.6.) (Ladefoged and Graves 2006). While competitive exclusion of outsider settlement of these core areas is expected, over time the descendant populations in these areas would increase in density. Initially this increase in population within these core areas would have created an Allee effect (Allee et al. 1949; Fretwell 1972), whereby additional individuals would have increased the suitability of the environment, for instance, through increased labor for agricultural production, more mates, or more territorial defense. However, over time the costs of increased population density from interference and depletion would begin to outweigh the benefits and these groups would begin to approach the Sibly size beyond which group living was overly costly (Krause and Ruxton 2002; Sibly 1983). At a certain point this threshold would be surpassed and groups would fission, possibly by creating new adjacent territories.

As Ladefoged et al. (2008) demonstrate, this increase in territory subdivision would have increased the already uneven distribution of resources and average life expectancy at birth values between communities. As viable habitat became increasingly rare in leeward Kohala, social inequality increased through differences in resource holding potential, the despotic distribution, and increased territoriality. Subordinates living in low quality areas would have faced a choice between staying within leeward Kohala or leaving to settle different areas. Because of increases in territoriality within Kohala and elsewhere on Hawai'i Island, options for emigration would have become

increasingly limited. At a certain point subordinates would likely do better to stay within the despotic group rather than risk a possibly lower quality option elsewhere. In this situation dominants would have likely begun to skew resources as much as possible in their favor without forcing subordinates out of the area (Boone 1992; Hamilton 2000; Vehrencamp 1983a). This may be what Ladefoged et al. (2008) are seeing in the increase of territoriality beyond the optimal configuration for all individuals in the LKFS. Under the conditions of despotism modeled in Chapter 3 (especially model prediction 1.4), we should not expect *ahupua'a* sizes to remain optimal; instead, we should expect sub-optimally large group sizes where dominants increasingly subdivide *ahupua'a* to the maximum level of despotism.

The evidence from leeward Kohala roughly meets the despotic conditions of model predictions 1.1 – 1.4. With these conditions being met we should expect some level of social stratification resulting from differences in resource holding potential to emerge. It is in the unfolding of these interrelated processes that we can explain the evolution of increased social inequality between elites (*ali'i*) and commoners (*maka āīnana*) in prehistoric Hawaiian society. Social inequality resulting from despotism, however, is *not* sufficient to select for the degree and maintenance of social hierarchy we see in Hawai'i at contact. Evaluation of prediction 2.1 – sufficient evidence of frequent resource shortages which would select for cooperation and special interest groups– is still required. This next prediction is evaluated in Chapter 5 with a geostatistical model of risk and uncertainty in the LKFS.

Chapter 5:

Risky and uncertain resource fluctuations in the Leeward Kohala Field System

5.1. Introduction

Prediction 2.1. from the model presented in Chapter 3 suggests that there should be evidence for environmental conditions favoring cooperation between dominants and subordinates in the Leeward Kohala Field System (LKFS), which would have in turn influenced the formation of special interest groups and the emergence of social hierarchies in prehistoric Hawai'i (Boone 1992). The particular environmental conditions predicted for the LKFS are distinct spatial patterns of economically defensible areas and areas with a high level of risk and uncertainty, such as evidence for unevenly distributed and frequent resource shortages stemming from environmental crises, especially drought events. That is, it is expected that the LKFS exhibits an uneven distribution of risk and uncertainty stemming from droughts. As the prehistoric inhabitants of LKFS relying on rain-fed agriculture, this prediction will be evaluated by quantifying and analyzing the spatiotemporal patterns droughts (risk) and the predictability of these drought events (uncertainty).

While some studies have focused on risk variation and minimization in Hawaiian dryland agriculture (e.g., Allen 2004; Lee et al. 2006), most studies of the LKFS have focused on agricultural intensification and measuring variation in the degree to which the field system could have produced surplus, or variation in their productive capacities in general (e.g., Kirch et al. 2012; Ladefoged et al. 2011; Ladefoged et al. 2008). While of undeniable utility, these studies often focus on resource maximization at the expense of other important evolutionary ecological (EE) topics, especially the effects of risk from crop failure and the uncertainty involved with these events.

Risk is here explicitly defined as variation in the outcome of some decision, whereas uncertainty involves a lack of perfect information about the outcome (Smith 1988). Problems of risk emerge from the selective pressures placed on individuals resulting from their behavior given the stochastic variation in some crucial resource (Smith 1988:231). While the effects of variation in agricultural yield or surplus, such as that measured by Lee et al. (2006) and Ladefoged et al. (2008; 2011), is of irrefutable relevance for studies of prehistoric agriculture, these studies would be improved by an explicit analysis of spatiotemporal patterns of risk from crop failure. The best measure of risk in a given situation will be the one with the strongest selective force. From an EE perspective, then, risk is more precisely defined as, “variation in an outcome *with consequences that matter*” (Winterhalder 2007:433 emphasis added). In agricultural activities, if the outcome of deciding to invest in planting crops in some location at some time varies greatly between a high crop yield and crop failure, then this activity includes a high measure of risk (Cashdan 1990b; Smith 1988; Winterhalder 1986; Winterhalder et al. 1999). In this way, measuring the spatial and temporal frequency of droughts is a

measure of agricultural risk, as the effect of droughts in dryland areas is either greatly reduced yield or complete crop failure. Furthermore, exploring the any predictable periodicities in these drought events provides a measure of the uncertainty involved with these risks.

Unpredictability is also a frequently cited characteristic of agriculture in the LKFS (e.g., Lee et al. 2006; Ladefoged and Graves 2000, 2008; Ladefoged et al. 2008); however, these studies have either treated high variability as indicative of unpredictability, which is not a true measure of the predictability of a phenomena (see Low 1990), or have not employed sufficient statistical measures of predictability. Furthermore, it is critical to clarify the linkage between unpredictability and the concept of uncertainty. This section complements these previous approaches with an explicit investigation of agricultural risk and uncertainty explored through an analysis of the spatiotemporal frequency and periodicity of droughts in the LKFS.

Because they are analytically distinct phenomena which affect individuals, risk and uncertainty must be measured differently (Low 1990). Having established that droughts are an appropriate proxy measure of risk from resource shortages, two important aspects of risk from droughts require examination – their spatiotemporal structure and their relative intensity (Halstead and O’Shea 1989:3). Understanding these aspects is crucially important for an analysis of risk because “these characteristics determine the scope and severity of the problem with which a society must contend. Knowledge of these features of the environment also provides the analyst with a powerful tool for predicting the kinds of strategies that would be successful in a given situation” (Halstead and O’Shea 1989:3).

Here, the spatiotemporal structure of risk is explored through a geostatistical model of droughts in the LKFS, and the uncertainty of these drought events is measured through a spectral analysis, which tests the statistical significance of any possible predictable cycles. In addition, this study contributes to previous agricultural modeling through the use of a large and highly resolute rainfall data set – the Rainfall Atlas of Hawai‘i (Giambelluca et al. 2012).

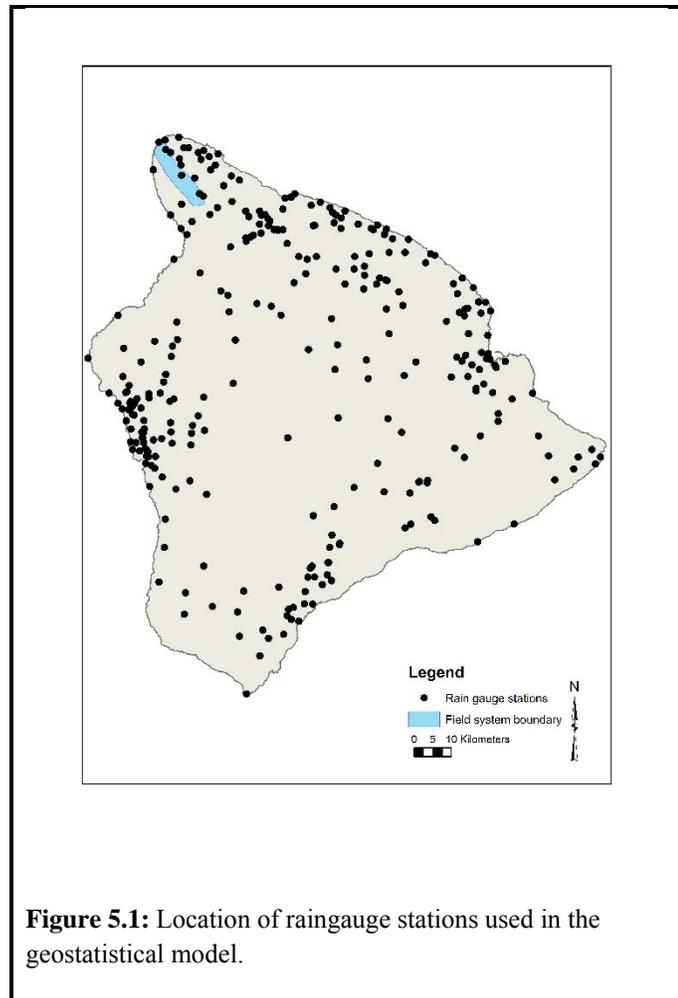
5.2. A geostatistical model of risk for the Leeward Kohala Field System

Here, differences in the level of risk involved in LKFS agriculture are evaluated through the use of a geostatistical model of spatiotemporal drought frequency. This model incorporates 81 years of historic rainfall measurements from the Rainfall Atlas of Hawai‘i (Giambelluca et al. 2012), which allows the derivation of drought estimates for the entire LKFS. The model is parameterized based on the minimum annual rainfall requirements of sweet potato (*Ipomoea batatas*), the main crop grown in the LKFS (Handy and Handy 1991; Ladefoged and Graves 2010; Yen 1974).

5.2.1. The Rainfall Atlas of Hawai‘i

The Rainfall Atlas of Hawai‘i is an online database (<http://rainfall.geography.hawaii.edu/>) consisting of a set of maps and tabular rainfall data from over 1,000 rain gauge stations across the Hawaiian Islands (Giambelluca et al. 2012). The atlas contains a number of different map collections and datasets consisting of

historical rainfall measurements from the mid-nineteenth century to 2007. Here, the “Filled Monthly Dataset, 1920-2007” is used, which consists of monthly total rainfall measurements and estimates derived from radar, vegetation distribution, the PRISM climate model (see Daly et al. 1994), and Bayesian data fusion (see Bogaert and Fasbender 2007) for every month from 1920 to 2007 (data from the years 2001-2007 is not used in the present analysis because the number of rain stations is much lower during this time period, use of which would lower the precision of the geostatistical model). This dataset offers the most complete and continuous rainfall measurements available for the Hawaiian Islands making it well suited for the present study. The spatial distribution of rain gauge stations for Hawai‘i Island is shown in Figure 5.1.



5.2.2. *Spatial interpolation and geostatistical modeling*

The tabular data provided by the Rainfall Atlas of Hawai‘i consist of a series of discrete points irregularly spaced over Hawai‘i Island. While useful, the rainfall data in this form is insufficient to provide the spatial continuity needed for the present investigation. As rainfall occurs in a relatively continuous pattern over the landscape, estimates of rainfall values for the entire LKFS are desired. To accomplish this goal

continuous rainfall surfaces are created using a geostatistical spatial interpolation method known as kriging.

Spatial interpolation methods operate by predicting the value of un-sampled locations using the values of sampled data points (Webster and Oliver 2007). Spatial interpolation methods are divided into two types, the mathematical and the geostatistical. Mathematical interpolation methods, such as Thiessen polygons, triangulation, and inverse distance weighting, rely on more deterministic equations. Geostatistical interpolation (kriging), in contrast, overcomes these drawbacks through its explicit use of weights derived from existing data points in estimation. For these reasons, kriging is widely considered the most preferable interpolation technique (Webster and Oliver 2007; McKillup and Dyar 2010; Conolly and Lake 2006). Several kriging methods exist, such as ordinary, simple, and universal kriging. Here, ordinary kriging is used, as it has been shown to be the most robust geostatistical method (Webster and Oliver 2007), and similar geostatistical studies on Hawaiian rainfall patterns have demonstrated that ordinary kriging out-performs other geostatistical methods (Frazier 2012).

Kriging operates by predicting the value of a spatial variable at an un-sampled location using known values within a given search neighborhood (Webster and Oliver 2007). Kriging is considered a weighted average of data and uses the following prediction formula (Webster and Oliver 2007:37,155):

$$z^*(\mathbf{x}_0) = \sum_{i=1}^n \lambda_i z(\mathbf{x}_i)$$

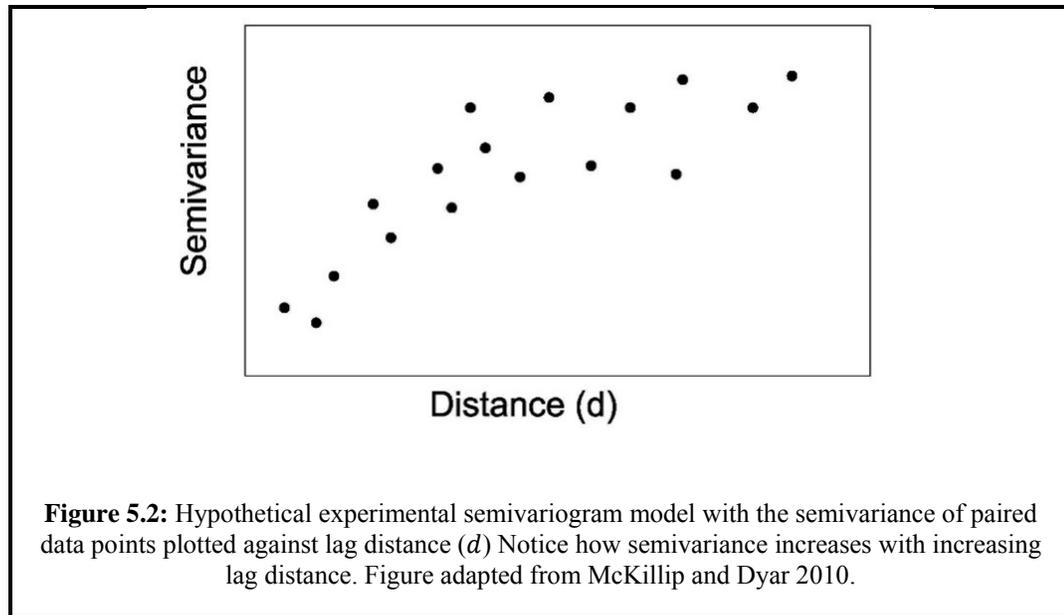
where $z^*(\mathbf{x}_0)$ is the estimation of z^* at unknown point \mathbf{x}_0 ; $z(\mathbf{x}_i)$ for $i = 1, 2, \dots, n$, at locations \mathbf{x}_i are the measured data points, and λ_i are the weights assigned to each measured data point. The difference in the accuracy of different spatial interpolation methods concerns the method by which weights are assigned to the existing data points used in estimation. In kriging, the weights (λ_i) are derived from a geostatistical model known as the semivariogram (Burt et al. 2009).

