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Dynamically Coupled Human and Natural Systems

Hawai'i as a Model System

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HUMAN-ENVIRONMENT INTERACTIONS AND THE PROBLEM OF AGRICULTURAL INTENSIFICATION

During the early to mid Holocene, seemingly independently in several parts of the Old and New worlds, human societies transformed themselves from hunters and gatherers dependent for their existence on natural resources provided by their environments, to cultivators (horticulturalists or agriculturalists, depending upon one's definitions) who brought a diversity of plants and animals under direct human control. This revolution in the way that humans interacted with the natural world provided the basis for other fundamental changes: the increasing size and density of human populations, the development of sedentary and urban lifestyles, and ultimately the rise of complex sociopolitical formations ranging from tribes to chiefdoms, states, and empires (Johnson and Earle 2000).

Once the majority of humankind had become dependent upon food production for its economic basis, another series of critical transformations was launched. These had to do with the immensely complex relationships linking people to their newly domesticated crops; crops to land, water, and nutrients; land to sociopolitical organization and cultural concepts of territory; and perceptions of yield, risk, and well-being to the inevitable efforts of humans to bend the natural world to their will through ritual performance and to understand it through myth and religion. With the development of agriculture as the primary basis for most human societies, the dynamic links between culture and nature became infinitely more complex and intertwined.

This book presents the efforts of a team of social and natural scientists to understand the complex, systemic linkages between land, climate, crops, human populations, and their cultural structures. Our research group, which includes archaeologists, ecologists, soil scientists, geographers, paleobotanists, and demographers, has focused on what might seem to some an unlikely locale to investigate a set of problems with worldwide significance: the Hawaiian Islands, perhaps the most isolated archipelago on Earth. And yet, for reasons we will make clear shortly, Hawai'i offers a "model system" for teasing out key linkages between land, agriculture, and society (this concept is explained in chapter 2). This problem, which has occupied the minds of scholars since at least Malthus (1798/1992) and Ricardo (1952–73), had by the late twentieth century come to be labeled as *agricultural intensification*. Our goal is to engage selectively with key concepts in the problem of agricultural intensification through the approach of dynamically coupled human and natural systems. Understanding the ways in which agro-ecosystems interact with aspects of the natural world (land, climate, stochastic variation) on the one hand and with human societies (population, social organization, political structures) on the other could not be more important as we face immense challenges of sustainability in the twenty-first century (National Research Council 1999).

Intensive agriculture and the processes through which it arises are ripe for close consideration as focal points of interdisciplinary frameworks that link the realms of social and ecological complexity. The ideas and analysis associated with these concepts have been highly valued and debated for several decades; our Hawai'i Biocomplexity Project provides an opportunity to engage in significant new ways with these concepts. The notion of agricultural *intensity* and its closely linked process term, *intensification*, is widely utilized as a key fulcrum in interpreting the interactions between the broadly defined realms of the social (including economic and cultural practices) and the ecological (including resources and land use). This fulcrum relates the multifaceted practices of agriculture to the broad contexts of the human condition and human interactions with the environment. We aim to elaborate a new framework for examining agricultural intensity and intensification, incorporating broad-based advances both in scholarly research and in public policy issues of social-environmental interactions and sustainability.[1]

First, however, let us clarify some terms. Agricultural *intensity* refers to the degree of resource utilization and food and crop production in agricultural systems. It is possible to distinguish between labor-intensive agriculture (based on time-demanding techniques) and intensive agriculture (Erickson 2006:337). The latter is characterized through use of an elevated level of inputs that can include machinery and land use (infrequent periods of fallow or crop rotation); it can also be distinguished by farm output or increased yields (Turner and Doolittle 1978; see also Kirch 1994:5). Other inputs include the use of tillage, fertilizers, cropping techniques (such as intercropping or polyculture and perennial tree cropping), and pest and weed control technologies (Brookfield 1972; Brookfield and Hart 1971; Turner, Hanham, and Portararo 1977). Another class of inputs to intensive agriculture includes the construction and maintenance of semipermanent earthworks, irrigation and crop-watering delivery systems, and field infrastructure such as terraced fields, raised planting surfaces in wetland environments, irrigation canals, and field border walls. This latter category is referred to as *landesque capital* (Blaikie and Brookfield 1987:9), and the irrigated pondfields of Hawai‘i are a prime example.[2] Landesque capital is present in many contemporary farming systems (e.g., Zimmerer 1991) and is one of the main forms of evidence of intensive agriculture in historical and especially archaeological contexts, as we shall see in the Hawaiian examples (e.g., Ladefoged and Graves 2000). A continuum typically exists between agricultural systems with intensive attributes and those with more extensive characteristics (Brookfield and Hart 1971; Marcus and Stanish 2006b).

Intensification in agricultural change refers in general to the processes that involve the increase over time of agricultural intensity on a given unit of land. More specific concepts tend to vary depending on the measure of agricultural intensity—which, following Boserup's classic work (1965), may be based on the frequency of cropping versus fallow, the presence of intensive agricultural practices including investments in landesque capital (Brookfield and Hart 1971), or the level of output or yield (Turner and Doolittle 1978). One common economic formulation is that the "intensification of production describes the addition of inputs up to the economic margin, and is logically linked to the concept of efficiency through consideration of marginal and average productivity obtained by such additional inputs" (Brookfield 1972:31). Critically, intensification refers to the process (or processes) constituting this phenomenon, as well as the distinct courses (referred to also as pathways or trajectories) contained within the general intensification trend (Bassett 2001; Leach 1999; Morrison 1994, 1996, 2006).

Intensification must also be realized to depend on the "documentation of previous states of the system" (Erickson 2006:338).

Because archaeology is especially able to access the long-term trends of agricultural systems (on a time scale of centuries to millennia), this approach offers a unique window into the processes of intensification. While intensification as a process inevitably involves time, most economists and other social scientists who study intensification have done so on relatively short time scales (years or decades). Exceptions include economic historians (e.g., Hatcher and Bailey 2001) who draw upon historical documents to study processes extending over centuries. Archaeologists have the capacity to investigate intensification over long time spans and to integrate data sets including environmental, demographic, agricultural, and sociopolitical variables. This has been one thrust of the Hawai'i Biocomplexity Project, to "unpack" the process of intensification in the intensive (especially dryland) agro-ecosystems that arose in this archipelago over the period from Polynesian colonization until European contact.

Involution and *disintensification* are other distinct trajectories of agricultural change that deserve mention. Agricultural involution refers to the pathway of incremental increases of crop production through increased labor inputs and refinement of techniques and technologies (Geertz 1963). While the term derives from the idea of change ("becoming internally more complicated" [Geertz 1963:80]), the concept itself originally derives from Clifford Geertz's observations on the remarkably renewable capacity for minor increases of marginal productivity in wet-rice agriculture in Java. The concept of agricultural involution has continued to serve as a cornerstone of studies of intensification (e.g., Marcus and Stanish 2006a, 2006b). Involution is a concept equally applicable to certain Hawaiian dryland agro-ecosystems. Disintensification, or the process whereby agricultural systems revert to forms that are less demanding of labor or capital inputs, is similarly widespread (Brookfield 1972), both in the historical and archaeological past of many world regions and in the present experience of many rural areas in the southern hemisphere where recent developments have undermined various types of staple food production (e.g., Zimmerer 2002). In the Hawaiian case, disintensification followed rapidly after European contact and the sickening decline in population that resulted from the introduction of Old World diseases.

