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Archaeological evidence for agricultural development in Kohala, Island of Hawai‘i

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Abstract

Measuring subsistence change, especially when it involves questions of resource intensification, requires special attention to issues of data quality and relevance. This is particularly so when, as in Remote Oceania, the archaeological record is of relatively short duration and the nature of subsistence change was mostly quantitative, not qualitative. Agricultural development, particularly focused on the practice of dry land fixed field cultivation, is reviewed and a method developed for chronologically ordering the development of walls and trails constructed as the main structural features in three areas of the Kohala Dry Land Field System of Hawai‘i Island. At least two different pathways to agricultural development are discernable, one of which documents intensification of effort over time and the other one shows the expansion of a relatively intensive system of dry land farming but little evidence of intensification. Differences in environment, geography, and the role of chiefs in underwriting agricultural development are likely factors that produce this pattern of dry land agriculture in Hawai‘i.

Keywords: Subsistence change; Agricultural development; Archaeological method; Chronology; Hawaiian archaeology

1. Introduction

Leach [24] has recently noted that subsistence change involving agricultural development includes processes of expansion and intensification (see also Morrison [26,27]). For archaeologists interested in prehistoric agriculture, these processes must have empirical referents that allow them to be identified and distinguished from one another. Agricultural expansion includes the lateral movement into, and management of plants within new, formerly uncultivated, areas. In contrast, agricultural intensification involves ‘increasing capital (such as infrastructural improvements), labor and skills in a constant area of land to increase either production or the frequency with which the land can be used’ [6, p. 31]. To document the process of intensification it is necessary to show how *levels of agricultural use* increased over time and how this increased productivity. As Leach [24, p. 315] notes, ‘establishing the fact of intensification depends on diachronic comparison’. To achieve this, the same unit of land must be divisible into two or more temporal segments and each segment must be reliably associated with a discrete set of agricultural artifacts, features, or by-products.

A number of archaeologists have suggested that the process of agricultural intensification involves a sequence of change from swiddening and plot rotation, to the construction of formal plots, to an increase in the density of formal plots or in cropping frequency (see Ref. [24, pp. 316–318] for a review). This viewpoint derives from the pioneering research of Boserup [5] whose studies suggested a directional or causal relationship between population pressure and agricultural intensification in Africa. Leach [24] and Morrison [26, 27]) rightfully question whether this sequence is necessarily unilinear and/or inevitable; Brookfield [6,7] and others [10,20] have questioned whether population (treated

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either as a variable or as a state) is causal with respect to agricultural change. Evolutionary archaeologists, in particular, would argue that expansion in or reduction of population is evidence for the effect(s) of selection operating on agricultural variability [11,21,33]. With respect to Pacific prehistories, Leach [24, p. 313] questions whether it is always the case that the process of 'intensification commenced with swiddening and cumulated in major capital investments such as earthworks and permanent fields'. The issue is further complicated because it is difficult to empirically demonstrate that swiddening which leaves few permanent cultivation traces was replaced by more intensive modes of production involving capital infrastructural improvements. As a consequence, assumption or presumption often replaces analyses and fact. The archaeological evidence for the initial stages of intensification is usually tenuous, and includes changes in charcoal concentrations and pollen or phytolith taxa (see Morrison, [26,27, pp. 589–595]). The latter portion of the intensification sequence, that is, an increase in intra-annual cropping or labor through additional partitioning of the land is also difficult to document. It should minimally involve archaeological evidence for increases in the quantity or variety of infrastructural improvements per unit of land over time. Kirch [20, pp. 258–259] suggests that one way we can document this aspect of intensification in the archaeological record is by showing the 'successive division of originally large fields into increasingly diminutive plots'.

In her recent review of Pacific agricultural development, Leach [24] questions whether archaeologists have been successful at documenting agricultural intensification. While she is suspicious of claims that large dry land field systems have been intensified over time, Leach also critiques the archaeological evidence used to support hypotheses for the intensification of ponded field or irrigation agriculture in parts of Oceania. Particular concern is directed by Leach [24] to the question of the prehistoric intensification of dry land agriculture as represented in the Kohala Field System (Fig. 1). Citing both earlier work by Newman [28] and Rosendahl [34,35], syntheses by Kirch [18,19], and more recent analyses by us [22], Leach suggests that we have conflated the processes of expansion and intensification. She contends that although the Kohala data are interpreted as evidence of agricultural change, they are also equally consistent with expansion at a constant level of agricultural intensity. Certainly we applaud efforts to improve the reliability of claims by archaeologists and to develop unambiguous evidence relative to the form of agricultural development and subsistence change. Further, we are in agreement that simple unilinear developmental sequences are unlikely to reflect the complexity of past processes of change.

While Leach [24] may be correct in some instances about the quality and empirical basis of archaeological evidence for documenting agricultural change, we can now demonstrate with relevant, high quality data how the Kohala Field System on the Island of Hawai'i changed over time. We have recently initiated a detailed global positioning system (GPS) survey of prehistoric agricultural walls and trails associated with two different portions of the Kohala Field System (which we use along with a third area previously mapped by Rosendahl [34,35]). Using the horizontal relationships of walls and trails to one another, we have ordered the dry land agricultural features in three sections of the field system into relative chronologies. Our study provides evidence that both processes of expansion and intensification of dry land agriculture have occurred in the past in this portion of Hawai'i Island. These localities also illustrate how different combinations of processes and rates of spatial and temporal development may characterize prehistoric agricultural change in Polynesia.

2. The Kohala dry land agricultural field system

The Kohala Field System consists of a series of more or less contiguous walls and trails spread over an area of approximately 19 by 4 km on the leeward undissected slope of the Kohala Mountains on the northern most tip of the Island of Hawai'i. A number of sources provide detailed discussions of the cultigens, environmental setting of the field system, and a review of past work in the area (see [19–22,25,34,35] and Newman [28]). During the later prehistoric period (ca. AD 1400–1800), sweet potato (*Ipomoea batatas*) was the main cultigen in the area although yams (*Dioscorea* sp.), dry-land taro (*Colocasia esculenta*), bananas (*Musa hybrids*), sugarcane (*Saacharum officinarum*), gourds, cucurbits (*Sicyos* sp. and *Momordica charantia*), and other food and industrial crops were also grown. A key environmental variable for growing sweet potato in this area is the amount of available water, usually in the form of rainfall. Optimum sweet potato production is obtained in areas receiving an annual rainfall of 30–50 in. (762–1270 mm) with approximately 18–20 in. (457–508 mm) being a minimum and over 90 in. (2286 mm) a maximum [17,29, p. 248,32]. The predominant rainfall pattern in this area is the result of an orographic effect, with the northeast trade winds releasing large quantities of moisture on the northeastern windward side of the Kohala Mountains' ridgeline and then decreasing to the west and south down slope on the leeward side of the island. There is considerable spatial variability in rainfall even on the drier leeward side. The archaeological walls and trails of the field system are shown here in relation to the contemporary rainfall isohyets (Fig. 2). In addition to spatial variation in rainfall, there is a significant inter-annual variation in rainfall [21, p. 429]. This is a function of overall rainfall totals, with drier areas more