A semivariogram is a plot of the semivariance of paired data points in relation to their separation, or lag, distances (Burt et al. 2009). Semivariance is a dissimilarity measure, meaning as the distance between two points increases, so will their semivariance. Therefore, the value of the semivariance for two points, x_i and x_j , quantifies their similarity, or regional dependence (McKillup and Dyar 2010). In mathematical terms, the semivariogram is modeled as half the average squared difference between pairs of data points at a given lag distance (Burt et al. 2009:547) or:

$$\gamma(d) = \frac{1}{2n(d)} \sum_{d_{ij}} (x_i - x_j)^2$$

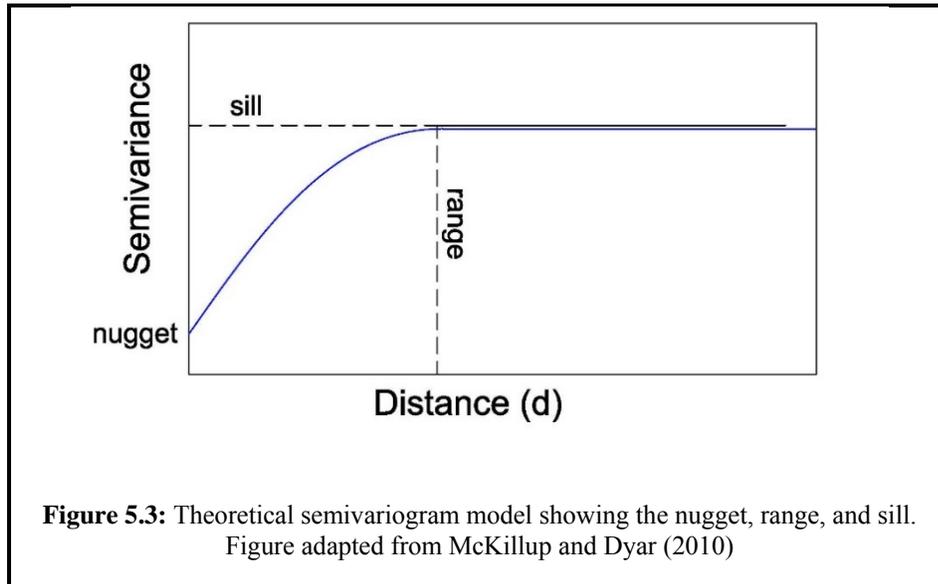
Where γ is the semivariance, d is the lag distance, d_{ij} is the sum of all pairs of points at a given lag, and n is the number of points. Once these semivariance values are derived, two steps are needed. The first step is to plot the experimental semivariogram, which is a plot of lag distance (d) against semivariance (γ) (McKillup and Dyar 2010). A hypothetical experimental semivariogram is shown in Figure 5.2. The next and most

important step in kriging is fitting a theoretical semivariogram model to the experimental semivariogram.



The theoretical semivariogram model is a smoothed line that is fitted through the points in the experimental semivariogram. This step is important because a close match between the experimental and theoretical semivariogram ensures an accurate derivation of the weights (λ_i) used in the kriging algorithm (Conolly and Lake 2006:99). Three features of the theoretical semivariogram are important to establish the regional dependence between points in the model: the nugget, sill, and range (McKillup and Dyar 2010). The nugget is the location on the theoretical semivariogram where the semivariance at location $x = 0$, the point at which the semivariance is at its maximum value and begins to plateau is known as the sill, and the range is 95% of the difference between the sill and the nugget (McKillup and Dyar 2010:357). The range specifies the distance beyond which there is little to no regional dependence in the data. These

features of a theoretical semivariogram can be seen in Figure 5.3. The semivariance derivations resulting from procedure are then used to calculate the weights used in the kriging algorithm (Conolly and Lake 2006).



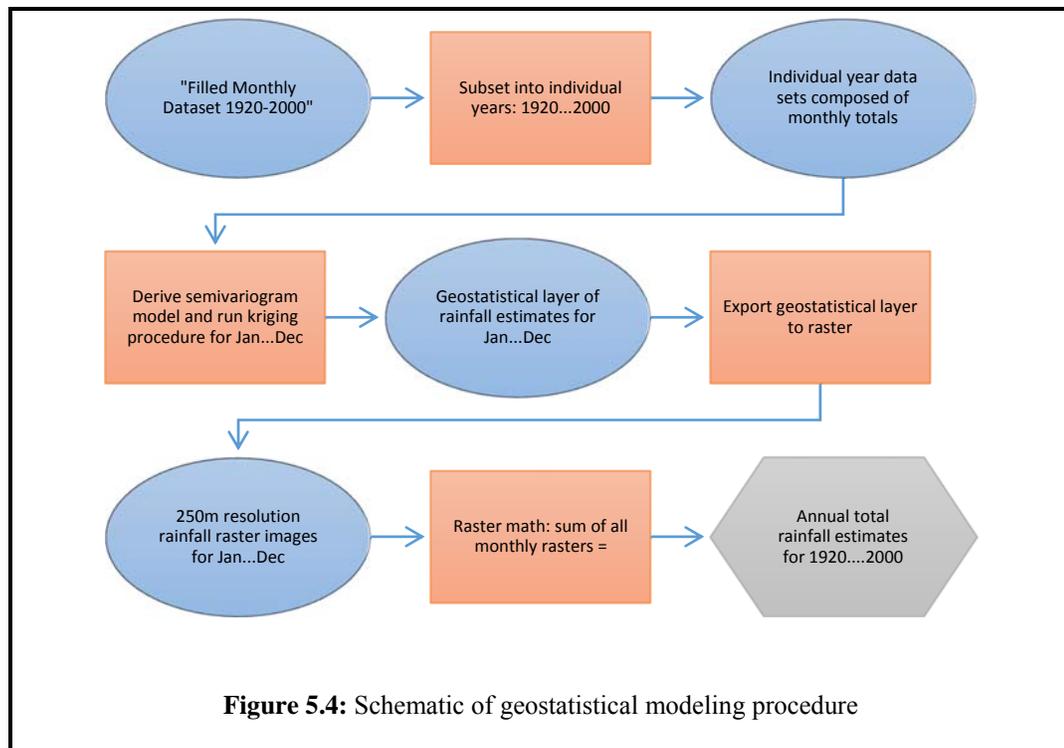
5.2.3. Geostatistical mapping procedure

Using the kriging algorithm outlined above, geostatistical maps are created of total annual rainfall for Hawai‘i Island for the years 1920 – 2000. Total monthly rainfall measurements are plotted from the Rainfall Atlas of Hawai‘i into a geographic information system consisting of these data points and a map of Hawai‘i Island obtained from the Hawai‘i Statewide GIS Program (Figure 5.1.).

The Rainfall Atlas of Hawai‘i dataset used here (“Filled Monthly Dataset 1920-2007”) is tabulated by monthly totals; however, certain months have missing data values.

These missing data values require modeling the semivariogram and running the kriging procedure for every month of each year. This procedure then provides an estimate for the missing monthly total, which can then be used in the annual total estimate.

For each month, the spherical semivariogram model is derived with weights assigned from a search neighborhood of up to ten neighbor data points. Using these semivariogram derivations, the kriging algorithm is then computed resulting in a continuous surface geostatistical map of rainfall estimates at a 250 m x 250 m resolution. Each of the monthly raster surfaces are then summed to obtain each annual total. A schematic of this procedure is shown in Figure 5.4.



5.2.4. Raster reclassification

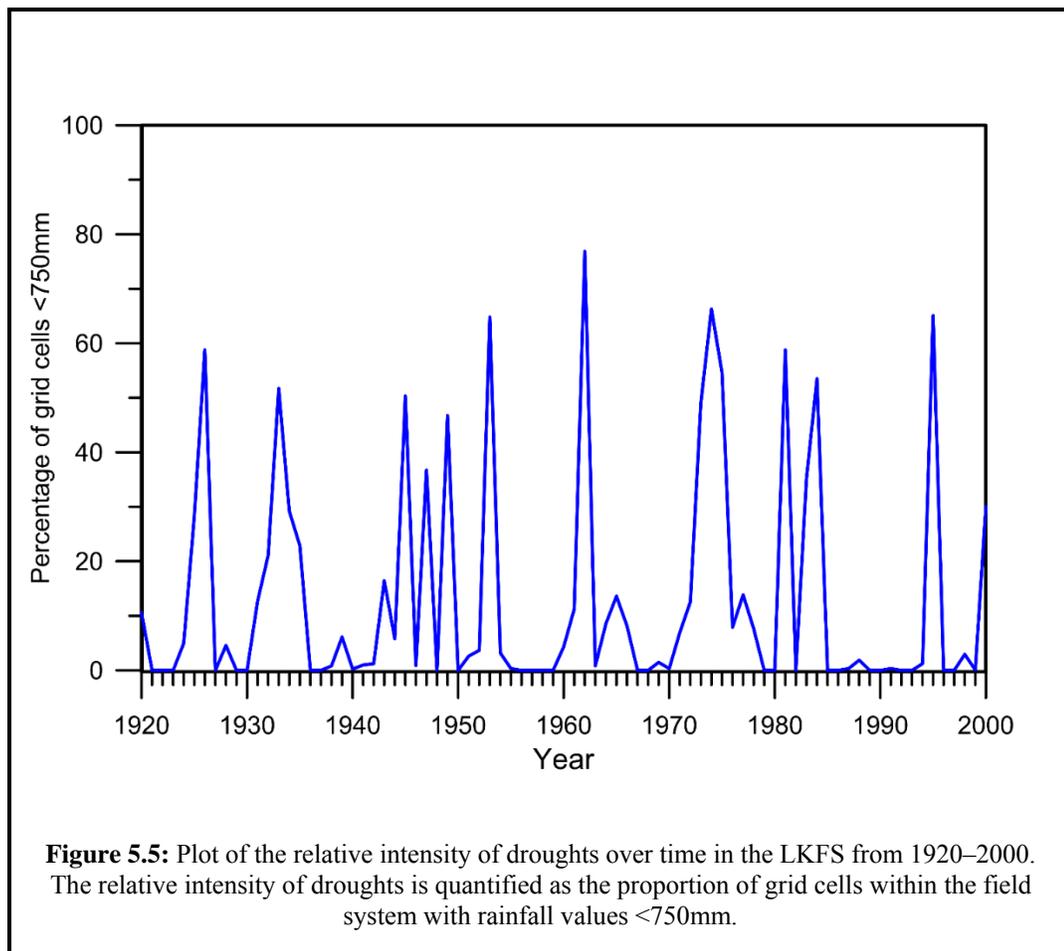
Because the risk model of interest here is specifically concerned with occurrence of droughts, the annual total rainfall raster cells are reclassified using the 750 mm annual rainfall critical threshold for sweet potato growth (Lebot 2008; Onwueme 1978). A binary reclassification procedure is performed in which grid cells with rainfall estimates <750 mm (drought conditions) are reclassified as 1 and grid cells with rainfall estimates ≥ 750 mm are reclassified as 0. This results in a series of maps for the years 1920-2000 showing the spatial distribution of drought and non-drought conditions.

Two methods are used to analyze the risk model – (1) measurement of the relative intensity of droughts for each modeled year, and (2) an investigation of the spatiotemporal structure and frequency of drought events in the LKFS. First, for each year modeled the percentage of grid cells within the LKFS with rainfall values less than the critical threshold of 750 mm is calculated, which gives a measure of the relative intensity of drought conditions¹⁶. Intense droughts are defined as years in which greater than 25% of the LKFS experiences crop failure. The change in the relative intensity of droughts over time is then plotted. Second, following Morrison (2012) a risk classification map is created by summing all reclassified drought maps to create a single map showing the spatiotemporal frequency of droughts in the LKFS.

¹⁶ It must be noted that this quantification of drought intensity is raster cell size dependent. If the size of raster cells were substantially increased or decreased, this could change slightly the results of the analysis. For example, very large raster cells could make drought events appear more intense as a greater proportion of the field system would be covered by each grid cell, whereas very small cells would result in false precision. However, the decision to model 250 m x 250 m raster cells is warranted in this case in that this cell size avoids false precision, given the relative coarseness of the present rainfall dataset, while not covering huge areas of *ahupua'a* or the field system.

5.2.5. Results of the geostatistical model

Reclassified drought maps for the years 1920 – 2000 can be seen in Appendix A. The red raster cells indicate rainfall model estimates <750 mm for that year (drought conditions), while green raster cells indicate rainfall model estimates ≥ 750 mm (non-drought conditions). In Figure 5.5, the results of these individual drought maps are summarized in the temporal dimension by plotting the relative intensity of droughts (quantified as the proportion of grid cells within the field system with rainfall <750 mm) over time.



The results of the geostatistical model suggest that most years do not experience relatively intense droughts, but also that droughts are relatively regular and often severe (see Table 5.1.). 33% of the modeled years experienced no drought conditions, and a further 34.6% of the modeled years less than 10% of the LKFS area experienced drought conditions. For the remaining years, and amount of the field system experiencing drought conditions fluctuates from >10% to a maximum of ~77%. Years with a relatively high percentage (>25%) of drought conditions are relatively evenly spread out over time, indicating that relatively intense droughts occur about every 6-10 years. The full table of drought percentages by year can be found in Appendix B.

Table 5.1: The temporal pattern of drought intensity for the LKFS. The left column shows categories of relative intensity quantified by the percentage of grid cells in the geostatistical model with total annual rainfall estimated to be lower than 750 mm. The right column shows the percentage of years in the geostatistical model that fall into each intensity category.

Relative intensity (% of LKFS < 750 mm annual rainfall)	Drought frequency (percentage of years out of the 81 modeled)
No droughts (0%)	33%
Low intensity (< 10%)	34.6%
Moderate intensity (10 – 24%)	11.4%
Relatively intense (> 25%)	21%

A risk classification map showing the estimated spatiotemporal frequency of droughts in the LKFS is shown in Figure 5.6. Grey areas indicate raster cells where no drought conditions occurred. For the remaining colored regions, green raster cells equal 1-5 years where rainfall estimates were <750 mm, whereas light green equal 5-10 years

<750 mm, yellow equal 10-15 years <750 mm, orange equal 15-20 years < 750 mm, and red equal >20 years with rainfall <750 mm.