This volume presents an archaeological and paleoecological perspective on the interwoven topics of intensive agriculture and intensification, using the Hawaiian Islands as a model system for understanding these processes generally. At the same time, our approach recognizes the value and relevance of the analysis of contemporary social-environmental linkages in intensive agriculture and intensification. Several probing analyses of intensive agriculture and intensification have focused either entirely or to a significant degree on contemporary situations (Boserup 1965; Netting 1993; Turner, Hyden, and Kates 1993). Our goal is to build a framework that places emphasis on the archaeological past while interweaving important insights from recent or contemporary studies.

FROM MALTHUS TO BOSERUP: AGRICULTURAL INTENSITY AND INTENSIFICATION

The concepts of agricultural intensity and intensification have advanced through several decades of vigorous and productive debate. Various key works have a sustained legacy, following on Geertz's formulation of the idea of involution and his application of this to Javanese wet-rice agriculture, referred to above. Using empirical data from Africa, Ester Boserup defined "intensification in agriculture" as "the gradual change towards patterns of land use which make it possible to crop a given area of land more frequently than before," in contrast to the "usual definition of intensification…[that] covers only the use of additional labour per hectare of cropped area" (Boserup 1965:43). One of several reasons for the lasting influence of Boserup's contribution, albeit one that has tended to be overlooked, is that it offers a common ground between economics and natural science regarding livelihood strategy and environmental impacts (Boserup 1965:12–14).

The foundational works of Geertz and Boserup can be traced and compared to similarly influential ideas of agricultural change and social-environmental interaction: Geertz's work can be traced to Wittfogel (1957) and Steward (1938), for example, while Boserup's contributions can be traced to the demographer and cleric Thomas Malthus (1798/1992) and to the Russian economist Chayanov (1966; see Brush and Turner 1987; Marcus and Stanish 2006b; Scatena, Walker, and Homma 1996). As background influences, Carl Sauer in geography, Alfred Kroeber in anthropology, and Woodrow Borah in historical demography all focused on interrelated agricultural, environmental, and demographic changes (Zimmerer 1996).

Numerous revisionist critiques and contributions have followed in the wake of these key works on agricultural intensity and intensification. Many drew from Boserup's framework and launched a raft of "beyond Boserup" engagements; other studies relied more heavily on Geertz and the "hydraulic civilization" style of interpretations that has resulted in the recent coining of a "neo-Wittfogelian" perspective (Erickson 2006). Several of these critiques and contributions are relevant to our current analysis, chief among them the incorporation of the spatial variation of environmental parameters, such as soils and climate heterogeneity, as a set of condition variables in intensive agriculture and the pathways of intensification (Brookfield 1972; see also Ali 1995; Brookfield 1984; Kirch 1994; Kirch et al. 2005; Kirch et al. 2004; Lee, Tuljapurkar, and Vitousek 2006; Netting 1993; Turner, Hanham, and Portararo 1977; Vitousek et al. 2004; Wilken 1987).[3] Another important contribution was an effort to distinguish between the different dynamics, associated with different purposes of production (such as subsistence, tribute or community outlets, and trade or cash production), that exerted different pressures on intensification (Brookfield 1972). At the same time, the wave of "beyond Boserup" studies generated new reflections and appreciation of the continued value of the Boserup vantage as a model seeking general applicability rather than comprehensive explanatory power (Stone 2001).

Understanding the complexities of agricultural intensity and intensification requires that we engage with certain political-economic, human-environmental, and cultural practices that have tended to be overlooked in the narrowly conceived rendering of the influences of population, technology, and food demand. Thus, the framework proposed in this volume is based on the recognition of multilevel spatial interactions involving the diverse human activities, landscapes, and environmental-change processes in which intensification is situated. Broadly speaking, four such dynamics are central to this framework. They will be described in more detail later in this chapter but can be succinctly outlined as follows:

1. The forces of political and social organizations that range from the distant rulers of expansive polities and state-level authorities to local chiefdoms and bottom-up aggregations of semiautonomous farmer groups and communities (e.g., Erickson 1993, 2006; Guillet 1992; Kirch 1994; Mitchell 1976; Mitchell and Guillet 1994; Stanish 2006)

2. The role of territory-making and control both within and beyond the areas of agriculture and potential agricultural intensification (Ladefoged and Graves 2000, 2006; Stanish 2006; Stone 1997; Stone and Downum 1999)

3. The role of environmental modifications in the context of the overall landscape (rather than solely the agricultural area) and as malleable factors subject to historical consequences and conditions (rather than

mere backdrop) (Balée 2006; Balée and Erickson 2006; Erickson 2006; Morrison 2006)

4. The role of economic activities in the broader social space that for many or most farmers extends well beyond the agricultural field and intensive techniques per se (for example, fallow reduction, timing of cropping cycles, and construction of irrigation infrastructure) to other areas of resource use and laboring that may include nonfarm wage labor and craft production (Brookfield 1972; Morrison 2006)[4]

Having introduced the larger problem of intensive agriculture and agricultural intensification and briefly summarized a few of the key proponents and their positions, we turn now to the specific case study that engages us in this volume. Hawai‘i offers an unparalleled opportunity to investigate the problem of agricultural intensification, including the kinds of political-economic, human-environmental, and cultural practices just referred to. Discovered and settled around AD 800–1000[5] by a small group of Polynesian voyagers, who brought with them in their double-hulled canoes the seedling crops and domestic animals that would be the basis for a new agricultural society, the Hawaiian archipelago became a kind of natural-cultural experiment (to invoke Mayr 1997:29). Over the succeeding eight centuries, descendants of this small group of colonists expanded over this large and environmentally diverse archipelago, adapting their knowledge of agricultural practices and developing societies that ultimately grew to comprise hundreds of thousands of individuals. Their agro-ecosystems developed along two major, contrastive pathways, following in general respects the labor-intensive and landesque capital trajectories outlined by Boserup and Geertz, thus offering us the unique opportunity to see how different pathways to intensification can arise within the same cultural sphere. But before delving too deeply into the particulars of Hawaiian prehistory, let us briefly view the islands at their peak of agricultural intensity, as seen through the eyes of the first European to pierce the veil of isolation.

HAWAI‘I AT FIRST CONTACT

In November 1778, fleeing the oncoming winter, HMS *Resolution* and *Discovery*, their crews worn down by a futile search for the fabled Northwest Passage, bore down on the Sandwich (Hawaiian) Islands. Under the command of seasoned navigator Captain James Cook, they had "discovered" and briefly visited the western islands of Kaua‘i and Ni‘ihau the previous winter. After months of exploring the Alaskan coastline and enduring

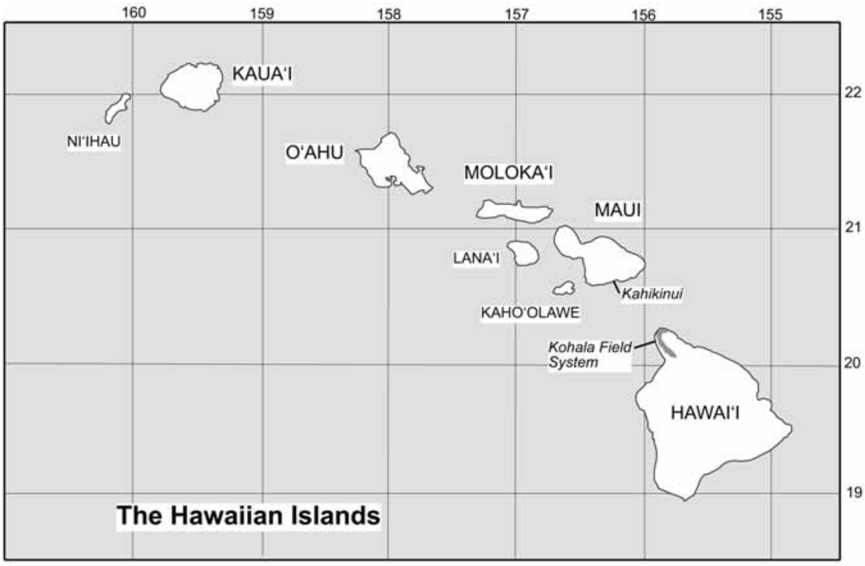

Figure 1.1.
Map of the main Hawaiian islands, showing the location of Kahikinui District on Maui and the Kohala field system on Hawai'i Island.