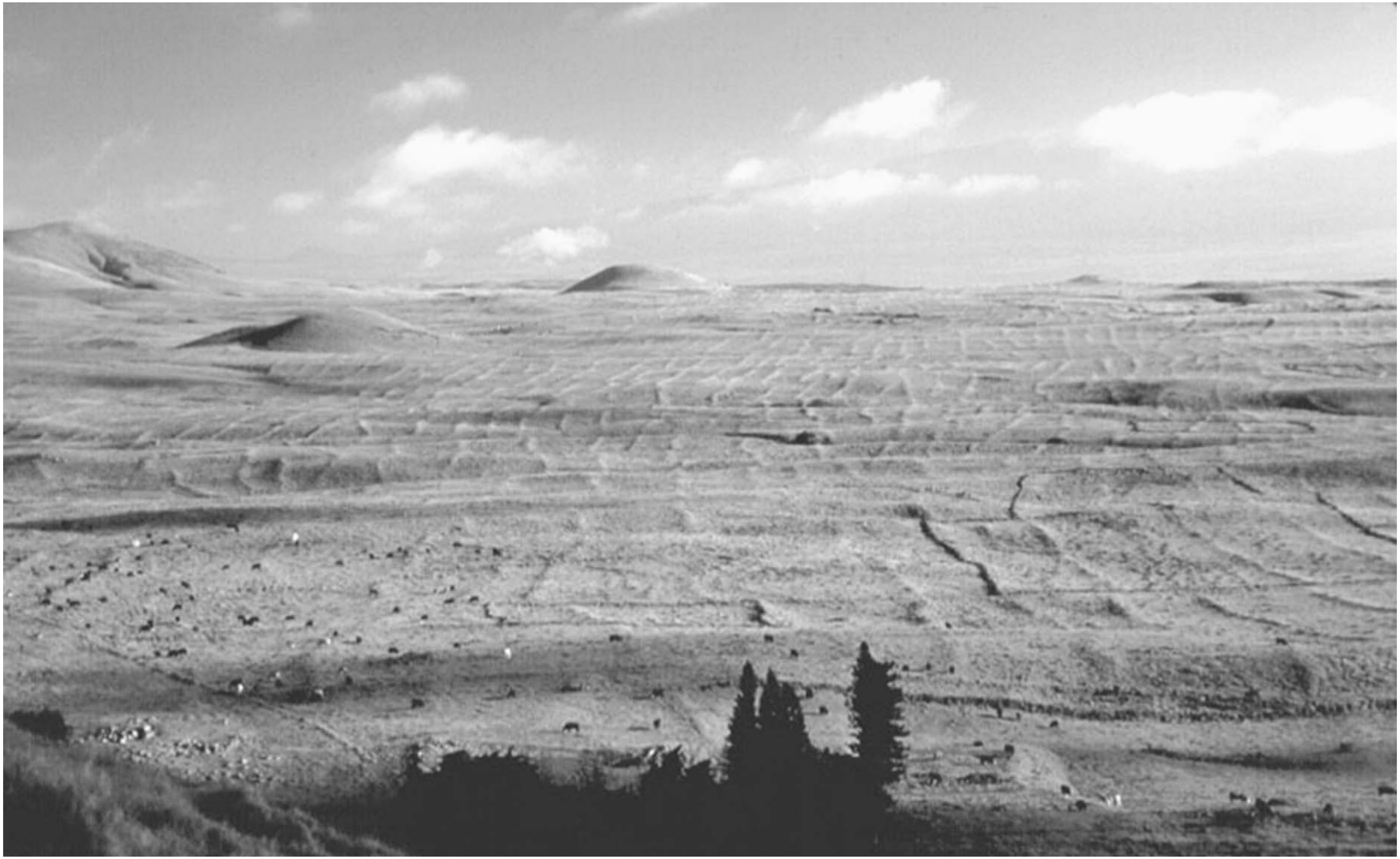

Fig. 1. Photograph of the Kohala Field System, looking south from Area B into Area A. Note the contour aligned field border walls (from top to bottom on the photograph). Trails are aligned across the photograph. (Photo courtesy of Terry Hunt).

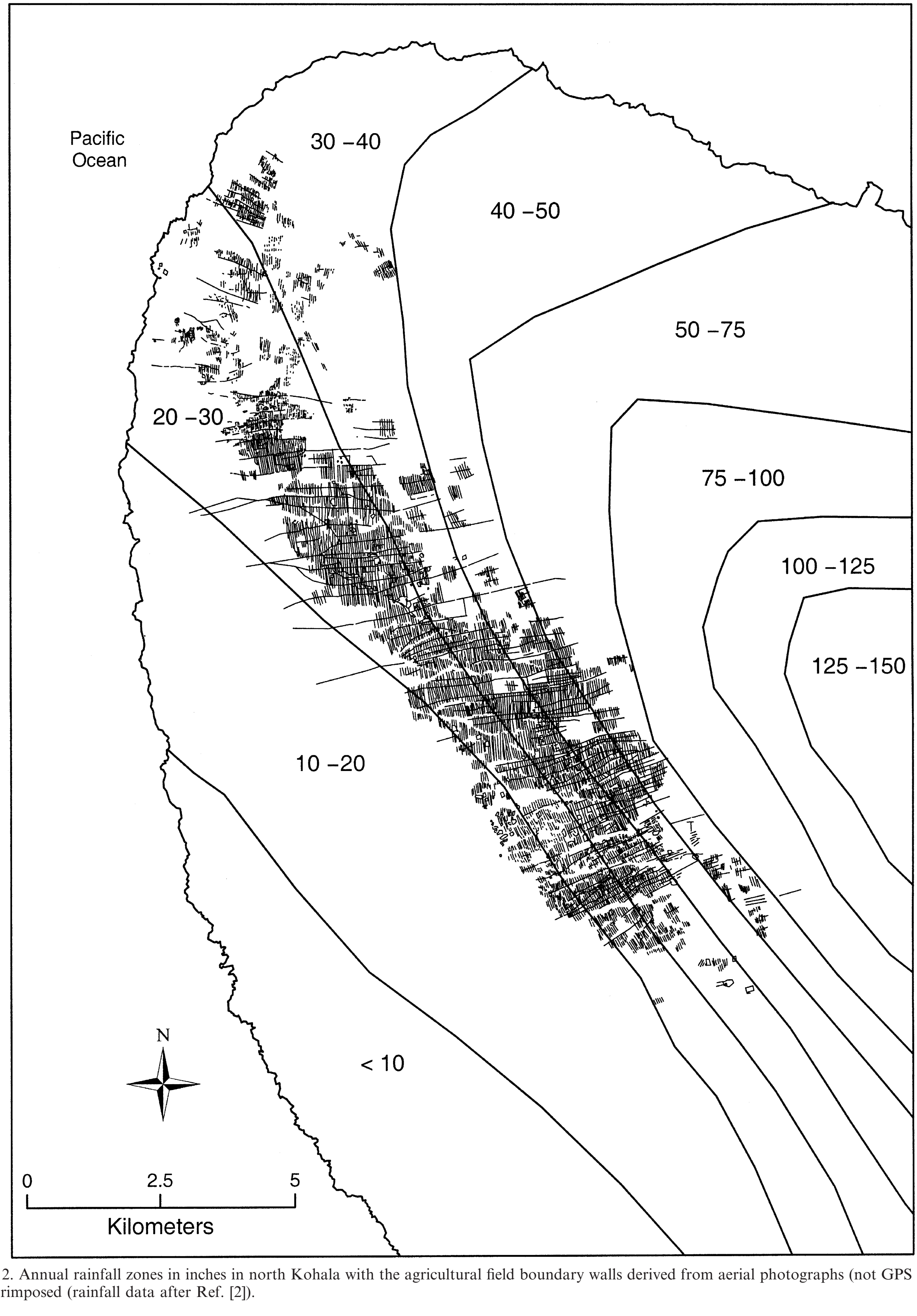

Fig. 2. Annual rainfall zones in inches in north Kohala with the agricultural field boundary walls derived from aerial photographs (not GPS data) superimposed (rainfall data after Ref. [2]).

likely to experience a greater number of drought conditions on an annual basis in comparison to wetter areas.

The level of moisture in the soils of Kohala necessary for growing sweet potato is highly influenced by the strong NE tradewinds. Empirical measurement of wind at Kahua Ranch (located close to the uppermost elevation of the Kohala Field System in Kahua 2 *ahupua'a* at an elevation of ca. 1000 m) from 1980 to 1982 by agencies associated with the Department of Energy determined that the area is one of the windiest in the archipelago with an average wind speed of 11.3 m/s (25.3 mph) at a level of 45.7 m above ground surface (ags), and 8.6 m/s (19.2 mph) at a level of 9.1 m ags (http://www.hawaii.gov/dbedt/ert/winddata). Measurement by agencies associated with the State of Hawai'i from 1992 to 1994 determined that the average wind speed at Kahua Ranch was 7.2 m/s (16.2 mph) at a height of 42.7 m ags and 7.0 m/s (15.8 mph) at 27.4 m ags (http://www.hawaii.gov/dbedt/ert/winddata). Berger [4, p. 72], in his authoritative book on plant and soil interactions, notes that 'under normal field conditions most of the water removed from the soil is lost by a combination of direct evaporation from the soil itself and transpiration from the leaf surfaces'. The combination of these processes is referred to as evapotranspiration, and Berger [4, p. 72] observes that high winds greatly increase the loss of water. Scott [36, p. 271] provides a detailed and quantified description of these processes, and demonstrates how the rate of evaporation is positively correlated with wind velocity (also see Ref. [8, pp. 24–27]).