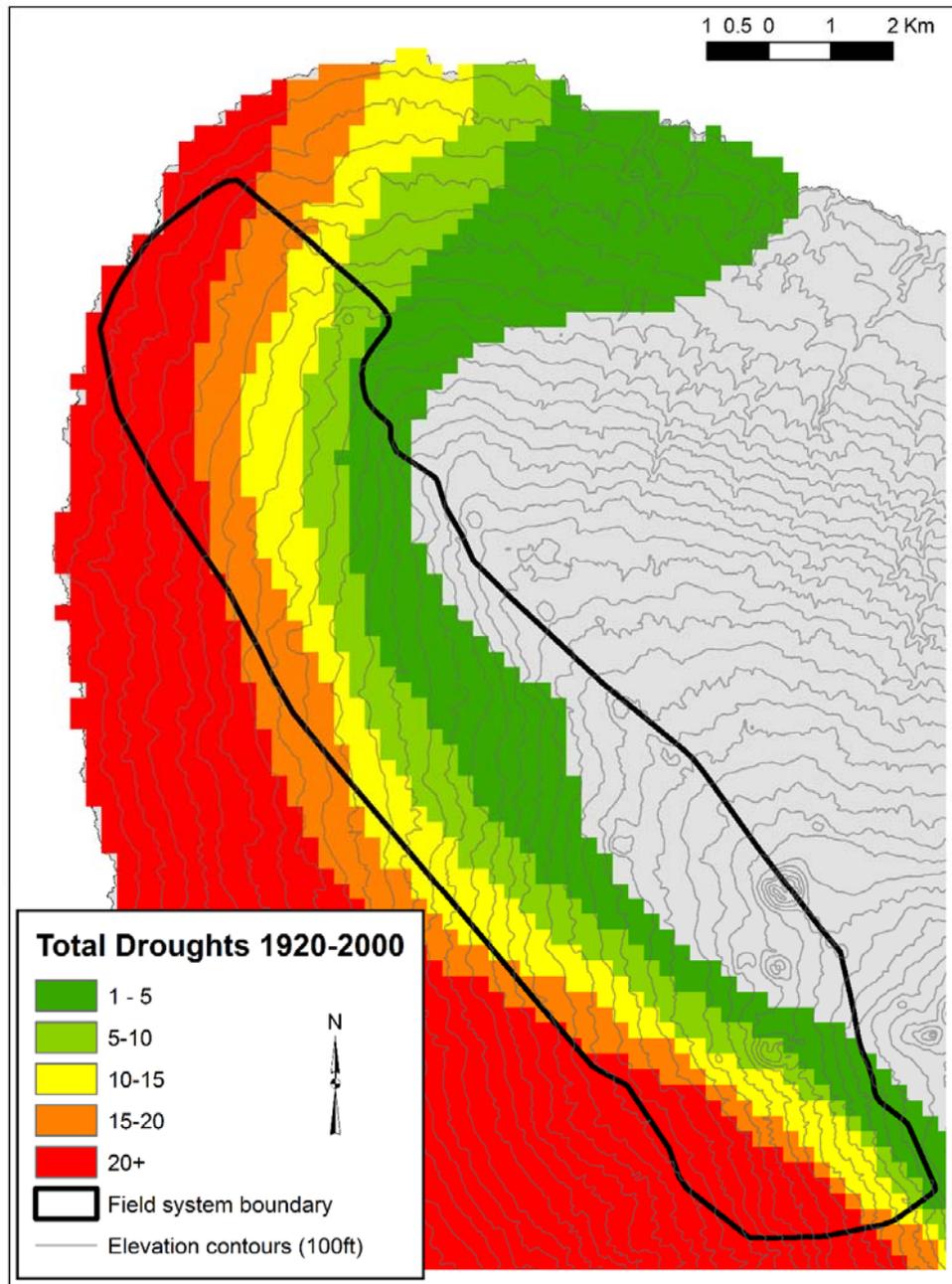


Figure 5.6: Spatiotemporal pattern of droughts in the LKFS from 1920 – 2000. Red, orange, and yellow raster cells indicate areas with a high level of agricultural risk, while and light green raster cells indicate moderately risky areas, and dark green show relatively low risk. The grey region in the central core of the field system experienced no droughts.

The model results shown in the risk classification map in Figure 5.6. indicate that droughts occur most frequently in northern and southern areas of the field system as well as at low elevation areas throughout its entirety. For example the majority of red, orange, and yellow raster cells (> 10 years with rainfall <750 mm) are found in northern and southern low elevation areas. This also suggests that risk is strongly related to elevation, with lower elevation areas tending to have a much higher level of risk than high elevations (however, very high elevation regions of the LKFS also tend to have reduced soil fertility [see Ladefoged et al. 2011]). These areas with red, orange, and yellow raster cells are interpreted as having a high level of agricultural risk. The central mid elevation areas of the field system (dark and light green raster cells) experienced between 1 and 10 droughts over the 81 years modeled. Light green areas are interpreted as having a moderate level of agricultural risk, while dark green regions are seen as relatively low risk areas. A large region of the high elevation areas of the central core of the field system experienced no droughts at all. Based on the model results, this area is interpreted as being risk-free in terms of the relation between rainfall and agricultural productivity. The implications of these results are discussed in Section 5.4., below.

5.3. Measuring uncertainty in leeward Kohala dryland agriculture

Several studies (e.g., Lee et al. 2006; Ladefoged and Graves 2000, 2008; Ladefoged et al. 2008) cite (un)predictability as an important characteristic of agriculture in the LKFS. However, these previous studies have treated high variability as an indication of unpredictability and in certain instances ambiguously presented their results

of measuring the temporal autocorrelation of annual agricultural yield (e.g., Lee et al. 2006). For example, Lee et al. (2006: 754) suggest low correlation values for year-to-year yield at their reference site B (which is located the southern region of the field system but not within its boundaries), however, it is not clear whether autocorrelation exists at larger time lags. Their autocorrelation test seems to merely suggest that site B does not exhibit a linear trend in yield over very short time lags (Warner 1998). Also, no significance values are presented with their test of temporal autocorrelation.

The amount of temporal variability in agricultural yield demonstrated in previous studies and in the drought modeling of the previous section suggests that many areas of the LKFS exhibit a *lack of constancy*, which *may* indicate unpredictability (Cashdan 1992; Low 1990). However, variability in itself is not sufficient to conclusively state that a series of events (i.e., a *time series*) is unpredictable. A phenomenon can also be unpredictable due to its *lack of contingency*, the degree to which events are correlated at different time lags (Cashdan 1990b; Colwell 1974; Low 1990). That is, in order to determine whether a time series is (un)predictable, we must test whether the phenomena in question exhibits periodic patterns which are detectable on human time scales (Shumway and Stoffer 2006). Following the suggestion of Low (1990) and Cashdan (1992), the level of uncertainty in LKFS drought events is measured using a spectral analysis.

5.3.1. Spectral analysis of annual rainfall

Spectral analysis is a method commonly used in EE for detecting repeating cyclical patterns, or *periodicities*, in time-series datasets (Platt and Denman 1975; Warner 1998). In spectral analysis the variance of the time-series is transformed and partitioned into a series of cycles of different lengths (i.e., periods). The inverse of these periods is derived, resulting in different frequency bands, which each account for different amounts of variance in the time-series (Warner 1998:9). The associated strength, or power of each of these frequency bands is then measured to determine the dominant periodicities in the time-series (Platt and Denman 1975; Shumway and Stoffer 2006). Power in this instance is defined as, “the estimated amount of variance in the time series that is accounted for by a particular band of frequencies” (Warner 1998:79). A power spectrum plot is then produced of these frequencies of the time-series against their associated power (Shumway and Stoffer 2006).

In any given time-series many high peaked frequency oscillations may exist. For example, repeating oscillations at both 4 year and 30 year periodicities. The following equation is used to determine the period of a particular high peaked frequency (Shumway and Stoffer 2006:176):

$$T = \frac{1}{\omega}$$

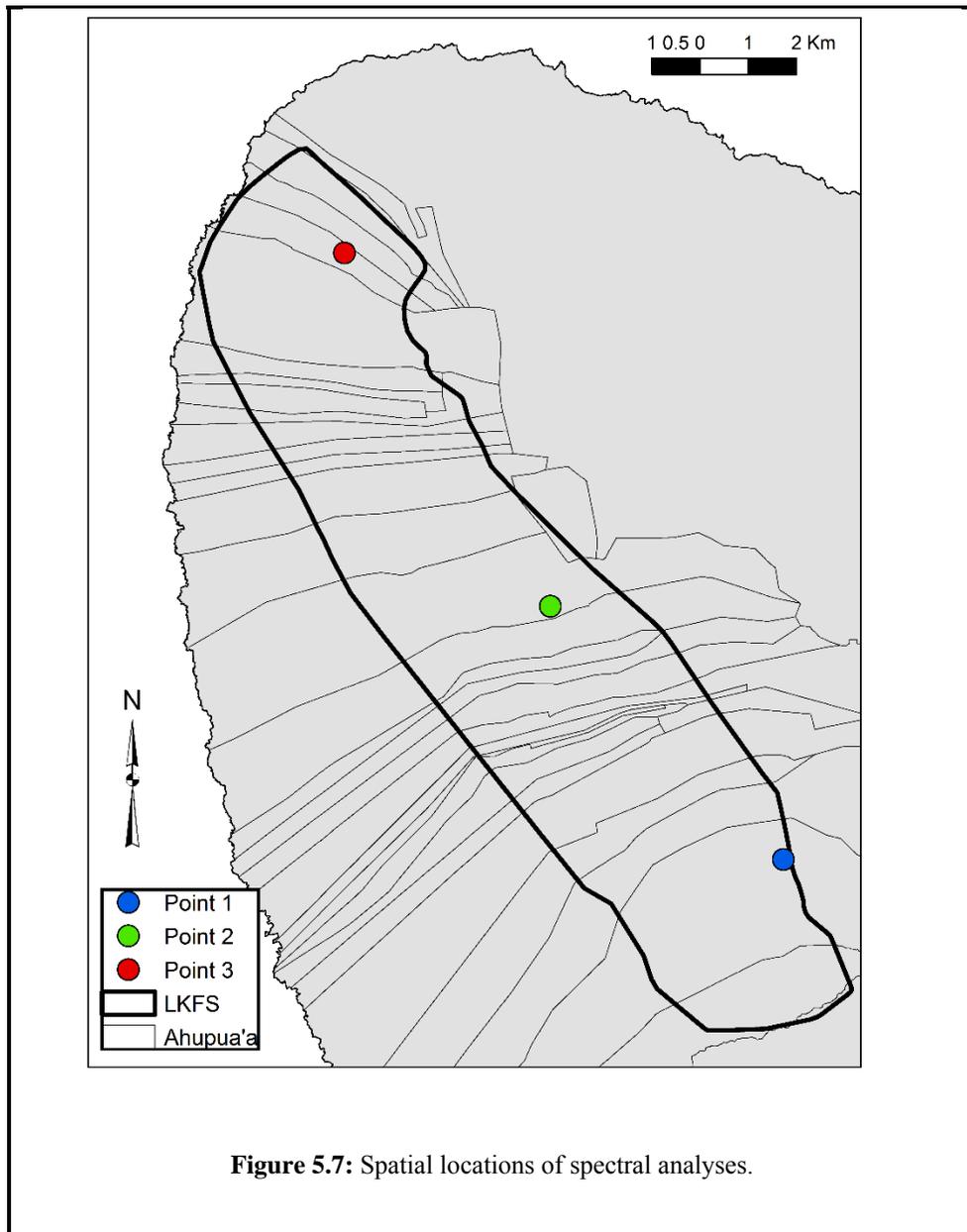
where T is the period of the time-series in sampling units (e.g., seconds, years, decades, etc), and ω is the frequency. For example, if our sampling unit is centuries and the

spectral analysis returns a high power frequency of .08, then the period of the time series is 12.5 centuries or 1,250 years.

A large peak in the power spectrum *may* indicate a predictable periodicity in the time-series at that specific temporal frequency; however, large peaks can arise by chance and it is therefore necessary to assess the significance of the results (Warner 1998:66). The level of statistical significance in spectral analyses is evaluated with reference to a random “white noise” model. That is, the significance of large frequency peaks in the power spectrum is measured as a significant deviation from randomness, which is often visually displayed in the power spectrum plot by horizontal lines representing different significance levels. If a given frequency peak surpasses these “white noise lines”, then that peak in the spectrum is said to be significantly different from random, indicated a predictable time-series.

Are there statistically significant cycles of drought in the LKFS that would be predictable on human time scales, hence reducing uncertainties involved with risky agriculture? A series of spectral analyses conducted on three rainfall time-series are presented below to assess the level of uncertainty in LKFS drought events. Any trend in the time-series is removed prior to running the spectral analysis. These three locations are located in the central core, far northern, and southern portions of the field system, spanning the range of rainfall variation in the LKFS (see Figure 5.7.). Each of these three sample points consists of 81 years of rainfall measurements aggregated at annual timescales. A fourth spectral analysis is also conducted on the time-series from Figure 5.5. of the proportion of grid cells experiencing drought conditions each year in an attempt to quantify and test the significance of any periodicities in the relative intensity of droughts

in the LKFS. These four spectral analyses provide true measure of the uncertainty of drought events across the range of the LKFS and at the scale of the system as a whole. All spectral analyses were computed using the Paleontological Statistics software package (PAST) (Hammer et al. 2001).