Pacific gales, Cook and his crews needed a safe harbor, a place for rest and reprovisioning. On the 26th of November at daybreak, land was sighted to the south-southeast "whose summit appear'd above the Clouds" (Beaglehole 1967:473–74). Cook had sighted Maui, second largest island in the chain, in the geologically youthful southeastern part of the archipelago (fig. 1.1). He would soon discover that Maui and an even larger island to the southeast, Hawai'i, dominated the archipelago. These two massive islands were home to large populations of Polynesians, whose settlements and farms densely spread over the volcanic slopes.

Approaching the windward coast of Maui, Cook could clearly discern the "steep rocky coast against which the sea broke in a dreadful surf" (Beaglehole 1967:474). Houses and plantations could be seen in the gently sloping countryside; soon outrigger canoes bearing root crops and pigs surrounded the *Resolution* and *Discovery*. It was quickly established that these people "were of the same Nation as those of the leeward islands" (Kaua'i and Ni'ihau). By the 27th, the Hawaiian canoes were bringing quantities of produce, including "bread fruit, [sweet] Potatoes, Tarra or eddy roots, a few plantains and small pigs" (1967:475), for which the British exchanged nails and iron tools. Finding that his trading partners were not disposed to bring out more canoe loads of provisions, Cook decided to set an easterly course, in the hopes of rounding the island and seeking shelter along its leeward shore.

On November 30, several canoes visited the *Resolution*, one carrying a chief whose name Cook transcribed as "Terryaboo," bringing a present of "two or three small pigs" (Beaglehole 1967:476). Unknown to Cook, this was no ordinary chief, but none other than Kalaniʻōpuʻu, king of the vast island of Hawaiʻi. Kalaniʻōpuʻu was in the midst of a war with his archrival Kahekili, king of Maui, from whom he had already wrested control of Hāna District, where Cook's ships now tacked offshore. Later, Cook would learn of the true status and power of Kalaniʻōpuʻu. Indeed, the British navigator would lose his life in a bungled attempt to take Kalaniʻōpuʻu hostage at Kaʻawaloa on Hawaiʻi. For the moment, however, Cook remained ignorant of the complex political dynamics of this vast archipelago.

Cook learned from Kalaniʻōpuʻu that the island they had been coasting along was named "Mowʻee" and that an even larger island visible to windward was called "Oʻwhyʻhe" (Hawaiʻi). The summits of its great volcanoes were capped in snow despite the subtropical latitude. Cook abandoned his plan of exploring leeward Maui and made for the weather coast of Hawaiʻi. Kalaniʻōpuʻu must have received this news with interest, and not a little disquiet, for this was the ritual season of the Makahiki, its onset marked as always by the first visibility after sunset of Makaliʻi, the Little Eyes, known to Western astronomers as the Pleiades. The Hawaiians divided their year into two seasons, one dedicated to the worship and rituals of the war god Kū, the other to the god of dryland agriculture, Lono. The Makahiki season of four lunar months duration, which was at this moment just opening, was sacred to Lono. During this time, the Lono priests would make a clockwise circuit of the island collecting the tribute (*hoʻokupu*) from each of hundreds of territorial segments. Collected in the name of the god, the hoʻokupu, was, in effect, taxation levied by the king. As in other archaic states, the Hawaiian political economy was embedded within and legitimated by the state religious cults (Valeri 1985).

The preceding year, when Cook had without warning burst through the curtain of isolation that had enveloped the Hawaiian Islands since at least the end of the fourteenth century, some of the Kauaʻi priests had immediately proclaimed him as the returning god Lono. In Hawaiian myth, Lono had once been a chief, Lonoikamakahiki by name, who had left the islands and voyaged back to the ancient homeland of Kahiki (Beckwith 1970; Sahlins 1981). Every year, during the Makahiki, Lono returned to the islands—in spiritual rather than corporeal form—to bring the winter rains that were so essential to agricultural productivity in the leeward, dryland parts of the islands. But in January 1778, Lono had seemed to return in person, carried to the islands in two large floating *heiau* (temples) as the Kauaʻi priests had proclaimed the British ships to be during their first visit (Kamakau 1961:92–93).

As Kalaniʻōpuʻu watched from his stronghold at Hāna on Maui, Cook began his own clockwise progression off the weather coast of Hawaiʻi, first along Hāmākua District, then off Puna, and rounding the southeastern cape to sail along the rugged volcanic shores of Kaʻū. Ignorant of the cultural logic that underlay the Hawaiian perceptions of this first contact, Cook/Lono was enacting a maritime version of the Makahiki circuit. From his viewpoint, all was simply good trade in provisions, with quantities of pork and vegetable produce coming daily onto the ships. These were the productions of vast inland field systems, highly intensive agro-ecosystems that underwrote the political economy of Kalaniʻōpuʻu's kingdom.

Cook remained greatly pleased at the regular "trade" he was receiving, contrasting the Hawaiians, "who have never once attempted to cheat us in exchanges," with the people of the Society Islands (Beaglehole 1967:483). Of course, it would be risky business to cheat a god. Other signs on land speak to how the Hawaiians viewed the relentless clockwise progression of the ships, such as the white flag interpreted by Cook as a signal of peace but without doubt the barkcloth *akua loa,* or "long god," marking Lono's progress through one *ahupuaʻa* territory after another (see Malo 1951; Sahlins 1995).

The ships progressed slowly throughout the month of December, tacking to and fro off the Hawaiʻi coast, unable to find a safe harbor but keenly engaged in what the British saw as trade and the Hawaiians saw as the offering of hoʻokupu or tribute, only this time accompanied by the unexpected reciprocal generosity of the god himself, who bestowed gifts of iron and nails. Rounding Ka Lae, South Point, on the 5th of January, the ships entered calmer, leeward waters. By the 16th, they were halfway up the western coast and approaching Kalaniʻōpuʻu's ancestral seat, the great bay of Kealakekua, the Road of the God. Overlooking the bay was Hikiau, primary temple of Lono, where the Makahiki circuits began and ended. After a reconnaissance party reported a good anchorage and fresh water available ashore, Cook brought the *Resolution* and *Discovery* into Kealakekua. A crowd of thousands greeted the ships, canoes choking the bay and hundreds of Hawaiians swimming around the ships "like shoals of fish" (Beaglehole 1967:491).

Kalaniʻōpuʻu was not among those who greeted Cook at Kealakekua;

he would arrive shortly after, in grand style aboard his largest double-hulled war canoe, carrying his war gods. This day it was the high priest Koʻaʻa who greeted Cook/Lono at Kealakekua, wrapping a red barkcloth over the captain's shoulders and presenting him with a small pig while offering prayers to Lono. Later, Koʻaʻa would lead Cook ashore and onto the temple platform of Hikiau to partake of the "feeding of the god," the rites of Hānaipū (Sahlins 1981, 1995; Valeri 1985). Cook, willingly adopting the persona of Lono, god of thunder, rain, and sweet potatoes, had arrived at the heart of the Hawaiʻi Island kingdom, a polity whose economy was intimately linked to Lono's life-giving rains.