Among the practices adapted traditionally by Hawaiians included the conservation of available moisture for sweet potato production by the construction of a series of impenetrable earthen embankments and relatively more penetrable rock walls. These features comprise one of the major elements of the Kohala Field System. There is an extensive literature on the physics of windbreaks and how they function to reduce wind and therefore the amount of evapotranspiration in an area (see Ref. [15] for a recent collection of essays; Ref. [8] for a historical review and monograph-length discussion of measuring and quantifying the effects of windbreaks; and Ref. [3] for an early seminal discussion). Solid windbreaks produce an eddying flow in their lee to a distance of ca. 10–15h, where h is the height of the windbreak, and a disturbed turbulent flow to ca. 30h (Fig. 3A) [8, p. 4]. More penetrable windbreaks produce less eddying flow and while they do not reduce the wind in the immediate lee of the windbreak to the extent of a solid windbreak, they produce relatively lower velocities over relatively longer distances, in relation to solid windbreaks [8, pp. 5–6]. Interestingly, the width of windbreaks seems to have very little effect, rather it is the height that is critical. Zones of wind abatement for a moderately penetrable windbreak are shown in Fig. 3B. In his review of empirical studies on the effect of windbreaks on levels of evaporation, Caborn [8, p. 27] notes that windbreaks can reduce evaporation by 20–30% in sheltered areas. In the Kohala Field System the windbreak walls are orientated perpendicular to the trade winds and parallel to the contour of the land. Individual field border walls range from ca. 7 to 590 m in length and are generally 0.5–1.5 m high and 1–2 m wide. In their final form the walls functioned not simply as field boundaries for leeward planting of cultigens, but as a series of alignments that disrupted and decreased surface wind flow within several meters of the ground, and hence reduced evapotranspiration. By significantly decreasing the wind flow over a large area, the walls functioned to conserve the amount of moisture available for sweet potato growth. By expending additional energy on constructing windbreak walls, pre-contact Hawaiians increased the productivity of set areas of land.

In addition to the walls, there are a series of parallel and branching trails originating at the coast connecting the area to the interior uplands [9,16]. They usually consist of raised or lowered pathways about 1–2 m wide that are sometimes stone curbed, or even paved, and vary in overall total length. Trails are orientated perpendicular to the walls and the contour of the land, and together with the field border walls form a grid of variable sized units (i.e. plots). Whereas field walls are common to dry land fields in the Hawaiian Islands, the trail system in the District (or *moku*) of North Kohala is unique. We are indeed fortunate to be able to study this intact trail system since we suspect others would have often been destroyed as they gave way to wider roads and horse trails during the historic era [1].

3. Developing archaeological methods for documenting large scale agricultural change

In our initial attempts at modeling agricultural development in North Kohala we analyzed a data set based on a series of aerial photographs that showed over 4500 walls with a total length of 570 km, and over 600 trails with a total length of 190 km [21,22]. We [22] first documented the expansive limits of the field system as well as what we thought were the differential levels of intensification across the undissected upland landscape. Later, we [21] added a theoretical and temporal component to the study, and analyzed how agricultural development (both expansion and intensification) varied over time and space. In that analysis we used a simple, rather crude method based on variation in the length of field walls to estimate agricultural development. We assumed that through time the larger plots had been subdivided into smaller units by the addition of trails and new walls

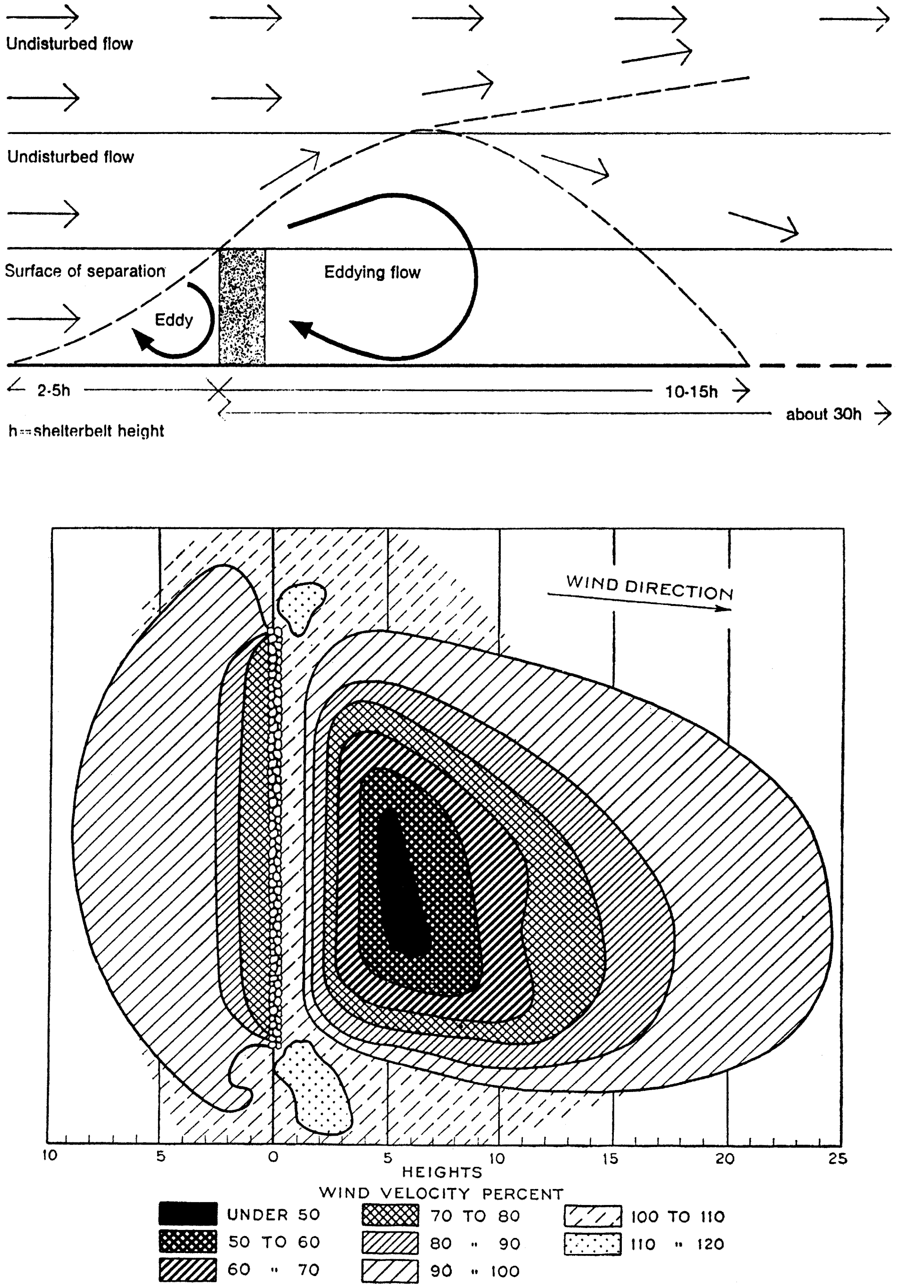

Fig. 3. (A) Characteristic airflow pattern due to a near-solid, cross-wind barrier (not to scale) (after Ref. [13, p. 209]). (B) Wind abatement behind a moderately penetrable windbreak. Wind speed is shown as percentages of free wind, and distances are shown as multiples of windbreak height (*h*) (after [3,13p. 210]).

and that more recent walls were constructed to form these smaller plots. More recent walls would thus be shorter in length, and therefore it was possible to model the spatial distribution of these changes over time by examining the distribution of the different length walls. We suggested that agricultural development was variable throughout the field system, with an initial expansion into two primary areas, followed by infilling (or intensification) and further expansion during the middle phase, and a final southern expansion of the field system late in prehistory. The spatial distribution of the walls suggests that early in the sequence fields were constructed closer to the coast where more abundant marine resources were located, whereas later in the sequence a whole new section of the field system was established in the southern zone located farther inland and with little evidence for earlier, associated occupation along the coastline. The subsistence practices of the inhabitants of North Kohala changed through time, with a shift from those which emphasized energy optimization to those which provided greater stability by means of buffering climatic variation in resource productivity [21].