5.3.2. Spectral analysis results

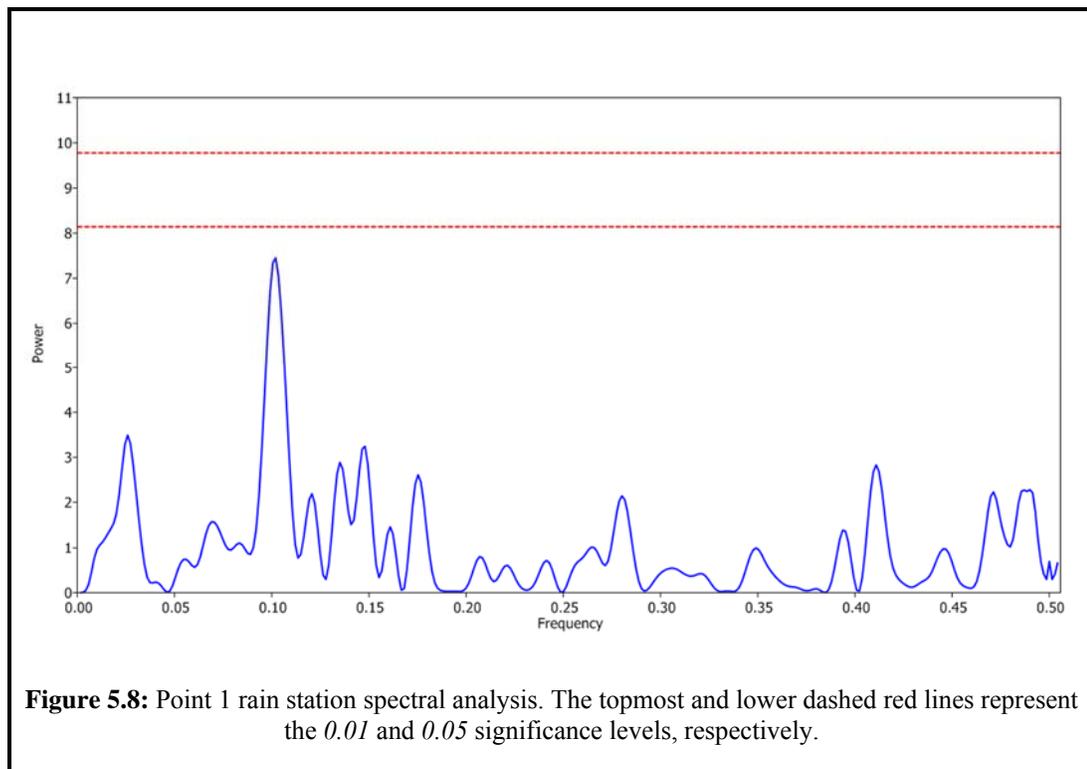


Figure 5.8., above, shows the results of the spectral analysis on the Point 1 rain station annual rainfall time-series. Point 1 spectral analysis has a peak frequency of 0.102 at a power of 7.452 which represents $T = 9.8$ years ($p = 0.097$).

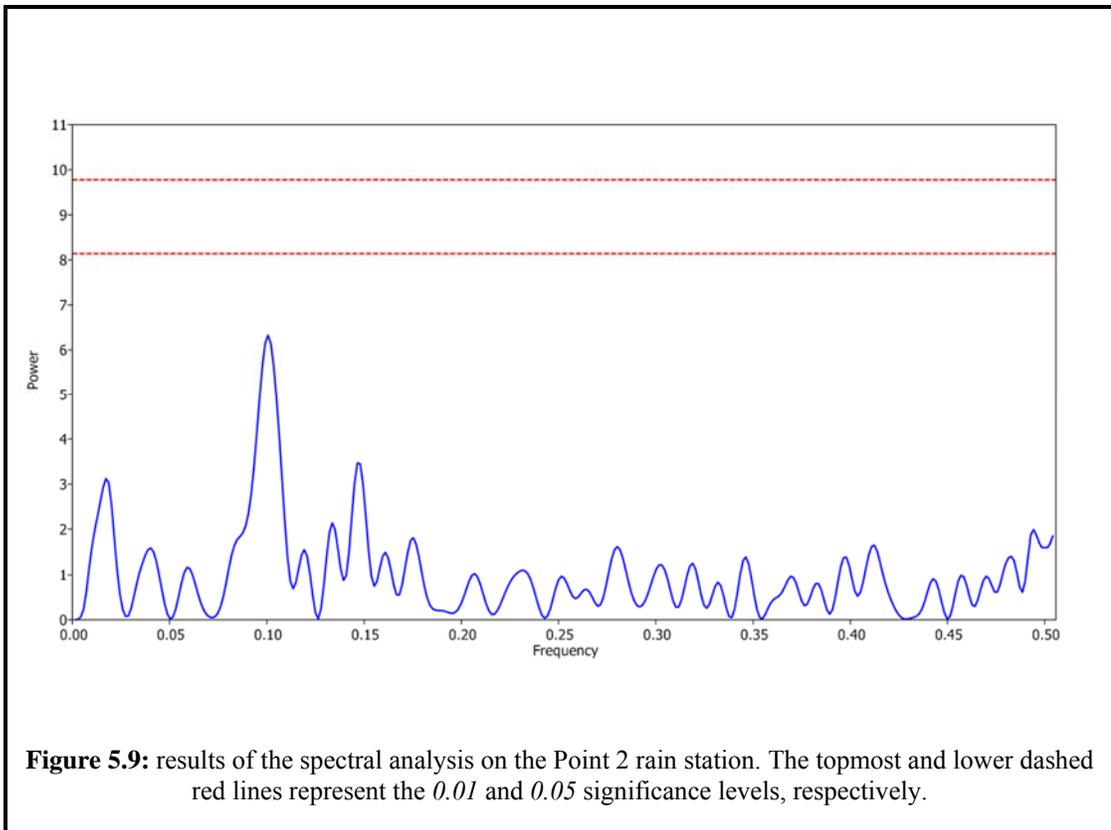
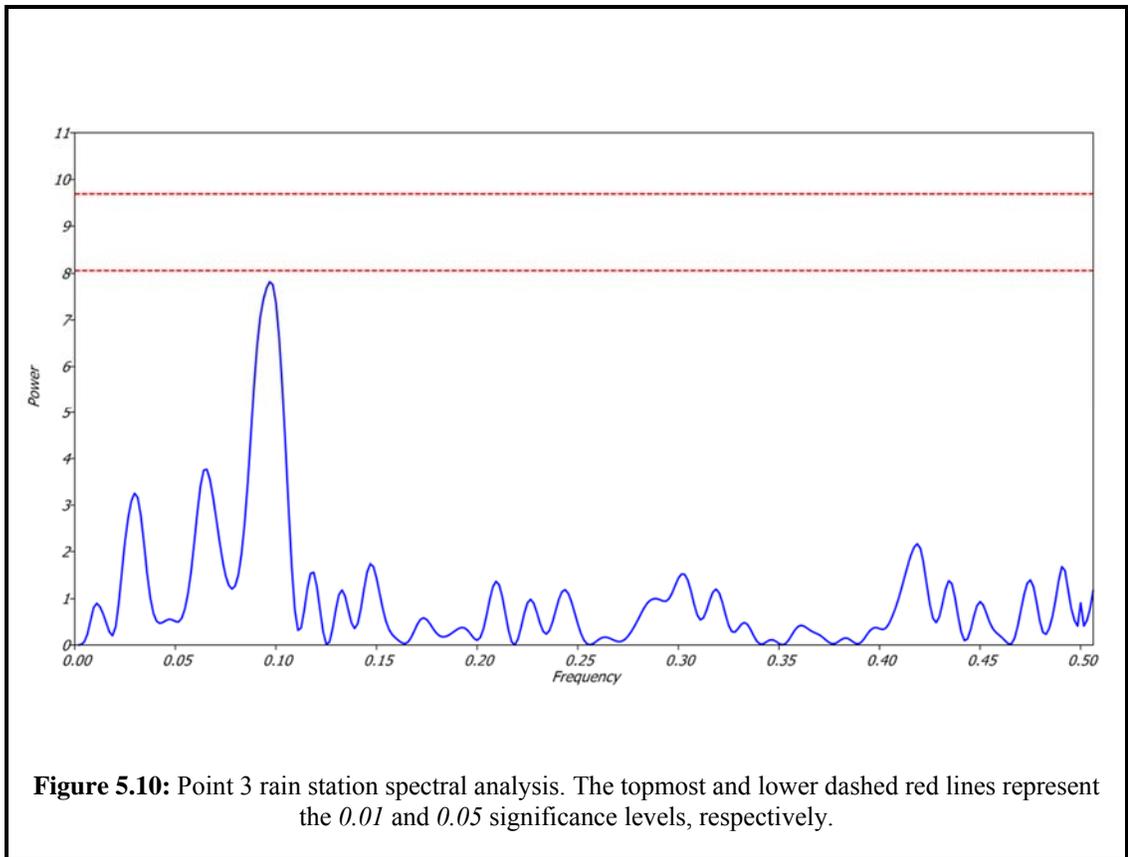


Figure 5.9., above, shows the results of the spectral analysis for the Point 2 rain station annual rainfall time-series. Point 2 spectral analysis has a peak frequency of 0.101 at a power of 6.325 which represents $T = 9.9$ years ($p = 0.271$).



The results of the Point 3 rain station spectral analysis is shown in Figure 5.10, above.

Point 3 spectral analysis has a peak frequency of 0.097 at a power of 7.819 which represents $T = 10.3$ years ($p = 0.063$).

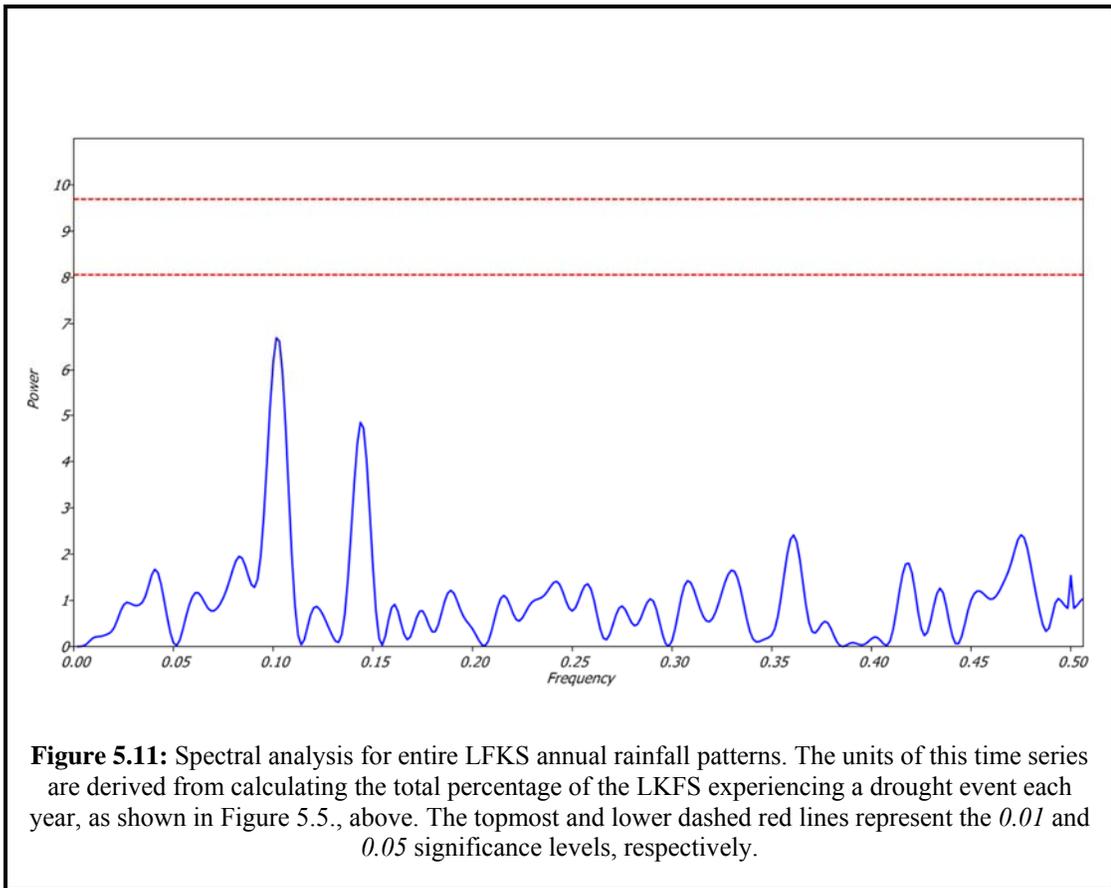


Figure 5.11. shows the results of the spectral analysis for annual rainfall patterns of the field system as a whole. The units of this time series are derived from calculating the total percentage of the LKFS experiencing a drought event each year, as shown in Figure 5.5., above. This spectral analysis has a peak frequency of 0.102 at a power of 6.695 which represents $T = 9.8$ years ($p = 0.18$).

5.4. Discussion

The results of the geostatistical model indicate distinct spatial patterns in droughts across the LKFS, with the majority occurring in low elevations and in the southern and northern regions. However, a large region of the central core of the field system experienced no droughts during the years modeled. This indicates that agricultural risk from droughts was high in certain areas of the LKFS but low in others, and that the frequency of drought events is closely related to elevation. In addition, the central core of the field system is shown to be relatively low risk, with risk increasing with distance away from this core. These results largely corroborate those of other models and simulations of agricultural productivity in leeward Kohala, such as those reviewed above by Kirch et al. (2012), Ladefoged et al. (2008, 2011), and Lee et al. (2006) and Lee and Tuljapurkar (2010). These results of the risk model suggest that frequent resource shortages would be disproportionately felt in certain sectors of the LKFS, which in turn would differentially affect different social groups. In particular, this spatial patterning of risk would have further increased despotism between the inhabitants of these different areas.

The geostatistical modeling results also suggest that relatively intense droughts (i.e., those in which greater than 25% of the LKFS experiences crop failure) occur frequently, about every 6-10 years. It may have been possible for prehistoric cultivators of the LKFS to track the temporal occurrence of these intense drought events at some level of precision. Indeed, the results of spectral analyses suggest that this approximately 6-10 year reoccurrence of intense drought events could have been relatively predictable at

about a 10 year periodicity. That is, each time-series exhibits a fairly high power spectrum around the 0.10 frequency band; when this value is input into the period defining equation, $T = \frac{1}{\omega}$, the resulting periodicity is approximately $T = 10$ years for each sample. To summarize: Point 1 (Figure 5.8.) in the southern high elevation of the LKFS there appears to be a 9.8 year periodicity ($p = 0.097$); Point 2 (Figure 5.9.) in the central core of the field system suggests a 9.9 year periodicity ($p = 0.271$); Point 3 (Figure 5.10.) in the northern lower elevation portion of the field system exhibits a 10.3 year periodicity ($p = 0.063$); and the time-series of drought frequency for the whole LKFS (Figure 5.11.) also suggests a 9.8 year periodicity ($p = 0.18$). This consistent pattern of ~10 year periodicities is the same as that suggested above for the approximately 6-10 year pattern of relatively intense drought events, and also that suggested by Ladefoged and Graves (2010:93).

The results of the spectral analyses suggest that drought events in LKFS would have been unpredictable over short and relatively long time-scales, but that there are statistically significant patterns in annual rainfall at an approximately 10 year periodicity. That is, for Point's 1 and 3 we can be > 90% confident that the resulting ~10 year periodicity *is not* due to the vagaries of sampling, i.e., is significantly different from a white noise model. In addition, we can be > 80% confident in the ~10 year periodicity for the field system as a whole (Figure 5.11.). There is much lower confidence (~73%) in the results of the Point 2 spectral analysis; however, this portion of the field system exhibits a very low level of risk droughts so it can be said to be relatively predictable (i.e., low uncertainty) because of its constancy. These results suggest that the low risk central core of the field system would have also been low in uncertainty. However, the

higher risk areas in the northern, southern, and low elevation areas would have also been highly uncertain at approximately 1 – 5 year periodicities and time-spans greater than 10 years, but likely were predictable and therefore low in uncertainty at 10 year cycles.