WET AND DRY AGRO-ECOSYSTEMS

Kealakekua Bay lies near the center of the Kona District, principal seat of Kalaniʻōpuʻu, who traced his lineage back to ʻUmi-a-Līloa, a famous king who had united the entire island of Hawaiʻi around AD 1570. Kona was one of three districts (*moku*) making up the leeward side of Hawaiʻi Island. Along with Kohala to the north and Kaʻū to the south, each leeward moku was formed around an upland zone with the fertile soil and abundant rainfall necessary to support intensive cultivation of the two root crops that provided the subsistence base of Hawaiian society: sweet potato (*Ipomoea batatas*) and taro (*Colocasia esculenta*). Polynesian voyagers had imported both crops to the islands, the sweet potato obtained via contact with South America (probably around AD 1000 [Hather and Kirch 1991]), the taro tracing its genetic ancestry back to island Southeast Asia. Supplemented by bananas (*Musa* hybrids), sugarcane (*Saccharum officinarum*), yams (*Dioscorea alata*), ti (*Cordyline fruticosum*), and some other minor crops, the dryland taro and sweet potato gardens underwrote the Hawaiian economy. As Earle (1997) has observed, this was largely a "staple finance" rather than a "wealth finance" economy (although the Hawaiians did have certain forms of durable wealth, such as their famous featherwork). Control over the production of the key staple crops was therefore the key to the Hawaiian political system.

On the slopes above Kealakekua Bay and stretching for many kilometers both north and south, the Kona field system covers an estimated 139 km^2 (M. Allen 2001:137). Although much of this dryland agricultural system has now been destroyed by development, remaining sections reveal a reticulate grid of stone garden divisions (*kuaiwi*, or "backbone") that run in parallel rows up and down the slopes (M. Allen 2001; Schilt 1984). In addition to the remaining archaeological evidence for this intensive production system, we have the firsthand account of an exploring party from

Cook's ships. On February 26, 1779, these individuals, accompanied by Hawaiian guides, walked up into "the regular & very extensive plantations" (Beaglehole 1967:521) and marveled at the sophistication of the Hawaiian farmers. Lieutenant James King summarized the observations of the exploring party:

> The Plantain trees [bananas] are mixd amongst the breadfruit trees & did not compose any part of the plantations except some in the Walls: these walls separate their property & are made of the Stones got on clearing the Ground; but they are hid by the sugar cane being planted on each side, whose leaves or stalk make a beautiful looking edge. The Tarrow or Eddy root & the sweet Potatoe with a few cloth plants [paper mulberry] are what grow in these cultivated spots.... The Potatoes & Tarrow are planted 4 feet from each other, the former is cover'd except the tops with about a bushel of light Mould, the latter is left bare to the roots, & the mould surrounding made in the form of a bason, in order to preserve the rain as this root is fond of & requires much humidity, it should be noted that the Tarro of these Islands is the best we have ever tasted....
>
> By their accounts it is hardly possible that this Country can be better cultivated or made to yield a greater sustenance for the inhabitants; they passed thro fields of hay [fallow], with which they cover the young Tarro Grounds, to prevent the suns drying it up. (Beaglehole 1967:521, 524)

King's description was no doubt obtained from the keen observations of David Nelson, a member of the inland exploring party. Nelson was officially listed on the *Discovery*'s Supernumerary List as "Servant to Mr. William Bailey," the expedition's astronomer (Beaglehole 1967:1478). But Nelson was a trained gardener and former member of the staff of the Royal Botanic Gardens at Kew and was in the service of Sir Joseph Banks to make botanical collections on the voyage (which still survive in the Kew Herbarium). Only a gardener such as Nelson would have noted such critical details as the presence of fallow fields providing "hay," the regular use of mulching to protect the taro plants, and the precise spacing between plants.

Cook's expedition did not visit or report on two other vast inland field systems on Hawai'i Island (or those on Maui). In the northern part of Hawai'i, in Kohala moku, is the Kohala field system, which will figure prominently in this book, for it has been a focus of the Hawai‘i Biocomplexity Project. Covering perhaps 60 km^2, this field system differs slightly from the Kona system in the orientation and construction details of its reticulate gridwork of field walls and trails, but it was equally intensive in its dense use of space and partitioning of the landscape into thousands of small delineated farming plots (plate 1). The Vancouver expedition, in 1793, sailed closely by Kohala and could clearly discern this field system, as recounted by the naturalist Archibald Menzies: the country “bears every appearance of industrious cultivation by the number of small fields into which it is laid out, and if we might judge by the vast number of houses we saw along the shore, it is by far the most populous part we had yet seen of the island” (Menzies 1920:52). The Kohala field system has suffered much less destruction than that in Kona and is much better understood from an archaeological perspective (Ladefoged and Graves 2000; Ladefoged, Graves, and Jennings 1996; Newman 1969, n.d.; Rosendahl 1972, 1994).

On the southern part of Hawai‘i, in the moku of Ka‘ū, yet a third vast field system covered the volcanic slopes with a reticulate pattern of walls and boundaries. Parts of this system can clearly be discerned on remote sensing images. To date, however, the Ka‘ū field system has not been intensively studied archaeologically, although the ethnographer Handy (1940; Handy and Handy 1972) described the continued practice of traditional dryland planting methods among Native Hawaiians living in Ka‘ū in the 1930s.

Along with similar dryland (that is, rain-fed) field systems on leeward Maui (especially in Kaupō, Kahikinui, Honua‘ula, and Kula districts), described in chapter 4 of this volume, and with the Kalaupapa field system on Moloka‘i (McCoy 2006), the vast Kohala, Kona, and Ka‘ū field systems represent one of two major types of agro-ecosystems that supported the Hawaiian archaic states at the time of first contact with Europeans. For environmental and ecological reasons that will be made clear in this volume, such dryland systems were largely confined to the volcanically youthful islands at the southeastern end of the archipelago, especially Hawai‘i and Maui (Vitousek et al. 2004). Beginning with West Maui (with a geological age of 1.3 million years) and proceeding westward up the island chain to Moloka‘i, O‘ahu, and Kaua‘i (with geological ages ranging from 2.5 to 5.1 million years), a different kind of intensive agro-ecosystem dominated agricultural production. This was based on the irrigated cultivation of taro in flooded pondfields, watered by canals tapping into permanent streams or in some cases springs. The dominance of irrigation on the geologically older islands correlates with the much greater availability of permanent watercourses and of suitable alluvial and colluvial landforms that could readily be terraced for pondfield construction. In chapter 3, we use a Geographic Information Systems (GIS) approach to precisely model the differential distribution of the environmental parameters (rainfall, soils, topography, and hydrology) that controlled the geographical distribution of these two contrastive agro-ecosystems throughout the Hawaiian archipelago.