The method presented in Ref. [21] was appropriate for documenting agricultural development given the large spatial scale and available data with which we were working at that time. Because the database used in that study was based on aerial photographs, many of the shorter walls and trails were not visible in the photos, and thus they were not recorded or included in our analyses. Additionally, we could not reliably observe the smaller scale spatial relations between the walls and trails. The digital map based on the aerial photographs could not be accurately used to depict whether walls ended at trails, or whether they intersected and continued over or through the trails. The temporal significance of these two alternatives was originally noted by Rosendahl [34, p. 502] when he observed that the 'matching and mismatching patterns of trail and field border (wall) interaction(s)' could be used to derive relative chronologies of agricultural development. Kirch [18] has used this observation in conjunction with an implicit methodology to identify a three-phase chronology for a portion of Lapakahi, one of the *ahupua'a* (the traditional term for a Hawaiian territory associated with a community) within North Kohala. The relative chronology by Kirch [18] demonstrated that it was possible to order the construction of the field walls and trails and served as the model for our explicit effort to undertake a similar fine-grained analysis utilizing geographic information systems (GIS) technology.

The advent of surveying with GPS units has enabled us to quickly and efficiently record the walls and trails in areas of the field system in greater detail (see Ref. [23] for a discussion of GPS survey and mapping along the Kohala coast). We can now determine the precise horizontal relationship between wall and trail abutments or intersections. We have used GPS units to intensively survey the agricultural walls and trails in two areas of the Kohala Field System (Fig. 4). The first locality, which we refer to as Area A, is located in the south and farthest inland section of the field system and includes portions of Kahua 1 and Pahinahina *ahupua'a*. In 1999 we surveyed approximately 41.2 ha and recorded 167 individual wall alignments with a total length of just over 14 km, and eight major trails. The second area, referred to as Area B, is near the middle of the field system and includes portions of Kehena, Kaupalaoa, and Makeanehu *ahupua'a*. In this area we surveyed approximately 21.6 ha, recording 74 walls with a combined total length of nearly 9 km, along with seven major trails. In addition to our GPS data, we have incorporated a portion of Rosendahl's [34,35] 'Detailed Study Area' within the Lapakahi *ahupua'a* into our analysis. This area, which we refer to as Area C, is located north of Area B, covers an area of ca. 25 ha, and contains 96 walls and seven trails. These three areas provide us with a good cross-section of the range of fields and trails established in the uplands and distributed along a north to south gradient. It should be noted that the fields of Lapakahi (Area C) are closer to the coast than the fields in Kehena, Kaupalaoa, and Makeanehu (Area B), and these, in turn, are closer to the coast than those in Kahua 1 and Pahinahina (Area A). Furthermore, due to the compression of rainfall isohyets in the area [21, p. 439], variation in rainfall would be somewhat less in Area C than in Area B or Area A.

3.1. Relative ordering rules

We have analyzed this database by defining five explicit rules that enable us to create relative chronologies of agricultural development in these areas. The first rule is: *The oldest walls are identified as those that intersect the trail with the highest ratio of abutting walls to intersecting walls*. We assume that the trail with the highest ratio of abutting walls to intersections is a 'boundary trail', which once established constrained agricultural development on one side from continuing on to the other. These trails have a large number of abutting walls and few walls that intersect them, indicating that once the trail was built, subsequent wall construction was independent on either side of the boundary. There is some independent evidence to support the assumption that the walls that intersect the boundary trails are older than those that abut the trail. We have examined the relation between field border walls and the historically documented[1] *ahupua'a* boundaries. We suggest that the boundary trails coincide with the relatively older *ahupua'a* boundaries depicted on contemporary USGS maps. Longer and presumably older field border walls do occasionally intersect the historically documented *ahupua'a* boundaries but these boundaries tend to be those that we suggest were established early. We suspect that these are relatively early boundaries because the *ahupua'a* they separate (as depicted on USGS maps) are generally larger and have unduplicated names, indicating that at that time they had not undergone internal subdivision and were independent units. Shorter walls, on the other hand, are less likely to cross historically documented *ahupua'a* boundaries and those boundaries which they do cross tend to be units which appear on USGS maps to have been sub-divided from once larger *ahupua'a* (e.g. the walls cross the boundaries of *ahupua'a* on USGS maps that are labeled 'Kehena 1' and 'Kehena 2'; 'Kahua 1' and 'Kahua 2'; and 'Puanui' [trans. 'Pua big'] and 'Puaili' [trans. 'Pua subdivision']). Community boundaries and

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[1] *Ahupua'a* boundaries were recorded in the 1850s as part of the Great Mahele (the process where Hawaiian land was made fee simple). These boundaries are now depicted on USGS maps.

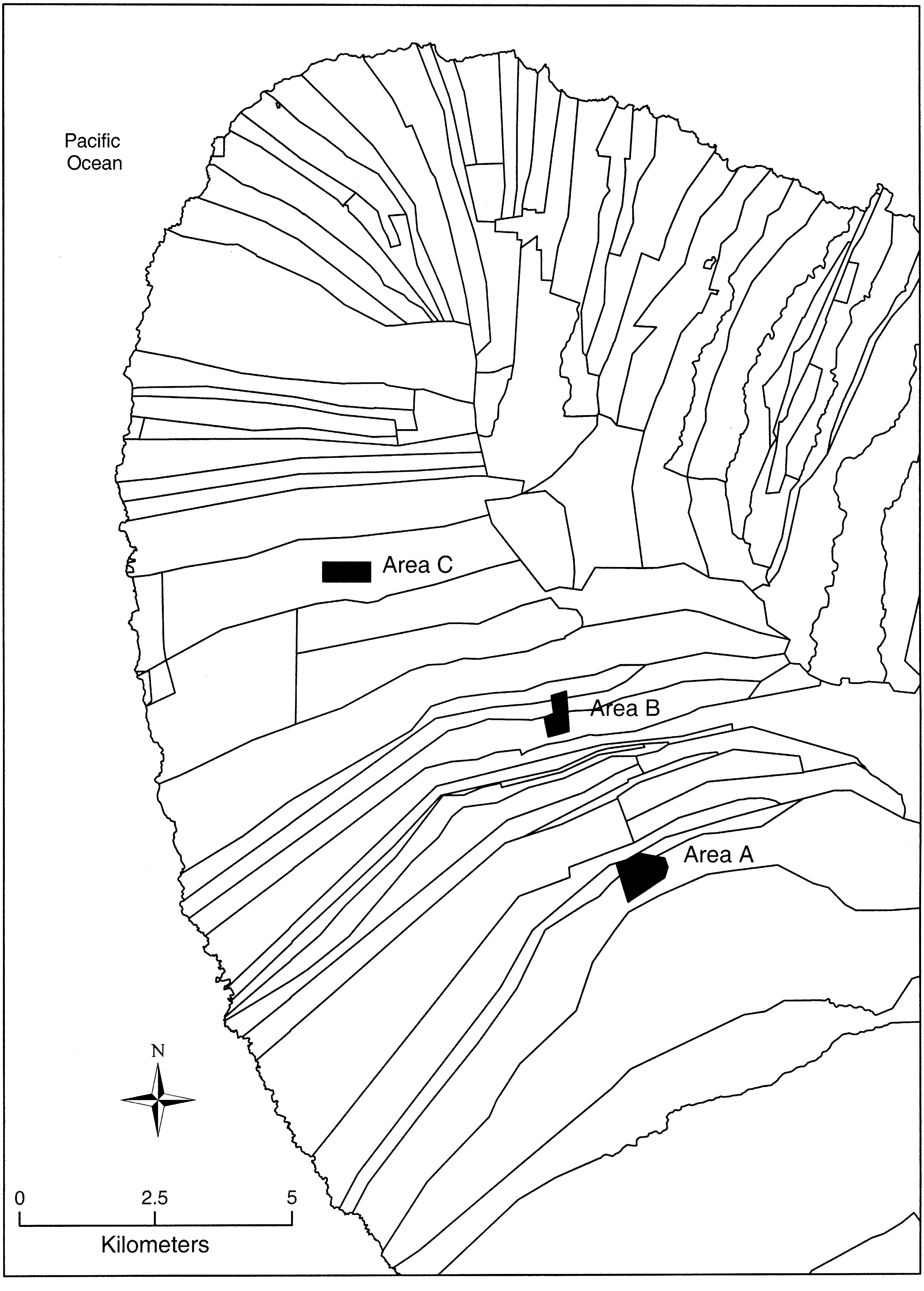

Fig. 4. *Ahupua'a* boundaries in Kohala with the location of the detailed survey areas A, B, and C.

their physical manifestations in parts of Kohala (i.e. trails) help to define the relative temporal relations between field border walls. Therefore, the walls that intersect a boundary-marking trail are some of the initial or oldest walls. A key element of this rule is the relation between walls and trails, i.e. whether the ends of walls abut trails or whether the walls intersect or cross trails. The first rule identifies the walls that intersect the trail with the highest abutting to intersecting ratio as the oldest walls in the study area.