It is unclear at present whether the prehistoric inhabitants of the LKFS could have tracked this 10 year periodicity. The fact that agricultural expansion into the areas around Point's 3 and 1 (regions with a high level of risk but low uncertainty at the 10 year periodicity [see Figure 5.12., below]) occurred relatively late in Hawaiian prehistory (Ladefoged and Graves 2008) suggests individuals may have been able to buffer against this uncertainty. However, the 10 year periodicity may have been infrequent enough that individuals would not have been able to adequately track and buffer against drought events as well as they could against a shorter, e.g., 1– 5 year, periodicity. More research is needed to evaluate whether a 10 year climatic cycle is perceptible to human individuals in the absence of the computing techniques used here. However, at present the results suggest low uncertainty at a 10 year periodicity, but very high and distinctly patterned risk and high uncertainty at short and very long time-scales.

The spatial patterning of agricultural risk from droughts in the LKFS shown here would have had important implications for agriculture in the field system and the people who depended on it. For example, the continued pattern of areas with a high frequency of droughts would have resulted in a high occurrence of crop failures in these areas, while the relatively risk-free areas would not have experienced these crop failures to the same degree. Over time, this spatial difference in the occurrence of crop failures would have resulted in differences in resource-holding potential between groups or families who depended on the agricultural resources from these areas (Boone 1992). Differences in

resource-holding potential would have manifested both within *ahupua'a* territories and between different *ahupua'a*.

When the results of the risk classification map are overlaid with the locations of the *ahupua'a* in leeward Kohala (Figure 5.12.), clear patterns of risk emerge both within and between *ahupua'a* in the LKFS. For example, lower elevation areas of all *ahupua'a* are at a much higher risk from food shortages than central and northern areas. Also, when risk is observed at the scale of the whole district (*moku*), *ahupua'a* in the north and south would have had much more agricultural risk than the *ahupua'a* in the central areas of the field system, a pattern also noted in Lee et al. (2006) and Ladefoged et al. (2008). These patterns of risk within and across communities have important implications for social interaction when explained in terms of the EE model.

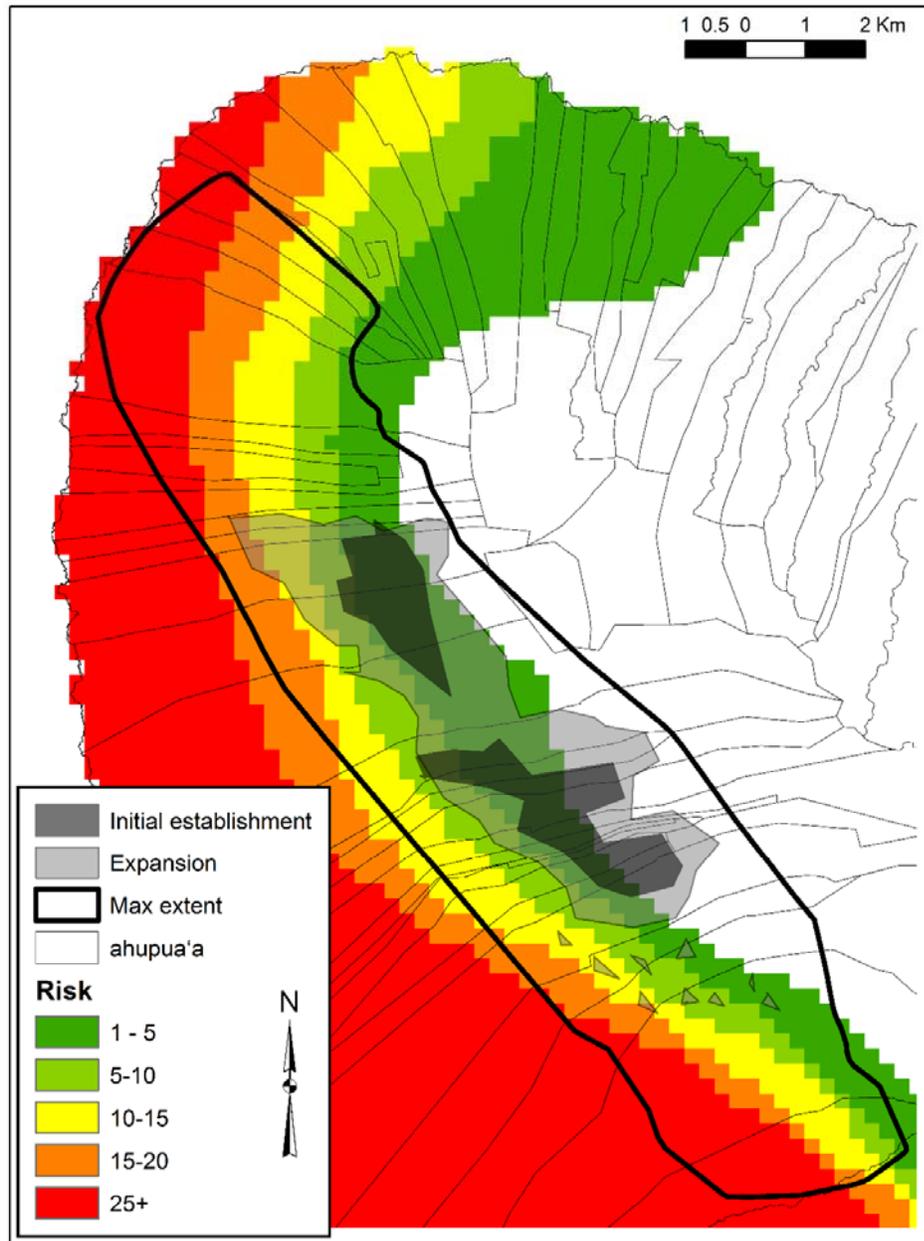


Figure 5.12: The spatial relationship between *ahupua'a* location, LKFS establishment and expansion, and the level of agricultural risk across the region. Approximate spatial locations of LKFS establishment and expansion derived from the published results of Ladefoged and Graves (2000; 2008) and Ladefoged et al. (2003).

Comparing the spatial patterns of risk with the temporal sequence of LKFS establishment and expansion suggests that the potential selection for cooperative despotism, or so-called “patron-client relationships” (Boone 1992), would have been very high (Figure 5.12.). Initially the field system was established in areas with high agricultural productivity and a relatively low level of risk. Due to the despotic distribution of individuals evolving in the LKFS at this time (see Chapter 4), land-use, settlement, and agricultural activities begin to expand into the less desirable lower-elevation areas. The geostatistical model indicates that these areas would have further been affected by much higher degrees of risk from crop failure. This likely would have provided the impetus for patron-client cooperative despotism between dominants (*ali'i*) and subordinates (*maka āinana*), whereby *ali'i* exchanged a portion of their resources in exchange for some form of repayment at a later time, likely a form of “social debt” (Diehl 2000b), such as labor, territory defense, or reciprocated resource exchange in good years. This kind of cooperative social arrangement would clearly have benefited both the *ali'i* and *maka āinana*. One possible correlate of this patron-client social debt is evidenced by the ethnohistoric accounts of so-called *ko'ele* and *haku-one* agricultural plots, which were lands which belonged to a chief or land-manger but which were worked by the commoners (Kamakau 1992b; Malo 1987:18) (see discussion in Chapter 2).

Over time, as human population density increased in leeward Kohala (Ladefoged and Graves 2007) reciprocal cooperation between *ali'i* in the economically defensible core of the LKFS and *maka āinana* in the resource-poor, high-risk areas and would have become increasingly problematic. Initially, problems would increase due to the difficulty

of maintaining reciprocal cooperative social relationships in large groups and then increasingly second-order collective action problems (Boyd and Richerson 1988, 1992). It is likely here that the distinct rank of Hawaiian land-managers – the *konohiki* – emerge as a kind of special interest group to enforce and maintain cooperation in the increasingly large and despotic Hawaiian communities (Boone 1992). Given multiple generations of frequent resource shortages and sustained differences in social inequality and resource holding potential, these processes of competition and cooperation may have laid the initial groundwork for the institutionalization of hierarchical social organization seen at in Hawaii at contact.

Chapter 6: Conclusion

Hawai‘i’s has figured prominently in discussions of the evolution of social complexity for decades. However, the vast majority of previous explanations have neglected to emphasize the Darwinian evolutionary influences on hierarchy formation. Instead, most previous research has focused on the evolution of particular societal types, such as complex-chiefdoms or archaic-states. Proponents of this neo-evolutionary approach have attempted to explain what they see as the development of greater social complexity through the supposed “hallmarks” of complex societies, especially agricultural intensification, monumental architecture, the rise of religious authority, conquest warfare, and in particular, the political agency of ambitious chiefs. To date, few archaeologists operating from this neo-evolutionary approach have attempted to derive testable archaeological predictions from evolutionary ecological theory regarding the evolution of prehistoric Hawai‘i’s distinct hierarchical social organization. This thesis is an attempt to fill this void using an evolutionary ecological modeling approach that can explain hierarchy formation in dynamically sufficient terms for prehistoric Hawai‘i.

Evolutionary and ecological mechanisms profoundly influence the evolved structure and characteristics of social groups. In relation to human behavior, these evolutionary ecological mechanisms result in a complicated interplay of evolved culture

and phenotypic behavioral plasticity (Boyd and Richerson 1985; Smith and Winterhalder 1992a). A relatively unique aspect of some human groups, including those of the Hawaiian Islands, is their hierarchical social organization and large-scale cooperation. The existence of these social phenomena poses an important evolutionary question: Why would the large subordinate groups in a hierarchy continue to cooperate in a social structure which by definition results in their lowered fitness relative to dominant group members? These despotic social groups are expected to form in environments where high quality resources are unevenly distributed, resulting in differences in resource holding potential and reproductive skew (Summers 2005; Vehrencamp 1983a, 1983b). This gap between dominants and subordinates is expected to widen further when emigration from the group is sufficiently costly for subordinate members, such as when additional viable habitat is limited. EE theory suggests that this kind of despotic group will be beneficial to individuals, subordinate and dominant alike, when there are large benefits to group cooperation. Because cooperation in large human groups inherently involves a number of first- and second-order collective-action problems (Boyd and Richerson 1988, 1992), special interest groups are expected to be selected for who receive special benefits which offset the costs of enforcing cooperation in large groups (Boone 1992; Hooper et al. 2010; Smith and Choi 2007). It is in these ecological conditions that the evolution and maintenance of large hierarchical human groups is predicted.

Here, this model has been applied to the archaeological and climatic record of the leeward Kohala region of Hawai'i Island, a locus for the evolution of hierarchical groups over the course of Hawai'i's approximately 800 year prehistory. Given what we know

about Hawaiian social organization at European contact and the evolutionary ecological model presented above, the following predictions were derived for archaeological record of leeward Kohala: 1.1: evidence for a patchy distribution of economically defensible resources which would favor a despotic distribution of individuals, 1.2-1.3: archaeological evidence for territoriality and an ideal-despotic pattern of land-use over the course of leeward Kohala prehistory, 1.4: evidence for group fissioning as the Sibly size is surpassed, and finally, 2.1: evidence for an uneven distribution of risk and uncertainty stemming from resource shortages. As the case study of interest involved populations relying on inherently risky rain-fed agriculture, this prediction was evaluated by quantifying and analyzing the spatiotemporal patterns droughts (risk) and the predictability of these drought events (uncertainty).

On the whole, the evidence presented in Chapters 4 and 5 largely meet the predictions of the EE model. The temporal trends in the spatial patterns of land-use in the LKFS approximate the predictions 1.1. – 1.4. of the IDD and economic defendability models, providing a testable explanation of the emergence of social inequality in prehistoric Hawai‘i rooted in Darwinian evolutionary theory for human cultural and social phenomena. Specifically, while it is generally assumed that some level of social inequality was present at the time the Hawaiian Islands were colonized (Kirch 1984; Kirch and Green 2001), the IDD and economic defendability models provide testable explanations for the increase in social inequality between the *ali‘i* and *maka āinana* classes over the course of Hawaiian prehistory. These models also provide an evolutionary ecological account of the concepts of agricultural “expansion” and “intensification,” an explanation previously absent from studies of Polynesian

agriculture. In addition, the historical climate data provide an affirmation of the prediction (2.1) of formal despotic and hierarchical cooperation models (e.g., Boone 1992; Hooper et al. 2010; Smith and Choi 2007), which indicate that spatiotemporal patterns in risk and a fairly high degree of uncertainty from food shortages would have resulted in a strong selective force for the evolution and maintenance of social hierarchies in Hawaiian prehistory.

However, some major drawbacks in the data of this thesis require discussion. While the use of the Rainfall Atlas of Hawai'i dataset (Giambelluca et al. 2012) gives the climatic analysis presented in Chapter 5 a longer temporal dimension to agricultural modeling than was previously possible, as with other studies of climatic and agricultural variability discussed in this thesis, the present analysis suffers from the serious and obvious lack of a sufficient paleoclimate record of rainfall for the Hawaiian Islands. Yet, because such paleoclimatic information is currently unavailable, the historical record of rainfall used here offers the most complete empirical dataset available for the Hawaiian Islands. The addition of more information on the temporal climatic variation in the Hawaiian Islands would greatly strengthen our ability to evaluate the risk and uncertainty model.

The spectral analysis method used in Chapter 5 to measure the degree of uncertainty in LKFS agriculture also has limitations. The spectral analysis detected a consistent ~10 year periodicity in annual rainfall at all sample points. This result suggests that annual rainfall and droughts were possibly predictable to LKFS agriculturalists at this 10 year cycle, meaning that uncertainty would have been low at this time-scale. However, the spectral analysis suggests that there would be low

predictability and therefore high uncertainty at short time-scales (~1 – 6 year cycles) and time-scales > ~10 years. One limitation of this spectral analysis is that the technique is only capable of detecting periodicities at the size of the sampling unit, in this case one year. This means that climatic events that happen at different aggregated intervals (e.g., the El Niño/Southern Oscillation which occurs at ~3 – 7 year intervals) might not be detectable with this technique. The use of more sophisticated time-series methods in future studies would strengthen the analysis presented in Chapter 5.