The irrigated taro systems that dominated the westerly islands caught the attention of the first European observers just as much as the vast dryland systems of Hawai'i (plate 2). Indeed, Captain Cook penned the first description of an irrigated field complex, in the alluvial plain at Waimea Valley on Kaua'i, after an inland excursion on January 21, 1778: "Our road lay in among the Plantations, which were chiefly of Tara [taro], and sunk a little below the common level so as to contain the water necessary to nourish the roots" (Beaglehole 1967:269). Later visitors to O'ahu were unstinting in their admiration for Hawaiian irrigation works. Russian explorer Otto von Kotzebue (182l, vol. 3:236) wrote of the irrigated landscape surrounding Honolulu: "The cultivation of the valleys behind Hanarura is remarkable; artificial ponds support, even on the mountains, the taro plantations, which are at the same time fish ponds." Von Kotzebue called attention to another intensive aspect of production on the older islands: coastal ponds for the husbandry of mullet and milkfish. Menzies (1920:23–24), with Captain George Vancouver in 1792, described the O'ahu fields as follows: "The whole [valley] was watered in a most ingenious manner by dividing the general stream into little aqueducts leading in various directions so as to supply the most distant fields at pleasure, and the soil seems to repay the labor and industry of these people by the luxuriancy of its production."

Across the environmental canvas of the Hawaiian archipelago, these two major agro-ecosystems—the wet, irrigated taro fields of the older, dissected valley landscapes and the dry, rain-fed field systems sprawling over the younger volcanic slopes—provided the economic bases for complex, hierarchically organized sociopolitical formations. At the time of Cook's arrival, the Hawaiian Islands were divided among four fiercely competing polities, centered respectively on Hawai'i, Maui, O'ahu, and Kaua'i (see fig. 1.1). As noted earlier, Hawai'i and Maui were locked in a war of territorial conquest at the very moment that Cook's ships returned in the winter of 1779. Part of what makes Hawai'i such a marvelous setting for understanding *human ecodynamics* (Kirch 2007a; McGlade 1995) is the dynamic interplay among the natural resource base, environmental conditions, and cultural systems. The Hawaiian Islands offer a unique model system with which to explore these relationships and practice a multidisciplinary science that is often referred to as *biocomplexity*.

HAWAI‘I AS A MODEL SYSTEM FOR INTENSIFICATION RESEARCH

As described in chapter 2, we treat Hawai‘i as a model system that can facilitate our understanding of evolution, ecosystems, and the development and dynamics of societies. Most importantly, the Hawaiian archipelago also presents an ideal region for understanding interactions between human populations and their environments over a controlled time scale. When Captain Cook first visited in AD 1778–79, Hawai‘i was occupied by an isolated population of probably 450,000 or more indigenous Polynesians (Stannard 1989), with economies based on complex systems of irrigated and dryland farming, aquaculture, and animal husbandry that varied in patterned ways across the archipelago (J. Allen 1991, 1992; Kirch 1985, 1994). Archaeological research suggests that humans first arrived in the archipelago between AD 800 and 1000 (Athens 1997; Athens et al. 2002; Kirch 1985, 2000). The size of the colonizing human population was small, probably fewer than 200 persons (although periodically increased by additional voyagers). Over about a thousand years, this population achieved high density (about 150–250/km^2 in some areas), supported by a remarkable landscape mosaic of highly intensified agro-ecosystems, as described above, representing distinct trajectories of agricultural intensification (Blaikie and Brookfield 1987; Brookfield 1972, 1984; Kirch 1994, 2007a).

Over this same millennium, Hawaiian society underwent dramatic changes including fundamental restructuring of household organization and the domestic economy, emergent complexity in sociopolitical organization, and elaboration of religious ideology and ritually organized economic control systems. The colonizing Ancestral Polynesian society (Kirch and Green 2001) was “house-based,” with a fluid kin structure and heterarchical competition between local groups, each associated with an estate of agricultural land. This early form of social organization had only minimally developed and largely symbolic modes of surplus extraction (such as first-fruits tribute), and its economy was largely organized around a “domestic mode of production” (Sahlins 1972). Between 400 and 600 years later, Hawaiian social units underwent variable amalgamation and dramatic hierarchization, and domestic production became highly embedded within a larger political economy (Cachola-Abad 2000; Cordy 1974a, 2000; Earle 1977, 1978, 1987a, 1997; Hommon 1976, 1986; Kirch 1985, 1990a, 1990b; Sahlins 1958). While most Polynesian societies are regarded by anthropologists as classic representatives of chiefdoms, protohistoric Hawaiian society is qualitatively distinct (Kirch 1984, 1985, 2007a; Sahlins 1958) for several reasons:

- Its highly intensive agriculture, aquaculture, and craft specialization
- Ritualized controls on production, manifested by a hierarchical temple system
- The emergence of endogamous classes, with divine kings at the apex of society
- Replacement of a lineage-based system of land control with a territorial system controlled by elites
- A formal system of corvée labor and surplus tribute extraction

Contact-period Hawaiian society is thus noted for its complexity, indexed by economic specialization (Earle 1977, 1978, 1987b; Kirch 1990a), social stratification (Sahlins 1958), and specialized religious cults and ritual regulation of production (Valeri 1985). Anthropologists and archaeologists have characterized Hawaiʻi variously as a "ranked society" (Fried 1967), "complex chiefdom" (Earle 1991a, 1991b, 1997; Johnson and Earle 2000; Kirch 1985), or "archaic state" (Feinman and Marcus 1998; Hommon 1976, 1986; Kirch 2000, 2006, forthcoming), and we believe that the latter rubric is the most accurate. At European contact, the Hawaiian Islands were divided into four competing, incipient archaic states, centered on the major islands of Hawaiʻi, Maui, Oʻahu, and Kauaʻi. While each polity exhibited the social, economic, and political characteristics noted above, they took different forms on the younger islands (Maui and Hawaiʻi), where rain-fed dryland agriculture predominated, than on Oʻahu and Kauaʻi, where food production was concentrated on irrigated wetland systems. Those polities based on intensified dryland agriculture were notably expansionist (J. Allen 1991; Earle 1997; Kirch 1994).

A variety of proximate or ultimate-causal factors have been identified or proposed as having played some role in the rise of this highly complex late-precontact society. These include demographic change, especially population increase (Clark 1987; Cordy 1981; Kirch 1984); agricultural intensification, including extensive irrigated and dryland systems (Earle 1978; Kirch 1994); warfare, especially territorial conquest (Kirch 1985; Kolb and Dixon 2002); status competition among chiefly lineages (Cachola-Abad 2000; Goldman 1955, 1970); and resource diversity coupled with a redistributive economy (Sahlins 1958).

What makes Hawai'i especially suited to studying these dynamics is that the Hawaiian socioecosystems encapsulate two contrasting agricultural systems that represent distinctive modes of agricultural intensification, modes that are found in many societies throughout the world: (1) irrigated wetland agriculture, representative of landesque capital intensification; and (2) rain-fed dryland agriculture, representative of cropping cycle intensification that is highly demanding of labor (Kirch 1994, 2006). Archaeological models of Hawaiian sociopolitical development have emphasized the dichotomy between windward and leeward environments that corresponds to these two modes. Kirch (1994) noted that the point of diminishing marginal returns in agricultural intensification was likely to have been reached at lower output levels in dry leeward areas than in wet windward environments and that yields in the dryland systems were more variable and more vulnerable to environmental risk and uncertainty associated with periodic drought. Reaching this critical inflection point could have provided a stimulus for warfare, territorial expansion, and the emergence of even greater hierarchy. Earle (1997) likewise suggested that with high population densities in circumscribed environments, leaders are likely to engage in warfare, ideological manipulation, and the control of subsistence resources to develop and maintain social inequalities.