The second rule states: *Walls are assigned to the same temporal unit as the most recent trail that they abut*. If a wall terminates at trails associated with two different chronological units, the wall must be assigned to the same temporal unit as the most recent trail that it abuts because the wall could not have been constructed until both trails were in place. The third rule is: *Trails are assigned to the interval of their oldest abutting wall*. Here, a trail has to be constructed at the same time or earlier than a wall that abuts against it. In one sense trails are the major structural unit of the field system, and walls are the units that infilled the land between trails. The fourth rule stipulates: *A trail assigned to the next subsequent chronological interval must have the highest number of wall abutments terminating at previously identified older trails*. This rule assumes that later trails are linked to earlier trails through wall abutments that end at each. To determine which of the remaining available trails can be assigned to the next temporal interval in the sequence, we identified the trails having the highest number of links or connections via walls back to the trails of the previous temporal unit. The fifth rule is: *Branching trails are younger than the trails from which they branch*. Branching is identified by the division of a single linear alignment into two sections, a stem and a branch. Branches diverge from and therefore become visible based on the heading and orientation of the stem. Trails may sometimes form dendritic patterns in which the more recent trails branch off from older trails.

Rules 1, 2, and 3 specify which walls and trails are assigned to the initial or oldest temporal unit in each area. The oldest walls are those that intersect the trail with the highest number of terminations. The oldest trails are those that terminate at the oldest walls, and additional walls are assigned to the initial construction phase if the most recent associated termination is at one of these oldest trails. The second temporal unit is identified using rules 4 or 5 to determine the next trail in the chronological series, and rules 2 and 3 to assign walls and trails to this series. The process of ordering walls and trails continues by applying these rules iteratively to identify the remaining walls and trails that were there during successive intervals. This process continues until all the walls and trails are assigned to chronological units within the series.

The explicit definition of the rules is a necessary step to assure consistency in chronology building. This method was developed to apply to a large number of walls and trails representing an unknown number of construction phases. When the rules are applied, the walls and trails in any given area can only be ordered into one sequence. Of course given the necessary information it is always possible to split the sequence into a greater number of more fine-grained temporal units.

This methodology has several commonalities with the famous Harris Matrix designed for identifying and ordering the human and natural actions that contribute to the creation of sites [14]. The Harris Matrix itself is based on the simple geomorphologic principals of deposition, defined as an additive process leaving behind cumulating sediment, and erosion, a process that subtracts what has cumulated often only visible as an interface surface between layers. In the relative chronology, the construction of field walls is treated as deposition since walls are always being added to the landscape. When trails are built, they are conceptually seen as episodes of erosion that remove small portions of all existing walls along their course. In the case of the fields, where a trail has cut across a set of walls an interface of a sort is left behind allowing us to order it in time.

4. The relative chronology of area A

Based on the method just presented the 167 walls and eight trails in Area A were sorted into four construction phases. The earliest interval of development included 22 walls and two trails (Fig. 5A). Walls are assigned to this unit because they either cross trail number 7 (the trail with the highest ratio of wall abutments to intersections), or they abut trails 8 and 3. Temporal Unit (TU) 2 developments included two additional trails, one of which was trail 7 which corresponds to the *ahupuaʻa* boundary between Kahua 1 (to the south) and Pahinahina (to the north) (Fig. 5B). This boundary is depicted on contemporary USGS topographic maps. It also defines a boundary that has significance for the construction of agricultural field border walls. Once this trail is established agricultural development was independent on either side of this boundary with no new walls constructed across the *ahupuaʻa* boundary. North of the Kahua 1–Pahinahina *ahupuaʻa* boundary (trail 7), in the *ahupuaʻa* of Pahinahina, we cannot model developments in any great detail because very little of this *ahupuaʻa* has been surveyed. Construction in Pahinahina during the second temporal unit is lumped into a single interval in which 35 walls were constructed (see Fig. 5B). In Kahua 1 during the second temporal unit 16 walls and an additional trail (trail 2) were constructed (see Fig. 5B). Construction in Kahua 1 during the third interval included an additional 27 walls and two trails (trails 1 and 5) (Fig. 5C). The final phase of construction

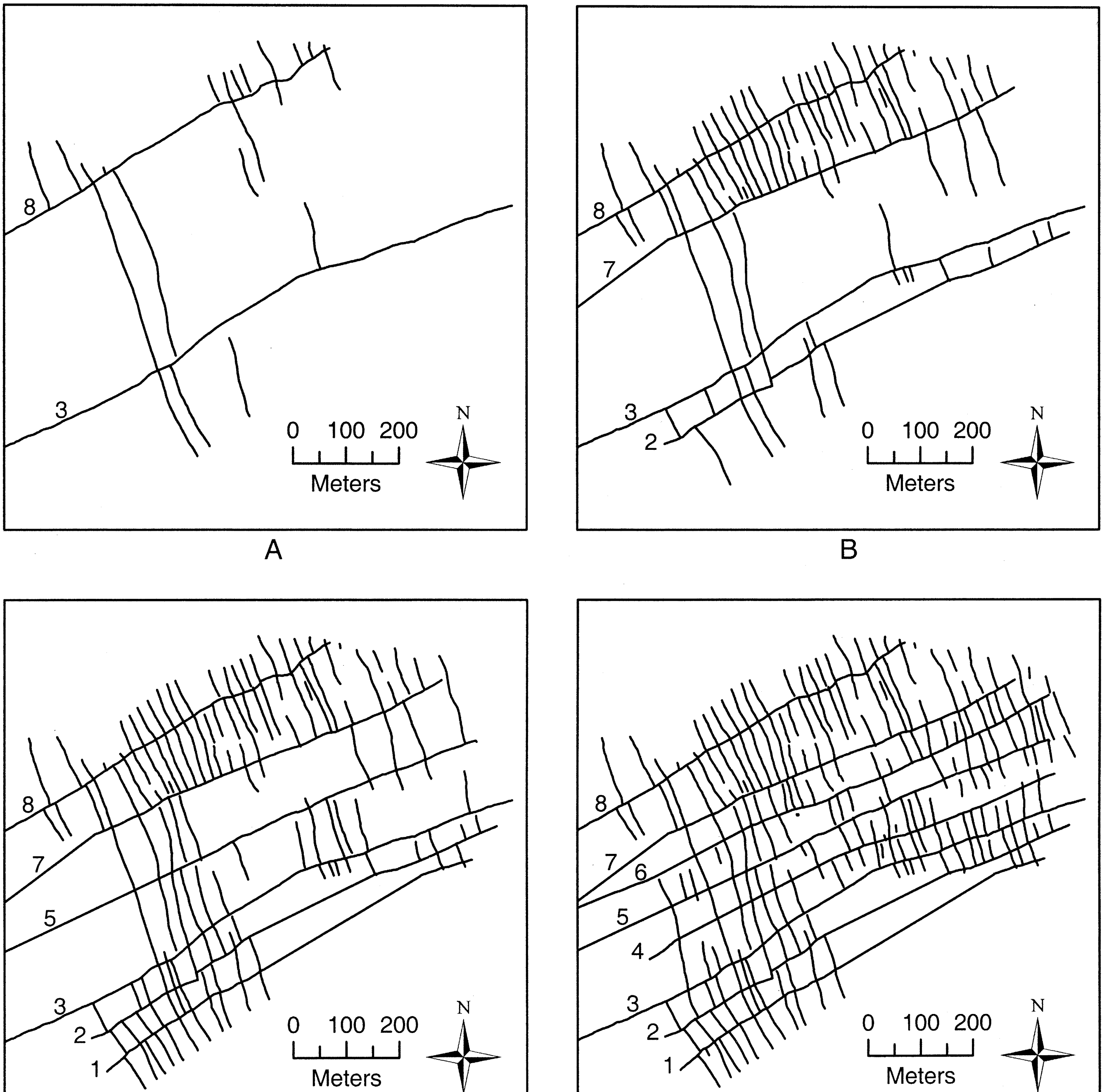

Fig. 5. (A) The walls and trails assigned to the first temporal unit in Area A. (B) The walls and trails assigned to the first and second temporal units in Area A. (C) The walls and trails assigned to the first, second, and third temporal units in Area A. (D) The walls and trails assigned to the first, second, third, and fourth temporal units in Area A.

in Kahua 1 included the addition of 64 walls and two trails (trails 4 and 6) (Fig. 5D). The construction of walls in this final phase occurs mainly between adjacent trails, and therefore many of the walls tend to be rather short.