Various theoretical and archaeological drawbacks of this thesis also require discussion. First, because this thesis focused purely on the leeward Kohala region of Hawai‘i Island it is relatively limited in scope. While the theoretical model and analytical methods of testing used will likely be useful in other dryland agricultural regions, it is not clear at present how the model can be used to explain the evolution of social hierarchies in the very different windward regions of the archipelago. This is because the EE model presented in Chapter 3 is explicitly focused on how differential spatial patterning of risk and uncertainty select for cooperative social hierarchies. However, the abstract theoretical models of hierarchy formation presented in Chapter 3 (e.g., those of Boone [1992]; Hooper et al. [2010]; Smith and Choi [2007]) predict that hierarchy will be the evolutionarily stable strategy in situations involving despotism and *any kind* of cooperation or collective action problem. Thus, the risk and uncertainty cooperation problem evident in the evolution of social hierarchy in leeward Kohala might not apply to the less risky and uncertain windward areas, but the basic theoretical prediction of despotism and some kind of collective action problem likely still hold. As the windward areas are generally thought to be relatively lower risk in terms of

agricultural productivity, the EE model will require a thoughtful reworking to be applicable to these areas.

Two theoretical gaps in the present thesis will also be apparent to those familiar with the evolutionary ecology of social hierarchy – the neglect of costly signaling models and multi-level selection theory. Briefly, signaling theory is a branch of EE models devoted to explaining non-human and human-communication (Maynard Smith and Harper 2003). Within this suite of models, costly signaling refers to an explanation for supposedly costly displays in nature, such as a male peacock’s tail or the construction of monumental architecture. Costly signaling is often employed to explain elaborate investments by elites in hierarchical groups, such as the construction of monumental architecture, and may also help explain how elites maintain status (e.g., Boone 1998, 2000). While an interesting application of EE theory, costly signaling models may be unnecessary in explaining the evolution of hierarchical groups. Thus, a more thoughtful incorporation of costly signaling and “waste” (see Dunnell 1999) models in the future will likely prove fruitful.

Multi-level selection theory is, as its name implies, concerned with explaining under what conditions the level of selection shifts from individual organisms to the level of groups (Okasha 2008; Sober and Wilson 1999). This thesis was specifically concerned with the evolution of despotism and initial formation of hierarchy at the analytical scale of groups at the *ahupua‘a*-level, thus making multi-level selection models appropriate at a larger scale. Nonetheless, it is likely that multi-level selection mechanisms were involved as the scale of social organization shifted in Hawaiian prehistory from the level of the *ahupua‘a* to the level of entire districts and islands. This would especially be the

case when large-scale warfare begins to emerge later in prehistory. Incorporation of these models and derivation of further testable archaeological predictions will be beneficial in future studies.

Another avenue for future research concerns the unification of the series of models presented in Chapter 3 into a single formalized model. While each of the EE models presented in Chapter 3 have either been formalized into mathematical or computer simulation form by the authors cited, when synthesized together they lack the desired rigor and elegance of a proper Darwinian model (McElreath and Boyd 2007). Formalizing the series of models presented in Chapter 3 into a single coherent agent-based simulation would be a sensible solution to this limitation. For example, agent-based modeling of social hierarchy formation has recently been successfully used in archaeological analyses, such as Kohler et al.'s (2012) application of Hooper et al.'s (2010) hierarchical cooperation model to pre-Hispanic Pueblo groups. An agent-based model would also be useful because it allows the incorporation of a higher level stochasticity in models, something not easily accomplished with standard mathematical models of social evolution (McElreath and Boyd 2007).

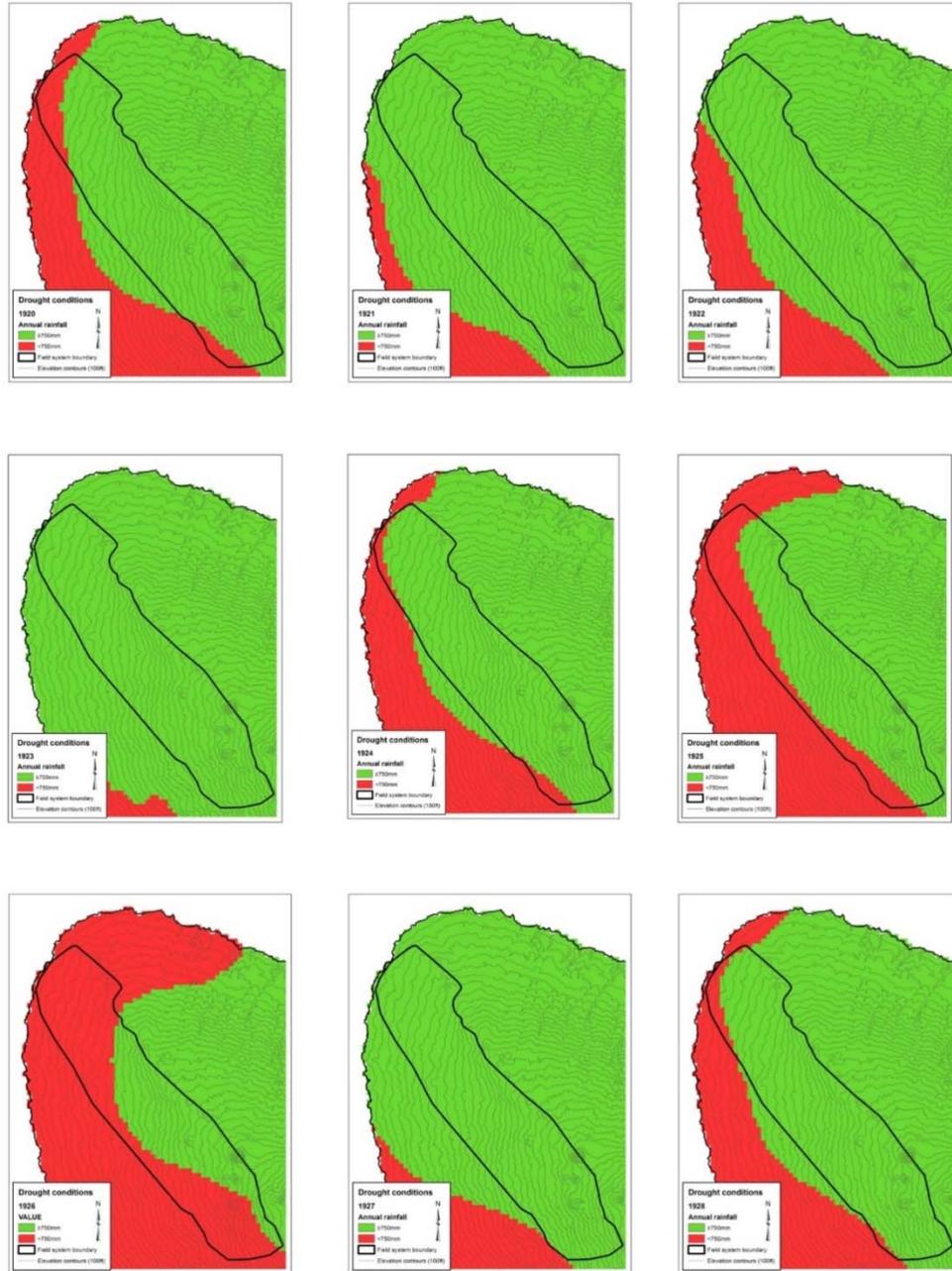
Briefly, an agent-based model is a computer simulation in which individual “agents” are programmed into a modeling environment where they behave according to a suite of very simple rules (Railsback and Grimm 2012). In archaeological applications agents are generally taken to represent idealized prehistoric inhabitants of the area being studied. It is possible to program into the model a multitude of different agents pursuing different strategies under a range of different environmental parameters. Possible agent states for a hierarchical cooperation model would involve strategies such as “always

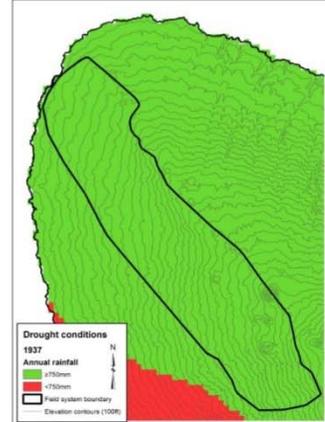
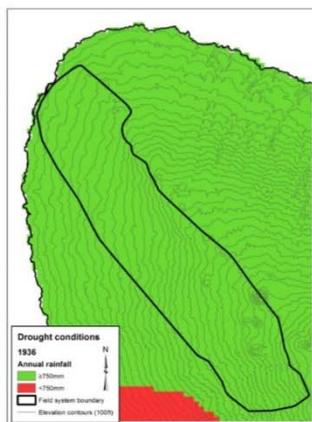
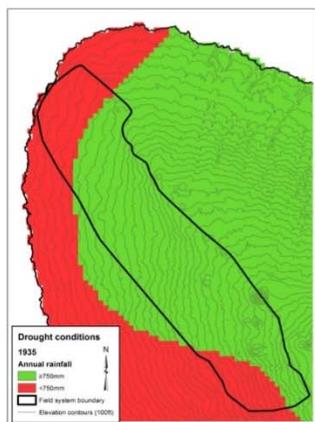
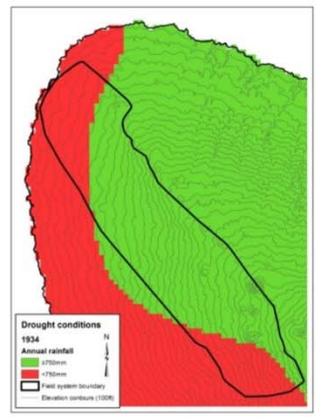
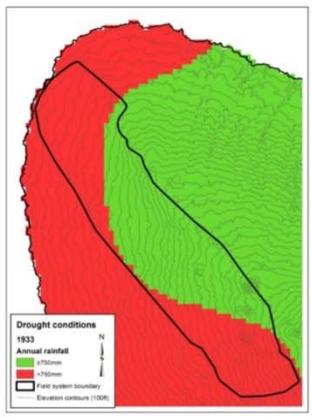
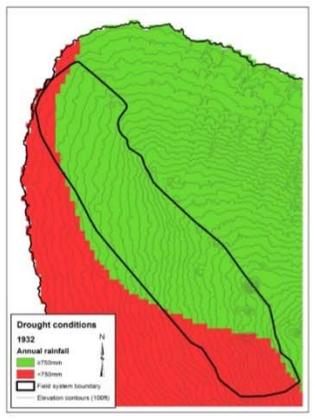
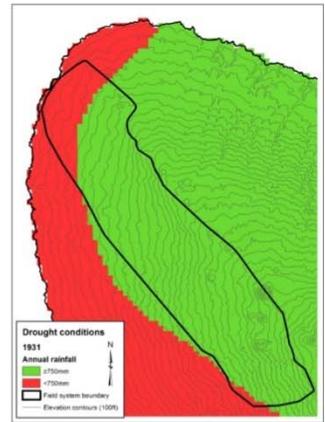
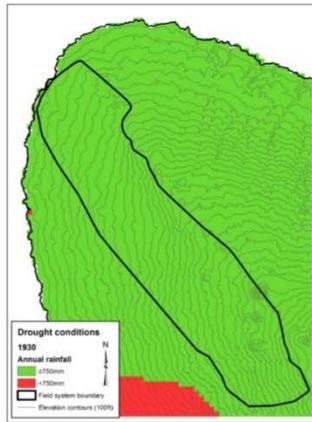
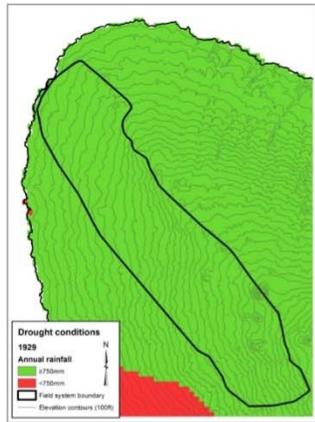
cooperate,” “always defect,” or “only cooperate when monitored by a special interest group” (Kohler et al. 2012). Different agents would then compete for resources under a variety of simulated environments, such as those approximating scarce and unpredictable or economically defensible environments. The benefit of these abstract models would be to track emergent outcomes under extremely simplified and ideal conditions. Then having established a series of null models, realistic environmental time-series from Hawai‘i could be plugged into the simulation, such as agricultural productivity and risk and uncertainty models. The results of this kind of simulation model would complement the efforts of this thesis.