THE HAWAI'I BIOCOMPLEXITY PROJECT

Since the late 1960s, archaeologists in Hawai'i have focused a great deal of energy on the identification, survey, and excavation of the physical remains of ancient cultivation systems throughout the archipelago, greatly advancing our understanding of their distribution, details of construction and operation, and chronology of development (for overviews, see J. Allen 1991, 1992; Kirch 1985, 1994). A major advance was the recognition of the importance of the dryland field systems on Hawai'i Island (M. Allen 2001; Ladefoged and Graves 2000; Newman n.d.; Rosendahl 1972, 1994; Schilt 1984)—systems that, because they were disintensified and abandoned early after European contact, had been largely overlooked in early twentieth-century ethnographic studies of "traditional" Hawaiian agriculture (Handy 1940; Handy and Handy 1972). While there was no doubt that the taro irrigation systems on the older, westerly islands had been critical in underwriting the political economies of the Kaua'i and O'ahu kingdoms (Kirch and Sahlins 1992), the even larger populations of Maui and Hawai'i had been largely supported by the rain-fed, dryland field systems. In a Polynesia-wide synthesis of "wet" and "dry" systems of agricultural production, Kirch (1994) drew attention to the significance of this contrast across the canvas of the Hawaiian archipelago, suggesting that inherent tensions between the wet and dry agro-ecosystems were at the core of late-precontact political dynamics.

In 2001 the opportunity to take the study of agricultural intensification and its broader linkages to land, demography, and sociopolitical complexity in Hawai'i to a new level arose with a call for proposals from the National Science Foundation's (NSF's) Biocomplexity in the Environment Program. Among several research themes, NSF was seeking projects that addressed dynamically coupled human and natural systems. Kirch and Vitousek, who had already begun informal discussions about the possibility of a joint research program that would combine their previous efforts in the islands (focused on archaeology and ecology, respectively), quickly assembled a research team including Shripad Tuljapurkar (demographic modeling), Oliver A. Chadwick (soils and biogeochemical gradients), Sara Hotchkiss (paleobotany and climate change), Thegn N. Ladefoged (archaeology and geographic information systems), and Michael W. Graves (archaeology). This team proposed to use Hawai'i as a model system for studying human ecodynamics (McGlade 1995; van der Leeuw and McGlade 1997) over a millennium. Four specific research topics were delineated, as briefly summarized below:

1. *Impact of an expanding human population on its resource base:* We proposed to link records of lowland population, land use, vegetation, and biogeochemistry to more continuous histories of climate, species composition, and disturbance in both upland and lowland areas to address the ways in which humans shaped and responded to the Hawaiian environment as the resource base itself changed over time. The following questions were especially salient: How did people use the upland forests? Was agriculture limited by the interaction of soils and climate in leeward lowland areas? Did agricultural intensification remove extensive pressure on residual natural systems, or did it increase pressure on natural systems, either periodically or continuously? Did human use of upland forests permanently change their structure, composition, or nutrient status?
2. *Agricultural intensification and the environmental mosaic:* We observed that the process of intensification occurs across and in relation to a specific environmental mosaic, which in the case of Hawai'i includes dramatic biogeochemical gradients. It was in this area, we argued, that significant progress could be achieved in understanding how agricultural change proceeds, by empirically studying the critical

nonlinear dynamics that occur as an expanding agricultural population moves onto landscape patches with dramatically different biogeochemical responses. In particular, we proposed to build upon the advances of Chadwick, Vitousek, and colleagues, who had determined controls of nutrient cycling and supply across a broad range of Hawaiian environments (Chadwick and Chorover 2001; Chadwick et al. 1999; Vitousek 2004). Again, we argued that Hawai‘i is unique in the precision with which general processes underlying human interactions with land can be elucidated in space and time.

3. *Demographic change over time and space:* The islands of Remote Oceania often witnessed explosive demographic growth following human colonization (Kirch 2000:307–11) and followed a progression from early, colonizing populations marked by high intrinsic growth, low density, density-independent mortality, and limited cultural regulation, which were well below carrying capacity, to populations in late prehistory characterized by low intrinsic growth, high density, density-dependent mortality, and the application of varied cultural forms of regulation, including abortion, celibacy, warfare, infanticide, or even cannibalism. For Hawai‘i, archaeological efforts at paleodemography had suggested that following initial colonization between AD 800 and 1000, the archipelago was rapidly explored, and permanent settlements were established in areas where resources were favorable to a mixed farming-fishing subsistence regime. A phase of exponential population growth ensued, possibly reaching a peak around AD 1400–1500. At this time, leeward zones on Maui and Hawai‘i Island began to be permanently occupied and their resources increasingly exploited. By the late eighteenth century, these leeward landscapes had been substantially modified through the development of intensified agricultural systems, supporting dense populations. Along with heightened efforts at agricultural intensification, other key sociopolitical indices of this late phase include cycles of territorial conquest (Sahlins 1972) and the imposition of a highly structured system of land tenure (the ahupua‘a system).
4. *Emergent sociocultural complexity:* Our proposal emphasized that contact-period Hawaiian society is anthropologically noted for its complexity, indexed by economic specialization (Earle 1977, 1978, 1987b; Kirch 1990a), social stratification (Sahlins 1958), and specialized religious cults and ritual regulation of production (Valeri 1985). Among the

> factors potentially contributing to this rise in complexity were population increase, agricultural intensification, warfare, status competition, and regional differences in resources. We argued that a compelling model linking these factors would need to be landscape- specific, as well as temporally dynamic, if it were to show how the kinds of causal factors listed above were linked with the spatial distribution of biotic resources and biogeochemical gradients.

We proposed to focus on two study areas whose human settlement histories were already fairly well resolved through prior archaeological investigation and which were relatively resource-restricted from the point of view of Polynesian colonists. Both areas began to be exploited and occupied by small human groups during the Expansion Period (AD 1100–1650) of the Hawaiian cultural sequence (Kirch 1985, 1990a, 2000), which was characterized by an archipelago-wide population increase at an exponential growth rate (Clark 1987; Dye and Komori 1992a, 1992b; Kirch 1994).

1. *The Kahikinui Study Area (Maui)* encompasses the ancient moku of Kahikinui, on the southern slope of Haleakalā Volcano, rising from the sea to 3,000 m above sea level, a magnificent altitudinal gradient crosscut by substrates of varied geological age. Kahikinui typifies a leeward climatic zone with pronounced seasonality (*kona* [southerly rains] predominate) and a total annual precipitation of 500–1,000 mm, which puts it on the margin for dryland cultivation of Polynesian crop plants, especially during droughts. The eastern half of the district has older substrates of the Kula Volcanic Series (400 kyr) with deeply weathered soil profiles and considerable hydrologic incision (Bergmanis 1998; Stearns and Macdonald 1942). In stark contrast, the western part of the district consists of young lava flows of the Hāna Volcanic Series (0–60 kyr), a rejuvenation phase of Haleakalā, resulting in rugged, unweathered or barely weathered surfaces lacking significant stream incision. We predicted that the differential weathering times of the Kula and Hāna surfaces would correlate with significant differentials in critical soil nutrients such as phosphorus and that these would have greatly affected patterns of human land use and tenure, especially after local populations became densely concentrated. A further resource restriction in Kahikinui was imposed by the coastal geomorphology, largely one of low sea cliffs

and an absence of coral reefs, hence relatively low biotic diversity and biomass, rendering marine protein exploitation marginal. Since 1994, Kahikinui has been archaeologically investigated by three coordinated teams of archaeologists from the University of California, Berkeley; Northern Illinois University; and the State of Hawai‘i (Dixon et al. 1999; Kirch 1997b).