5. The relative chronology of area B

In area B, the 74 walls and seven trails were divided into four construction intervals. In TU 1 a total of nine

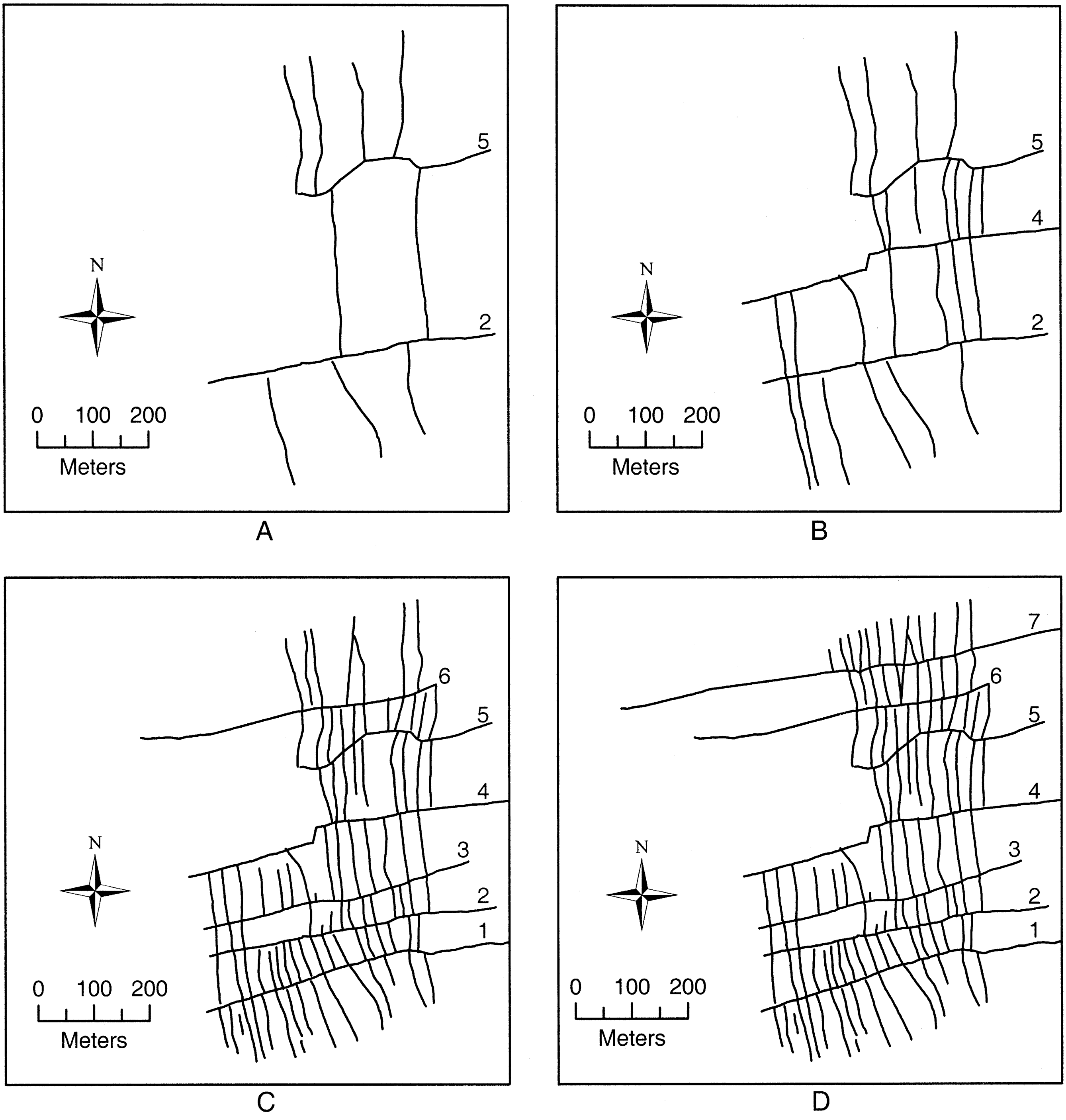

Fig. 6. (A) The walls and trails assigned to the first temporal unit in Area B. (B) The walls and trails assigned to the first and second temporal units in Area B. (C) The walls and trails assigned to the first, second, and third temporal units in Area B. (D) The walls and trails assigned to the first, second, third, and fourth temporal units in Area B.

walls and two trails were built (Fig. 6A). In the second interval an *ahupua'a* boundary trail, trail number 4, separating Kehena 1 and Kaupalaoa *ahupua'a* was created (Fig. 6B). With the construction of trail 4, construction sequences become independent in the north and south of Area B (that is no additional walls were constructed that cross trail 4). To the south, in the *ahupua'a* of Kehena 1, five walls were constructed during TU 2, and in the north in Kaupalaoa, an additional five walls were constructed (see Fig. 6B). In TU 3, two trails and 35 walls were built in Kehena 1 (Fig. 6C). During the same temporal unit in the area to the north of trail 4, in the *ahupua'a* of Kaupalaoa and Makeanehu, one trail and 10 walls were constructed (see Fig. 6C). The final interval, TU 4, in the north of Area B included the construction of 10 additional walls and trail 7 (Fig. 6D). This trail defines the second *ahupua'a* boundary in Area B, marking the border between Kaupalaoa and Makeanehu.

6. The relative chronology of area C

Kirch [18] originally identified a three-phase chronology of agricultural development in a portion of Lapakahi *ahupua'a*, or what we refer to as Area C. His approach was implicit, but by applying the five rules described here, we are able to replicate his sequence almost exactly. During the first interval, 16 walls and two trails were constructed (Fig. 7A). An additional 40 walls and one trail were built during the second interval (Fig. 7B) and another 40 walls and four more trails were constructed during the final unit (Fig. 7C).

7. Expansion and intensification of the Kohala field system

Some general comparisons can be made between the relative chronologies of agricultural development in each study area. Keep in mind that these three relative chronologies may not be absolutely contemporaneous across temporal intervals. In what follows, we focus on the *ahupua'a* in each study area which has produced the largest spatial sample and therefore the chronologies with the greatest precision, that is in Kahua 1 in Area A, in Kaupalaoa and Makeanehu in Area B, and in the single section of Lapakahi in Area C. Agricultural development in these three areas included the processes of expansion and intensification. We describe these processes with two measures. Our measure of the level of agricultural expansion is the area bound within plots at any one temporal interval expressed as a percentage of the final total area covered by the plots. To model the process of expansion, we consider how the spatial scale of fixed plot agricultural land has changed over time. We measure the level of agricultural intensity by calculating the percentage of the total length of walls constructed within each temporal unit. We track the process of intensification by considering how the level of agricultural intensity varies over time. Intensification is documented when increases in the levels of intensity outpace, or are greater, than increases in the relative scale of expansion. In this case, greater amounts of labor were expended on wall construction in relation to the increase in the area under cultivation. This increase in labor per area of land (e.g. agricultural intensification via wall construction) would have increased productivity by reducing evaporation and increasing the quantity and quality of cultigens that could have been grown. Together, these measures of expansion and intensification allow us to examine historical developments in the field system.