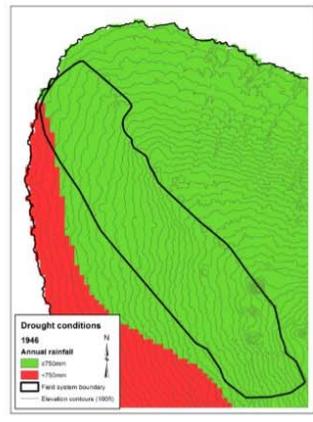
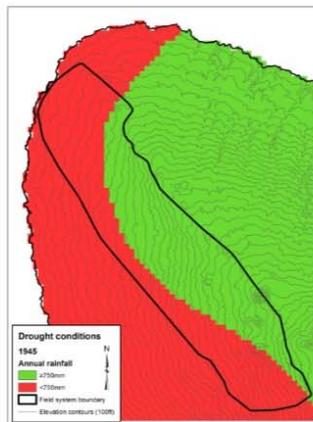
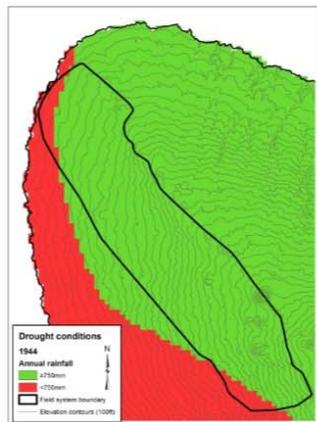
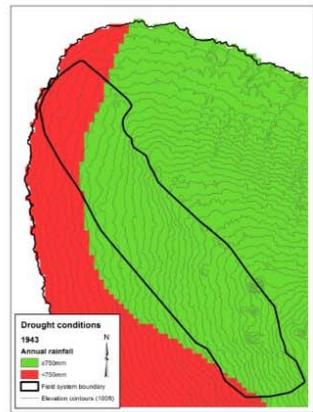
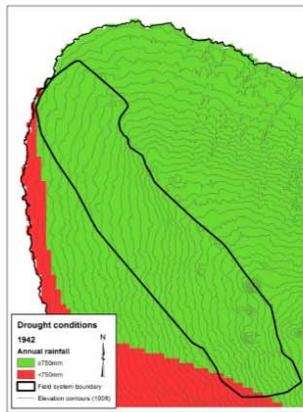
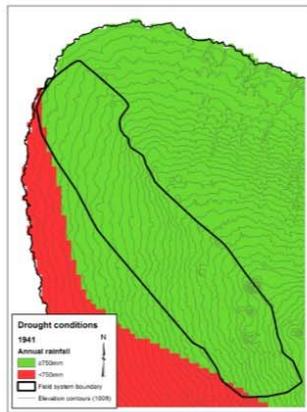
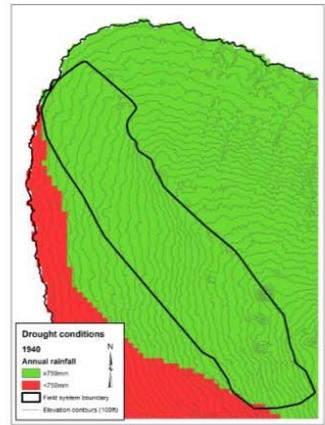
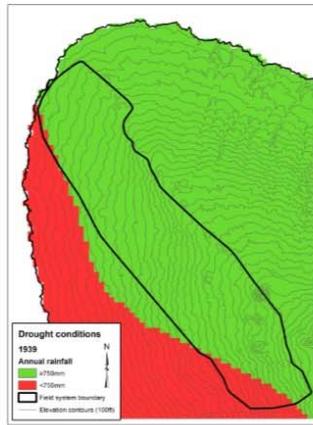
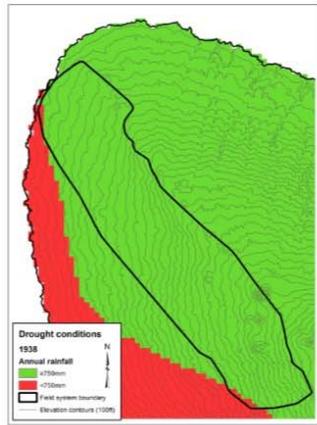
This thesis has been an attempt to augment previous research in Hawaiian archaeology with an explicit evolutionary ecological approach to the evolution of social hierarchy. Despite the problems discussed above, the main significance of this work has been to offer up a set of formalized arguments which likely explain why and under what conditions membership in a hierarchical group would have been an optimal strategy for individuals in prehistoric Hawai‘i. This explanation is useful because it provides an internally consistent explanation which fills the gaps in previous research, specifically those lacking ultimate explanatory models (e.g., Hommon 2013). The benefit of this explicit modeling approach is the formation of new research questions and the resultant testable predictions, many of which await further exploration. The continued application of evolutionary ecological modeling to problems in Hawaiian archaeology will greatly add to Hawai‘i’s significance as a so-called “model system” (sensu Kirch 2007) for human-environment interactions.

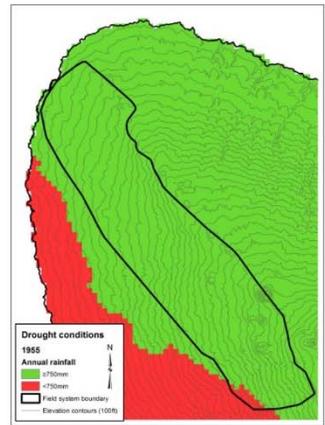
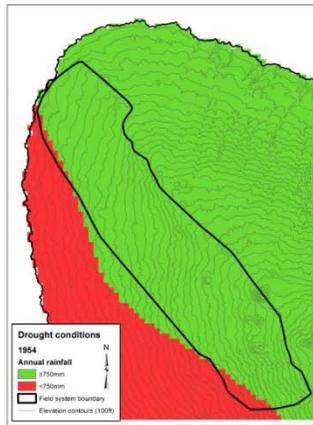
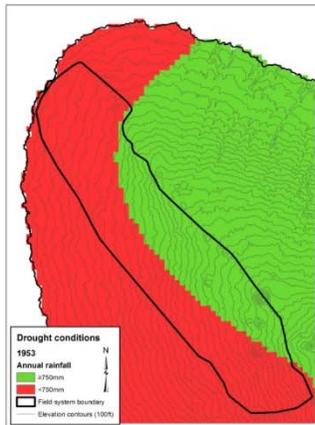
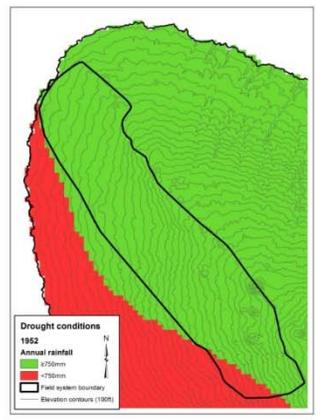
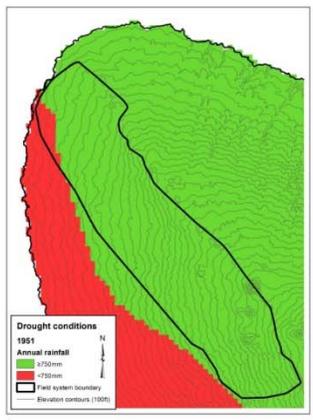
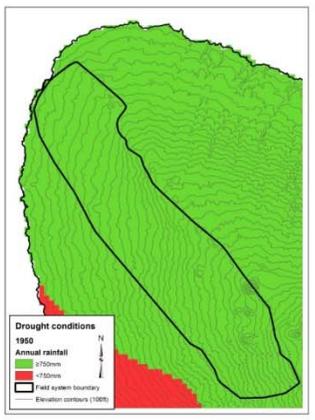
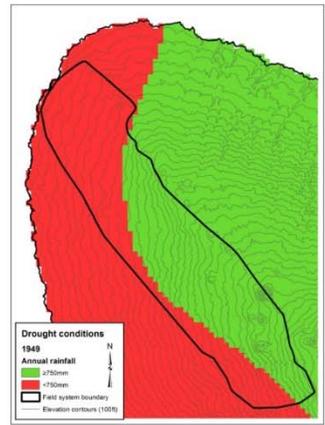
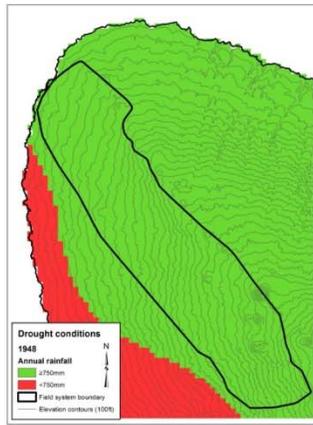
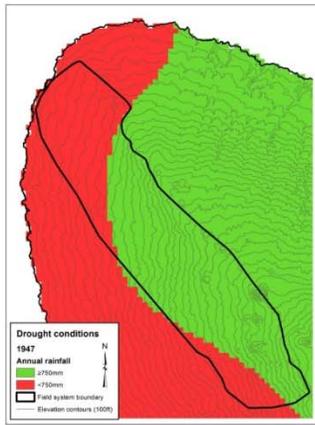
Appendix A

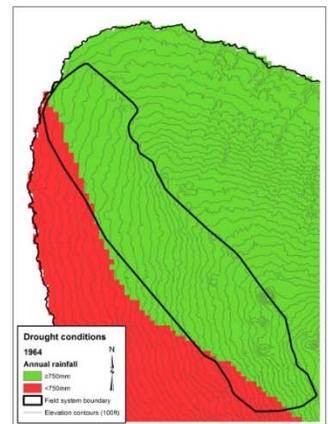
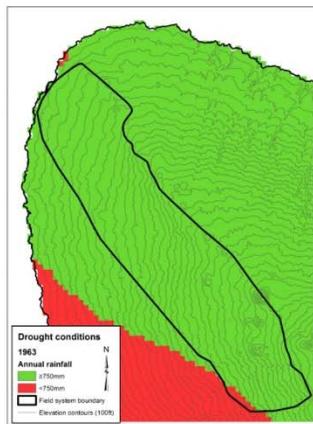
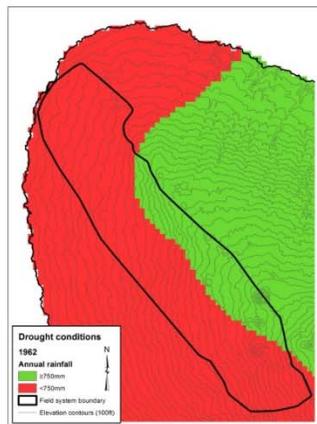
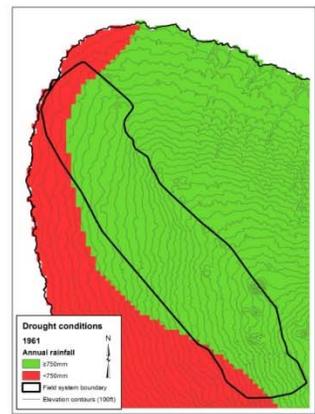
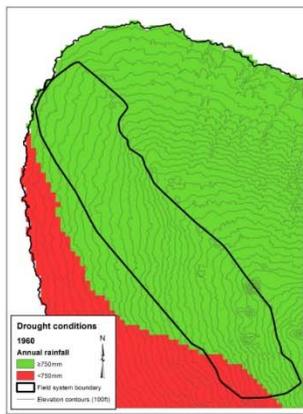
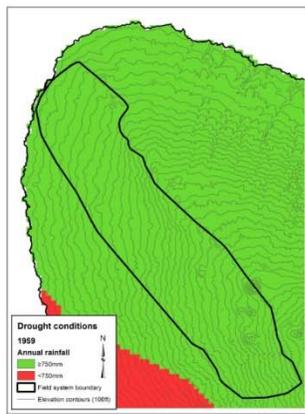
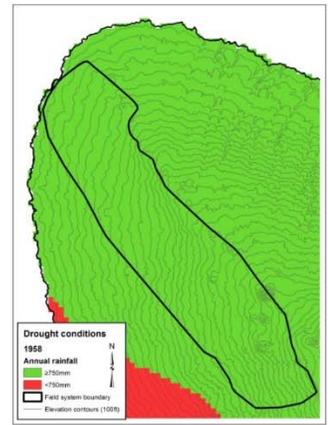
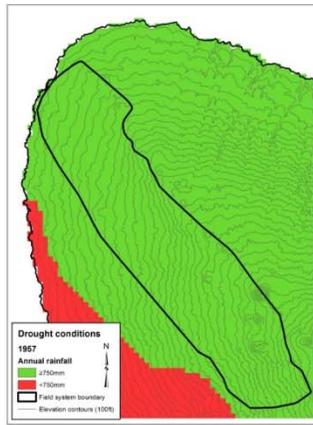
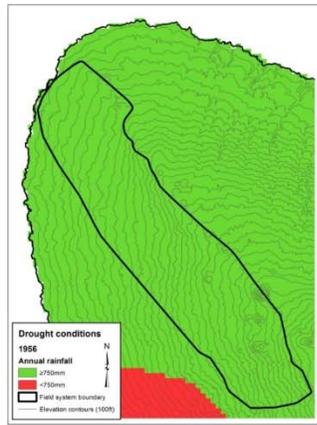
Individual drought estimation maps of the LKFS for the years 1920-2000. Green areas show non-drought conditions (rainfall ≥ 750 mm), while red areas show drought conditions (rainfall < 750 mm). The dark black line indicated the LKFS boundary. Light grey lines show 100ft elevation contours.

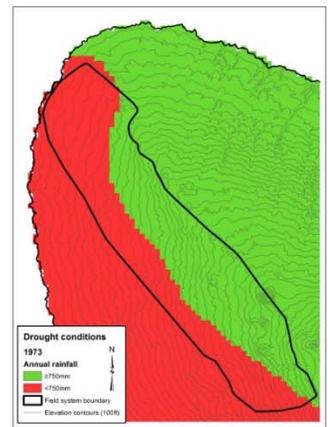
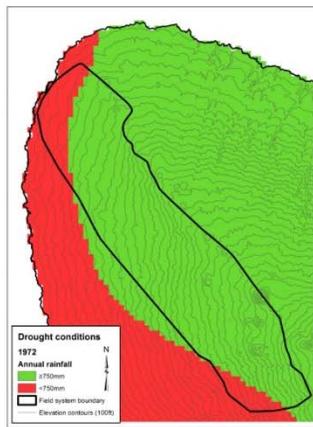
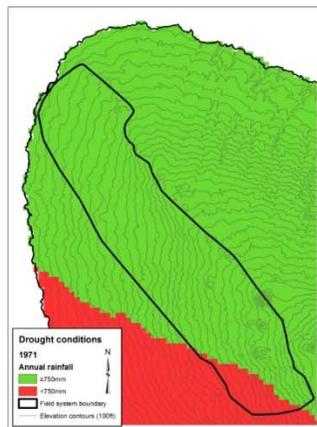
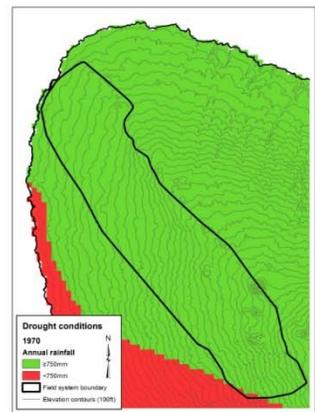
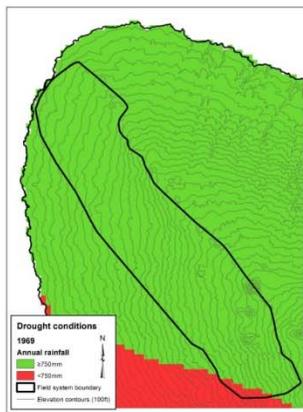
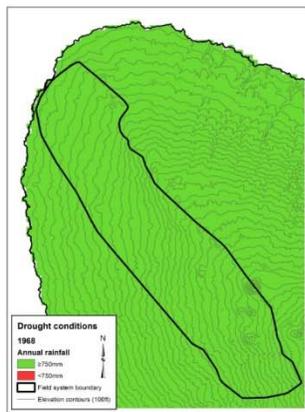
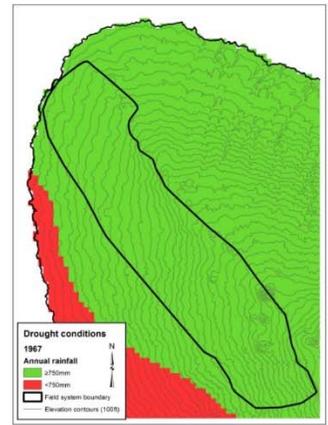
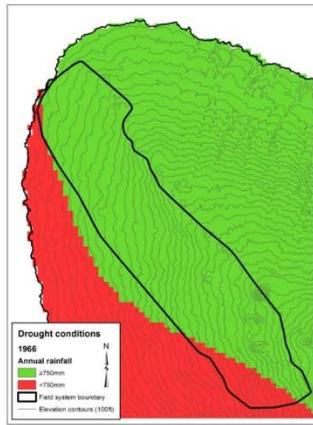
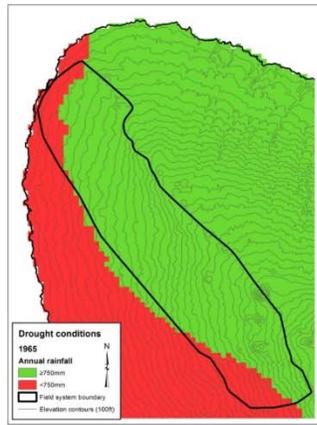