2. *The Kohala Study Area (Hawai‘i Island)* encompasses the oldest volcano on the island of Hawai‘i. The edifice of Kohala Volcano was formed by 400 kyr (Pololū series); substantial areas of its surface were covered by post-shield eruptions about 150 kyr (Hāwī series). The volcano’s wet windward slope is divided by deeply incised valleys, the largest of which (Waipi‘o Valley) was the major locus of irrigated taro agriculture and (probably not coincidentally) an important seat of the paramount chiefs of the island (Cordy 2000).The undissected leeward slope supports one of the most spectacular rainfall gradients on Earth, reaching from less than 200 mm to more than 3,500 mm annual precipitation in a distance of 15 km (Giambelluca and Schroeder 1998). Leeward Kohala also supported one of the most extensive dryland farming systems in the archipelago, covering perhaps 60 km^2 (Kirch 1984, 1985, 1994; Rosendahl 1972, 1994). The Kohala study region had already been the focus of extensive archaeological, pedological, and ecological investigations, and we proposed to build upon these in our investigation of the dynamic linkages between soils, rainfall gradients, and the intensification of the field system.

Our proposal to the National Science Foundation was accepted and funded on January 1, 2001 (NSF Grant no. BCS-0119819), and our team carried out field and laboratory research over the following four years. Many of the results of our research have already been published in a series of journal articles (Hartshorn et al. 2006; Kirch et al. 2005; Kirch et al. 2004; Ladefoged, Lee, and Graves 2008; Lee, Tuljapurkar, and Vitousek, 2006; Meyer, Ladefoged, and Vitousek 2007; Vitousek et al. 2004). Nonetheless, we felt compelled to integrate project results more thoroughly. The School for Advanced Research gave us the opportunity to achieve such integration by agreeing to host an advanced seminar in Santa Fe. The week-long seminar in fall 2006 gave Hawai‘i Biocomplexity Project members the opportunity to discuss our achievements—as well as shortcomings

—at length. The two major outcomes of the seminar were this book and a proposal to the NSF to continue the project. The latter was funded in 2007 under the Human Social Dynamics Program of NSF, and the results of our continued research in Hawai‘i will be published in due course. Meanwhile, even as the team continues its work, this volume summarizes the first important phase of our research on the dynamic linkages between soils, agriculture, and society.

A THEORETICAL FRAMEWORK FOR INTENSIFICATION

Interpretations of agricultural intensity and intensification depend inevitably upon concepts that relate agricultural practices to two types of changes and conditions: those that are broadly social, economic, and cultural and those that are environmental (related to cropping systems, soil and water management, and climate and other large-scale ecosystem effects). These concepts provide a basis for analysis and understanding of social-environmental interconnections. The framework described below is intended to provide a kind of fulcrum suited to the interdisciplinary approach we have taken in the Hawai‘i Biocomplexity Project. We propose a framework that relates different categories of data and analysis and integrates them with modeling. The model of crop yield and consequences for human population introduced in chapter 6 was central to the project, as was our emphasis throughout on systematic data collection and analysis. Providing a relational framework at the outset of this volume enables us to explore the interconnections among the different and often diverse types of data that we are dealing with in our interdisciplinary research.

The emphasis of our framework is on agricultural intensity and intensification, both of which are varied and frequently nonlinear. Key variables often change over time; they also often interact, and the interactions are as important as the variables themselves. We focus on three such variables or themes—population, technology and techniques, and political economy (Brush and Turner 1987):

1. *Population* density, age profiles, and other demographic conditions tend to bear important relations to intensive agriculture (Netting 1993). At the same time, the processes of demographic change—in forms ranging from contemporary population growth to historical demography (population decline or increase)—have been central to nearly all accounts of intensification (Turner, Hyden, and Kates 1993). While enshrined in Boserup’s work and traceable to her precursors, the actual mechanisms that relate population to agricultural intensity and intensification are complex. One aspect of this

complexity is social organization, since it determines the demographic unit(s) through which population pressures are exerted (for example, household, lineage group, village).

Here our recognition of the importance of population dynamics draws from recent studies in environmental science of contemporary land use and land cover change (Perz and Walker 2002; Perz, Walker, and Caldas 2006; Scatena, Walker, and Homma 1996; Zimmerer 2004). Although focused primarily on current forest frontier settings (given the emphasis on tropical deforestation and reliance on the analysis of remotely sensed images), these studies have established a new level of analysis and awareness of microdemographic processes that presently operate in agriculture and environmental modification and that are relevant to past episodes of change as well (Zimmerer 2004).

2. *Technology and skills or techniques* are central to explanations of agricultural intensity and intensification. The planned expansion of Green Revolution farming systems, for example, depended on newly introduced and scientifically bred high-yielding varieties of crops and the requisite technological packages (Brush and Turner 1987). Involution of wet-rice farming in Java, by contrast, depended on the continued local innovation and farmer-led adoption of technology and techniques that supported higher yields (Boserup 1965; Geertz 1963).[6] Intensification in pre-European Peru depended on the construction of new terracing and irrigation works, which represented still another niche for the role of technology and techniques in agricultural change (Williams 2006:316).

   In our framework, the general category of technology and techniques includes forms of landesque capital such as field border walls (Ladefoged and Graves 2000; Ladefoged, Graves, and Jennings 1996); these particulars are explored from an archaeological perspective in greater detail in chapters 4 and 5. We note that whether such landesque capital can be acquired depends on the resource status and investment capacity of economic decision-making units; farm households, for example, may experience "investment poverty" that prevents the acquisition and even the maintenance of such forms of intensive agriculture (Reardon and Vosti 1995).

3. *Political economy* factors affecting intensification have ranged from relatively tractable mechanisms—for example, taxes and tribute demanded by rulers, requiring crop or animal production—to

processes that are less direct and often less known (at least in archaeological contexts), such as levies for labor (Erickson 2006; Kirch 1985, 1994, 2006; Stanish 2006). Our framework attempts to account for this multiplicity of forms while recognizing that the spatial and material manifestations may also be more complex than was previously thought. Brookfield (1972), for example, envisaged production systems that are spatially segregated between those intended for subsistence, social organization (local gift-giving, for example), and trade or monetary purposes (surplus extraction). Recent studies show, however, that the spatial organization of agriculture may mix the other types of production together with subsistence growing and thus spatially intermix production for different end uses.

FURTHER INTEGRATION OF COMPLEX SOCIAL-ENVIRONMENTAL DYNAMICS

Our framework for studying agricultural intensity and intensification is based also on a new conceptual apparatus. We begin by introducing a model of environmental variation and agricultural production (with special attention to implications for human demography) that provides insights into the needs for food production along with the probability of food shortages and famines (Lee, Tuljapurkar, and Vitousek 2006). Subsequently, we move to the role of environmental change, outlining key processes in the human-induced spatial and temporal variation of biophysical environments. Finally, we describe the concept of multilevel spatial dynamics. As developed especially in chapter 6, we use the concepts of landscape and political territory in order to discuss a range of social-environmental dynamics that inscribe spaces within and between such territories. The above elements may be seen as problem-specific to our research because they are demonstrably applicable to the analysis and understanding of agricultural intensity and intensification in the context of precontact and early-contact Hawai‘i. At the same time, we argue that this framework offers the potential of general applicability to understanding agricultural intensification historically, as well as in the contemporary world.