The history of expansion and intensification in Area C is shown in Fig. 8 . This is the northern-most section of the field system included in this analysis and the one closest to the coast. At Lapakahi the level of expansion was relatively high during the first interval with agricultural walls distributed across about 90% of the total cultivated area; subsequent intervals involved only small increases in the expansion of area. In comparison, the level of agricultural intensity during the first interval was relatively low (about 30% of the walls were constructed in TU 1). It also shows a convex growth curve demonstrating that the increase in intensification from TU 1 to TU 2 was greater than the increase from TU 2 to TU 3. In Area B, located in the middle of the field system, the level of expansion was also relatively high during TU 1 with walls located in about 80% of the land; subsequent intervals involved only small increases in area (Fig. 9). The level of agricultural intensity in Area B increased in a more linear fashion than Area C. There was a relatively low rate of intensification between TU 1 and TU 2. The greatest increase in intensification occurred between TU 2 and TU 3. In Area A, which is located farthest inland in the south, a very different pattern of agricultural development was observed (Fig. 10). In this area there is a close correlation between the processes of expansion and intensification over time as is shown by the near match between the cumulative distributions of plot area and total length of walls across all four temporal intervals. The level of initial expansion was slow followed by increased levels of expansion and agricultural intensity in TU 2 to TU 3, and from TU 3 to TU 4. Intensification is represented by a concave growth curve showing that the level of agricultural intensity increased most in the last interval of development, although effort scarcely outpaced expansion.

8. Discussion

The identification of at least two different pathways of dry land agricultural development in North Kohala allows us to consider the complexities of subsistence change and the processes of expansion and intensification. In each of the field boundary construction sequences for Areas B and C we documented an early (80–90% of the area by TU 1) more rapid expansion of field plots followed by an intensification of effort. Effort, as measured by the percentage of walls built in each temporal unit, was approximately the same (ca. 30% in TU 1 across the three localities). In Area C the largest increase in the level of agricultural intensity occurred early between TU 1 and TU 2, and it declines thereafter. In Area B the level of agricultural intensity increased in a more uniform manner across temporal units but at a more rapid rate than the increase in total area. In Area

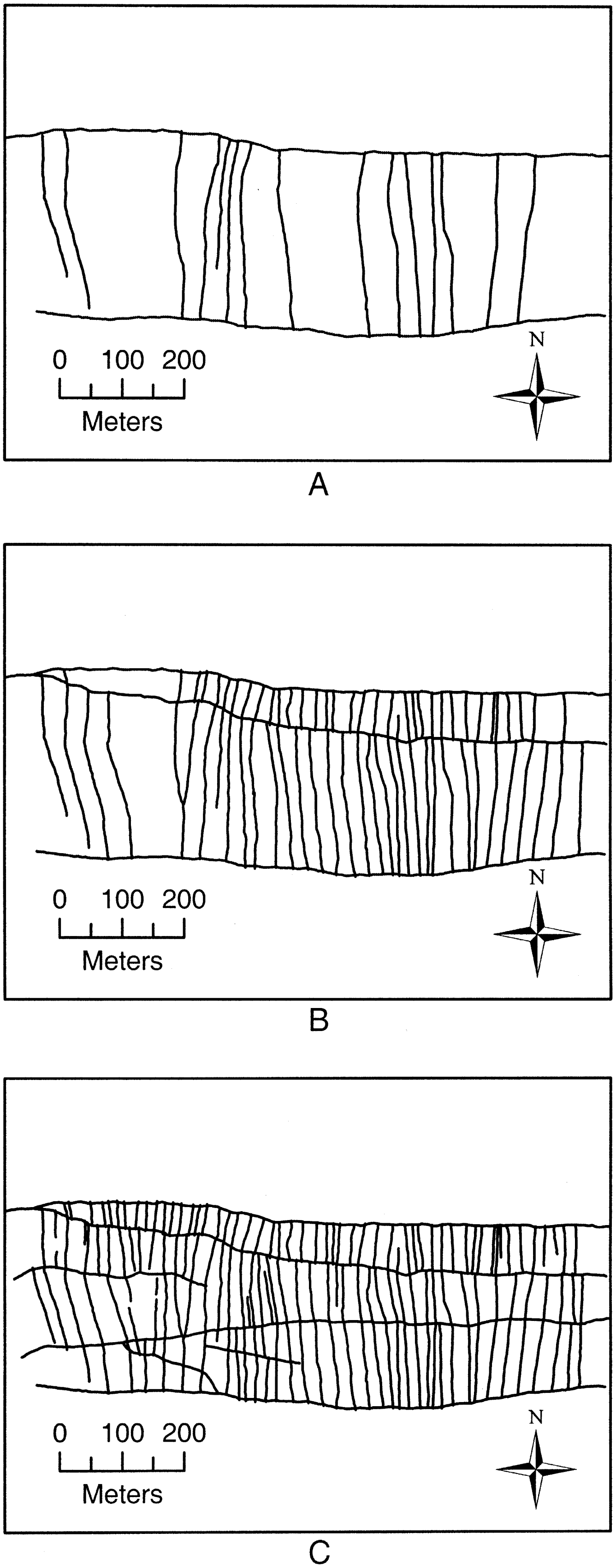

Fig. 7. (A) The walls and trails assigned to the first temporal unit in Area C. (B) The walls and trails assigned to the first and second temporal units in Area C (original data for Area C derived from Kirch [18]. (C) The walls and trails assigned to the first, second, and third temporal units in Area C.

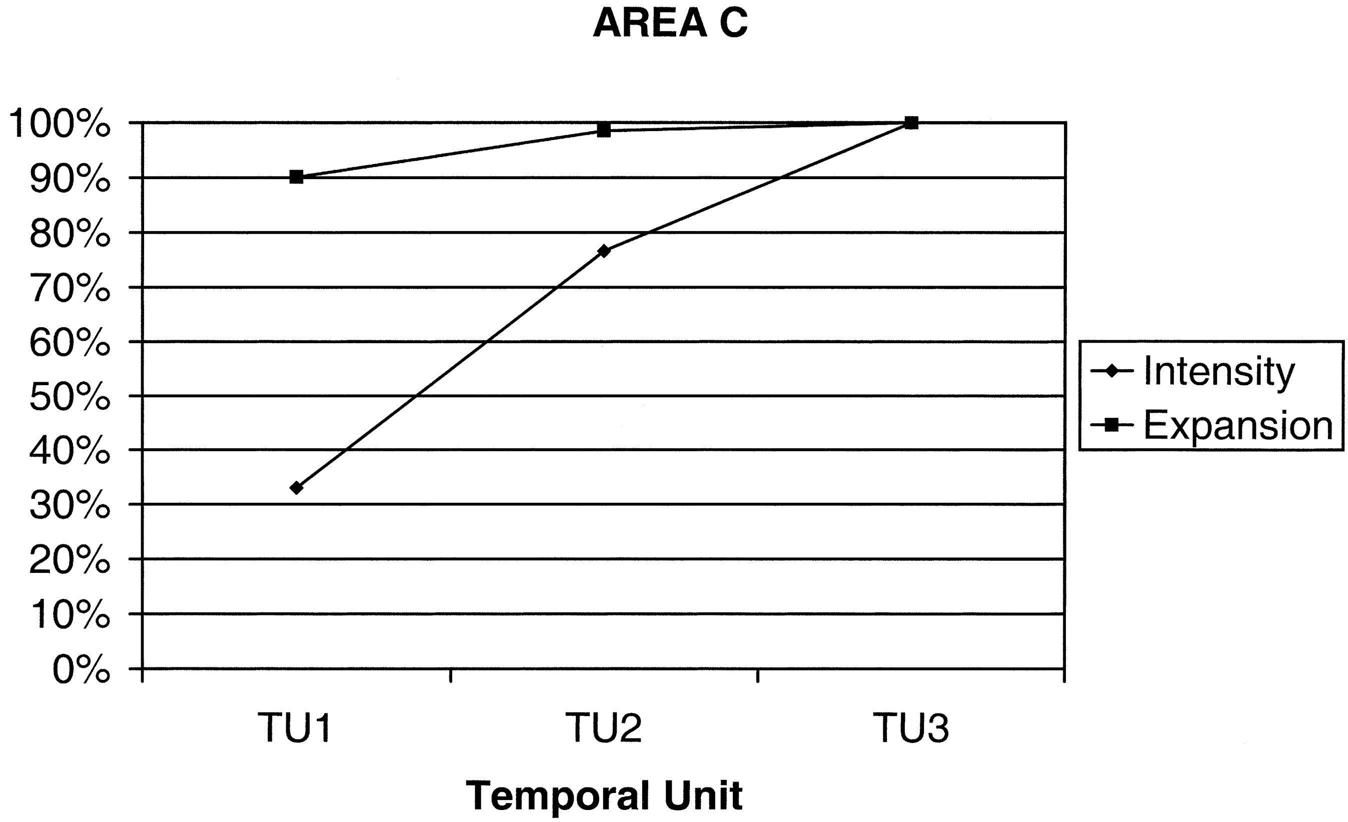

Fig. 8. The relative amount of agricultural expansion and intensity levels across three temporal units in Area C. Note that expansion precedes increases in intensification.