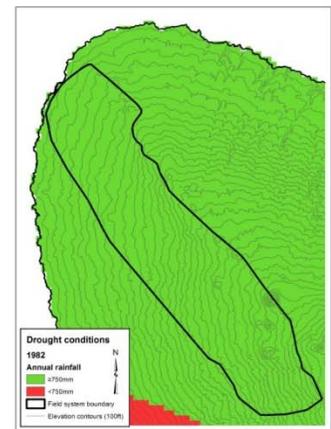
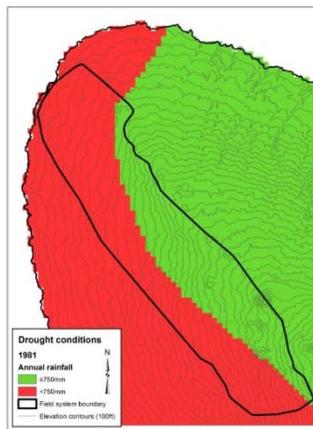
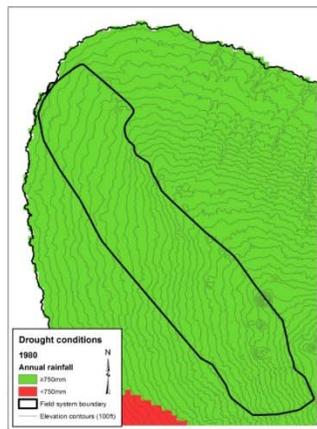
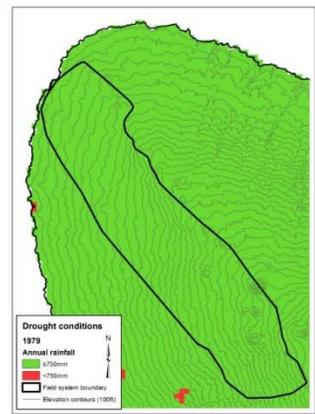
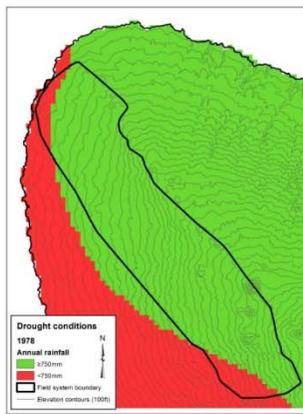
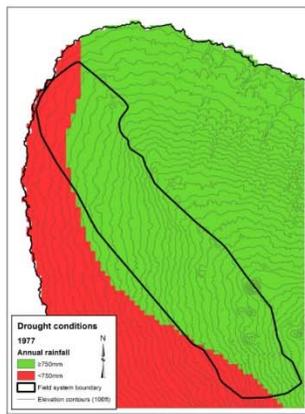
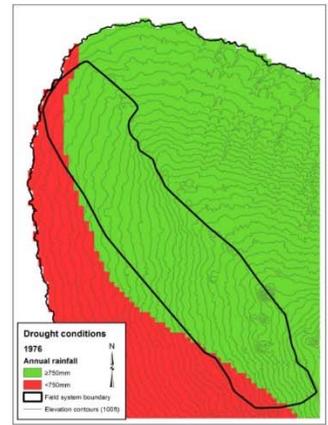
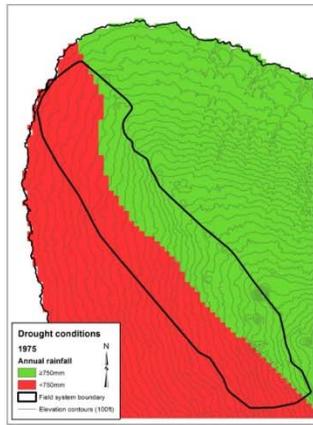
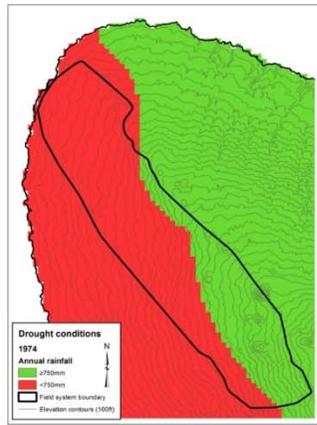


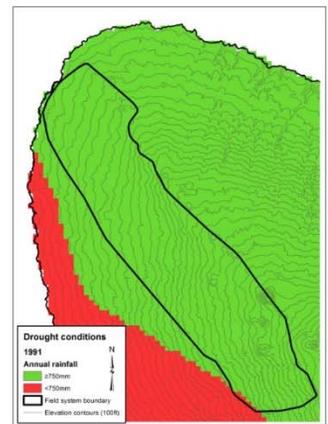
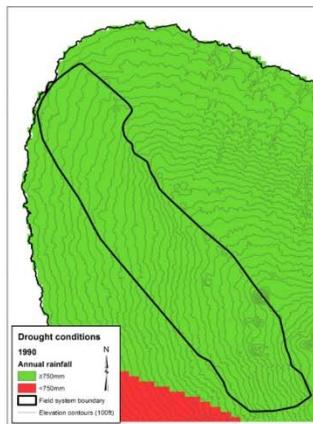
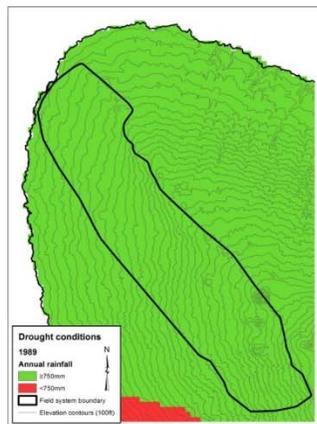
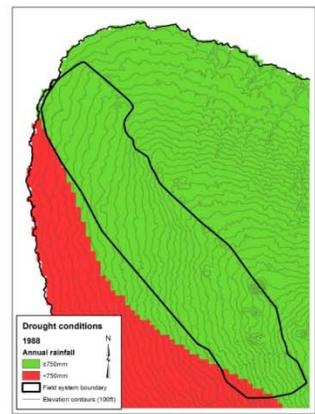
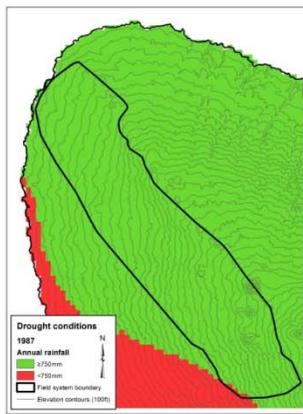
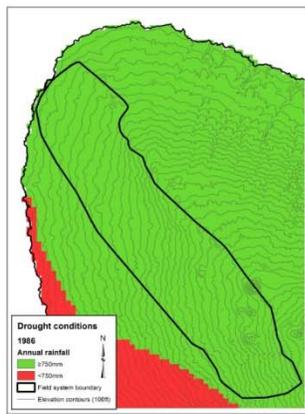
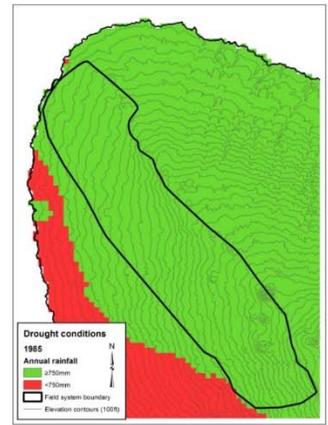
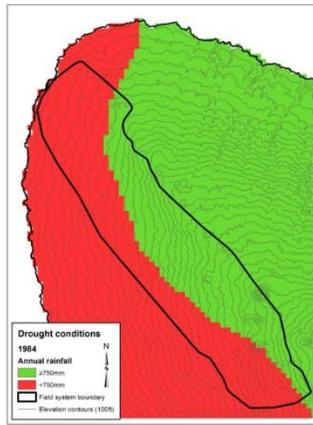
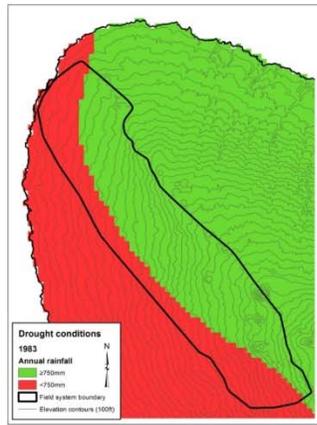


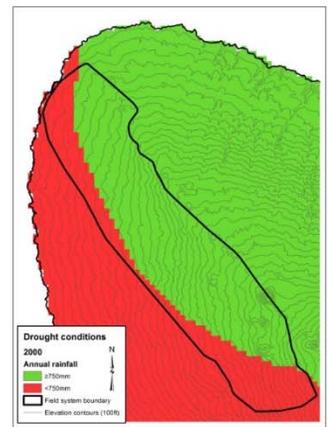
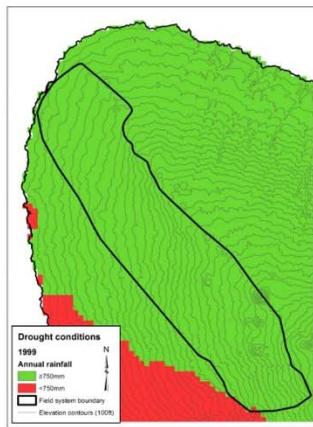
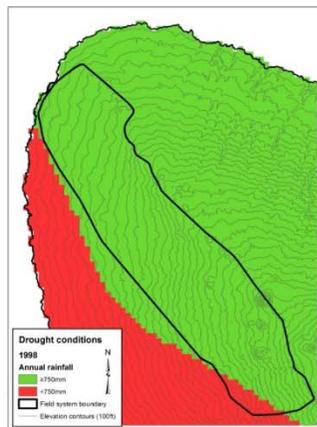
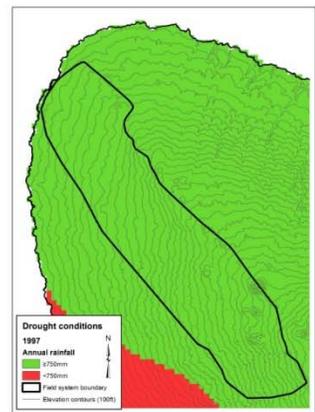
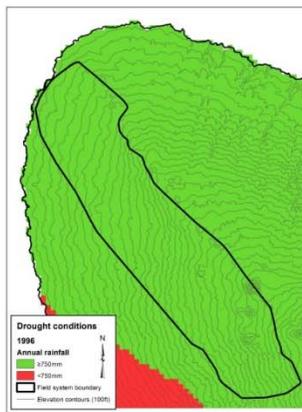
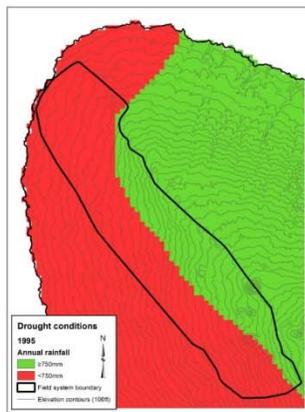
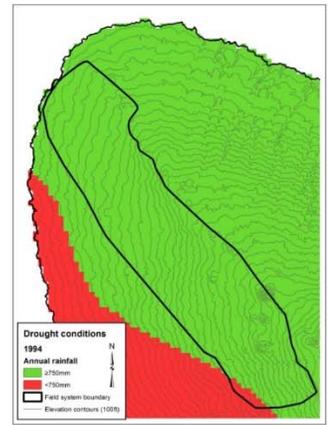
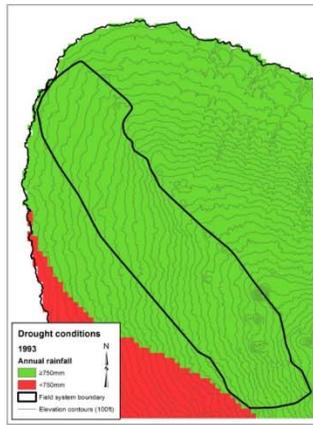
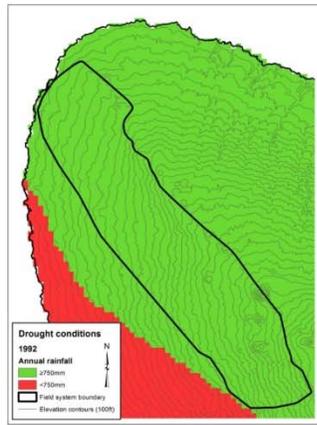












Appendix B

Results of Chapter 5 geostatistical analysis – table below shows the percentage of the Leeward Kohala Field System experiencing droughts from the years 1920-2000.

Year	% droughts
1920	0.105863
1921	0
1922	0
1923	0
1924	0.049674
1925	0.281759
1926	0.587948
1927	0
1928	0.045603
1929	0
1930	0
1931	0.127036
1932	0.210912
1933	0.517101
1934	0.292345
1935	0.228827
1936	0
1937	0
1938	0.008143

1939	0.061075
1940	0.002443
1941	0.009772
1942	0.012215
1943	0.164495
1944	0.057818
1945	0.503257
1946	0.008958
1947	0.367264
1948	0
1949	0.467427
1950	0
1951	0.026059
1952	0.036645
1953	0.648208
1954	0.031759
1955	0.003257
1956	0
1957	0
1958	0
1959	0

1960	0.04316
1961	0.112378
1962	0.76873
1963	0.008143
1964	0.085505
1965	0.135993
1966	0.081433
1967	0
1968	0
1969	0.014658
1970	0.003257
1971	0.069218
1972	0.125407
1973	0.491042
1974	0.662866
1975	0.546417
1976	0.07899
1977	0.138436
1978	0.076547
1979	0
1980	0

1981	0.587948
1982	0
1983	0.350977
1984	0.535016
1985	0
1986	0
1987	0.003257
1988	0.01873
1989	0
1990	0
1991	0.003257
1992	0
1993	0
1994	0.012215
1995	0.650651
1996	0
1997	0
1998	0.029316
1999	0.000814
2000	0.300489

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