The modeling of temporal and spatial variation of agricultural productivity and its relation to human population offers a focused examination of these interdependent conditions that fits within our overall framework (Lee, Tuljapurkar, and Vitousek 2006; chapter 6 of this volume). This model generates estimates of food production based on local environmental variation and the within- and between-season processes that impinge on crop yield. It is relevant to the interpretation of agricultural intensity and intensification since it is focused on crop yield, which is a major factor that influences the capacity for human populations and population level. As a focus for modeling, the nexus of crop yield and population is well suited to our framework. It is sensitive to small-scale or microenvironmental variation and accounts for the impact of different soil and plant nutrients and the process of nutrient cycles. It is possible, therefore, to gain estimates of the fine-grain relations between environmental variation (both spatial and temporal) and yield. The elaboration and use of this model can therefore promise insight even in those settings, such as the research reported in this volume, that otherwise offer large differences in cultural, environmental, and historical context.

The incorporation of environmental change is likewise central to our framework for understanding intensive agriculture and intensification. Environmental change refers to the semipermanent alteration of biogeophysical processes or conditions within an ecological system. Such change may be due to human activities, or it may result from nonhuman causes (e.g., Hotchkiss et al. 2000). The general level of analysis and understanding of environmental change, as well as concern over human-induced problems, has grown significantly during the past decade (Kirch 1996, 2005; Vitousek et al. 1997). This growth of interest, knowledge, and analytical methods offers a perspective that is ripe for fuller incorporation into frameworks for studying intensive agriculture and intensification. At the same time, the vantage point for viewing environmental change must build upon existing insights. Chief among these is the analysis of how the incremental modification of environments in intensive agriculture commonly entails biogeophysical changes that influence intensification (Doolittle 1984, 1988, 1990).

Our framework emphasizes both temporal and spatial components of environmental change. Temporal change can play a crucial part in the capacity for intensive agriculture and the process of intensification. Climate change, for example, figured prominently in the intensification of agriculture during the pre-European period in the Peruvian Andes (e.g., Williams 2006). The impacts of humans on soils and soil-nutrient availability are also thought to be an important type of environmental change that has widely influenced intensive agriculture and intensification (Hartshorn et al. 2006; Marcus and Stanish 2006b:5). Spatial variation of environments is similarly important and is likewise subject to processes of change. Favorable microenvironments that are differentially well suited to irrigation or subsurface soil moisture (as in the case of topographic swales) have been demonstrated to serve as preferred sites of intensive agriculture and intensification (Zimmerer 1991). As a result, alterations of these sites may potentially serve as sensitive indicators of the processes of agricultural change.

Human-induced changes in vegetative cover are perhaps the most well-known and widespread form of environmental change that accompanies intensive agriculture and intensification. Deforestation has accompanied transitions to more intensive agriculture worldwide, both in the distant past and presently. The removal of forest cover has led, moreover, to wide-spread changes in soils, water resources, and nutrient cycles that have affected both agricultural and nonagricultural environments (Vitousek et al. 1997). At the same time, certain types of agricultural change and even intensification may involve the use of trees and in some cases the maintenance or increase of tree cover. Perennial tree cropping in Polynesia and the park woodlands of West Africa offer two examples of tree cover that is compatible with fairly intensive agriculture (e.g., Kirch 1994; Stone 1996). Our volume uses these findings in order to approach the nature of environmental change involving vegetative cover as potentially multidirectional with regard to intensive agriculture and intensification.

Finally, our framework hinges on the idea of multilevel spatial interactions. Here we rely on the concepts of landscape and territory. These two concepts have become increasingly familiar to treatments of agricultural intensity and intensification. *Landscape* refers to the lived-in environments comprising multiple, overlapping spaces within and among places and generally within the unit that can be referred to as a region (see Balée 2006; Balée and Erickson 2006; Morrison 2006). *Territory* is used to signify the space under the political or economic control of a socially organized group (Stanish 2006; Stone and Downum 1999). The concepts of landscape and territory help enable us to see that households and community groups may rely on land-extensive forms of production that coexist or are added to an existing repertoire involving more land-intensive forms (Morrison 2006:72; see also Morrison 1994).[7] Interactions involving intensive and extensive production are distinguished through coordination between diverse spaces within the territory of a group, albeit ones whose significance to the economic landscape are trending in opposite directions.

SUMMARY

Our framework for the analysis of intensive agriculture and intensification focuses on environmental change and multilevel spatial interactions. It includes a model of the relation of spatial and temporal environmental variation to crop yield, with attention to the consequences for human population. It also incorporates three key themes common to this area of study: population, technology, and political economy. We have endeavored to create a flexible architecture that enables us to account for the social-environmental complexity that is integral to intensive agriculture and intensification. Our emphasis throughout the volume is on intensive agriculture and intensification in the archaeological past. However, we have interwoven analysis from contemporary studies in order to broaden the scope of what is possible to address in studies of the past in general and in Hawai‘i in particular.

While social-ecological complexity emerges from environmental change and multilevel spatial interactions, it is important to reflect on the need for additional conceptual framings in our analysis. As elaborated above, the framework is fashioned through such concepts as landesque capital (including investment capacity), incremental or accretionary agroenvironmental change, spatialities of the livelihood landscape, and political territory. Our elaboration of the framework is thus dependent on an actively evolving interdisciplinary dialogue. As will be seen subsequently, it depends on ideas and approaches from archaeology, anthropology, geoarchaeology, ecology, demography, earth-system and geosciences, and geography.[8]

Notes

1. Examples include studies of how agricultural intensity and intensification are increasingly being related to key indicators of environmental sustainability, such as nutrient cycles in agro-ecosystems, and to the socioenvironmental analysis of the prospects for biodiversity and protected-area conservation (Keys and McConnell 2005; Matson and Vitousek 2006; Vitousek et al. 1997; Zimmerer 2006). Other examples include the use of agricultural intensity and intensification themes in fostering public awareness of issues such as environmental sustainability and social-environmental collapse (Diamond 2005; Kirch 1997a; Tainter 2006).

2. Blaikie and Brookfield (1987:9) defined landesque capital as “any investment in land with an anticipated life well beyond that of the present crop, or crop cycle…[that] involves substantial ‘saving’ of labour and other inputs for future production.” They note that the impetus for farm-level investments in landesque capital may not be strictly economic or explicable in cost-benefit comparisons but rather is likely to include necessity (for example, improving otherwise nonarable sites) and coercive social relationships (for example, forced labor).

3. These condition variables influence the distinction of “low-performing” and

"high-performing" villages in the Boserupian analysis of agricultural intensification in Bangladesh (Turner and Ali 1996:14988).

4. Arguably, such nonfarm economic activities do not qualify as intensification strategies unless the earnings or surplus they produce is invested in intensive agriculture (see Ali and Ali 1993; Zimmerer 2004).

5. The date for initial Polynesian settlement of Hawai'i remains a matter of considerable dispute and ongoing research. Reanalysis and redating of key sites once thought to provide evidence for settlement between AD 300 and 600 (Kirch 1985) now suggest that Polynesian settlement is unlikely to have occurred before about AD 800. Indeed, the best evidence for early settlement now derives from pollen cores and similar proxy indicators of anthropogenic environmental disturbance, primarily from O'ahu (Athens 1997; Athens et al. 2002).

6. On knowledge- and technique-driven intensification of rice farming and the role of African Americans in the southeastern United States, see Carney 2001.

7. On the coexistence of agricultural intensification and disintensification in the present-day Andes, see Zimmerer 1996, 2002.

8. Given the use of some key ideas from these fields, it is important to reiterate the contribution of, and prospect of enlarged connections to, related subareas within the environmental and global-change sciences (for example, the land use/cover change approach) and economics (especially agricultural and resource economics).