A, agricultural development occurred in an altogether different manner with the processes of expansion and intensification being more closely synchronized in time. This is shown by the nearly identical values and slopes between points for both measures: percentage of area in plots and percentage of total length of walls constructed. Effort, as measured by the proportion of wall length constructed in a temporal unit, actually is less during the early portion of the sequence in Area A. In this area, the largest increase in effort occurred late in the sequence, that is, between TU 3 and TU 4. We conclude that agricultural development in Area A consists of expansion at a relatively high and constant level of effort to agricultural area, and hence, did not undergo significant amounts of intensification of dry land agriculture.

Our analysis does not enable us to link together the relative chronologies from the different areas. It is possible, although unlikely, that TU 1 through 4 in Area A correspond in absolute time to a single temporal unit or a limited part of the sequence from the two other study areas. Having noted that, archaeological evidence from along the Kohala coast does suggest that the developments in Areas B and C began earlier (ca. AD 1400–1500) and occurred over a longer period of time (300–400 years) than the developments in Area A where permanent occupation along the coast may not have occurred until ca. AD 1600 [12,30,31].

The pattern of agricultural change that we have described here for Areas A, B, and C is fairly congruent with our [21] previous and less accurate effort to order agricultural walls across much of the Kohala Field System based on overall wall length. Lapakahi (Area C) was characterized by relatively early and rapid expansion and intensification using both methods. The Makeanehu and Kaupalaoa localities (in Area B) were somewhat less rapidly developed and intensification was greatest toward the middle to the end of the sequence. For Kahua 1 (in Area A), we now have a chronology based on the relations of walls and trails that can be partitioned into four temporal units, a feature we were unable to produce previously. However, as we [21] first noted based on the distribution of wall length, agricultural development in Kahua 1 was primarily a function of expansion, not intensification. Here we are able to show how expansion in Kahua 1 did occur over some interval of time.

In the future, the method developed here will be assessed with other independent data. However, for the moment our analysis supports the proposition that the process of agricultural expansion can be distinguished from intensification in the development of dry land

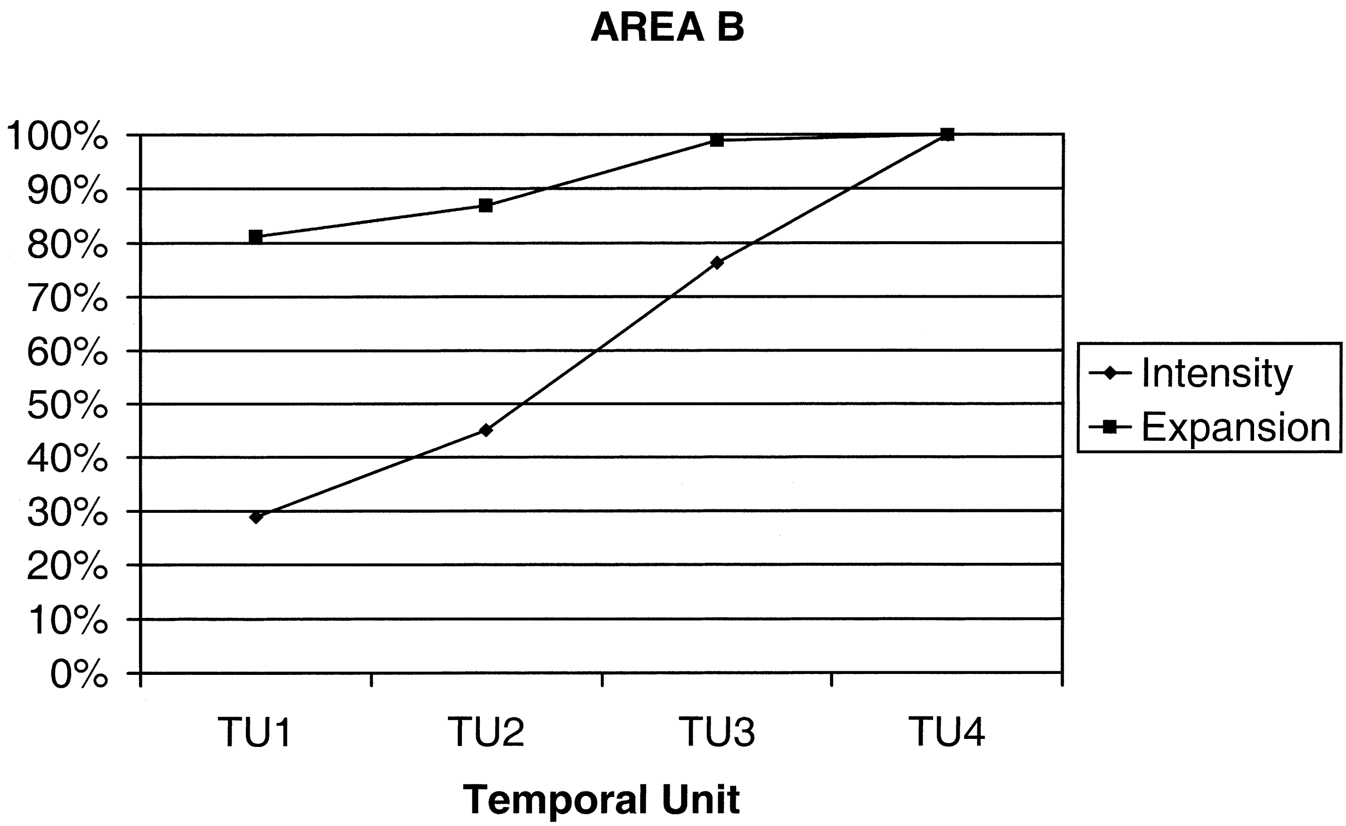

Fig. 9. The relative amount of agricultural expansion and intensity levels across four temporal units in Area B. Note that expansion precedes increases in intensification.

agriculture, even in the absence of stratigraphic evidence. We would, however, encourage other archaeologists to develop their evidence relative to the important analytical and substantive issues raised by Leach [24]. The demonstration of temporal differences is a necessary component of intensification, and while the appearance of a remnant agricultural system such as the Kohala Field System can look superficially similar throughout different sections, this may well disguise spatial variation in the processes of expansion and intensification.

Ladefoged and Graves [21] have outlined some of the evidence for, and evolutionary reasons why, agricultural development might have occurred relatively early in Area C and relatively late in Area A. We suggest that early in the sequence people constructed their fields closer to the coast whereas during the late prehistory people were compelled by their chiefs to develop a whole new section of the field system in the previously unoccupied southern zone that is located farther inland from the coastline. Our evidence regarding intensification in Areas B and C is consistent with this interpretation. Also, the evidence for expansion at a relatively high, constant level of labor in Area A would be expected if these fields were primarily under the control of chiefs and not local households. We [21] have concluded that through time a shift occurred from energy optimization to an emphasis on stability and buffering resource productivity. The analysis of the GPS data is consistent with our earlier work and shows that it is possible to document expansion and intensification both within and across traditional Hawaiian communities. Our results support the notion that there were differential paths of agricultural and community development, even in those areas dependant on dry land agriculture. These pathways are the result of the complex, dynamic, interplay between the natural and social environments in which different groups found themselves.

9. Conclusions

Our analysis has documented a subsistence change in the Kohala Field System from reliance on a relatively low-density expansive agricultural productive system to use of an increasingly intensified one. We were able to accomplish this because the relevant high quality data for documenting this subsistence change includes a large sample of agricultural walls and trails distributed over a sizeable area. We have further established a functional link between the contour walls and embankments and agricultural production. These walls, constructed along the contour of the land and distributed in a series down slope, disrupt the flow of wind within a few meters of the

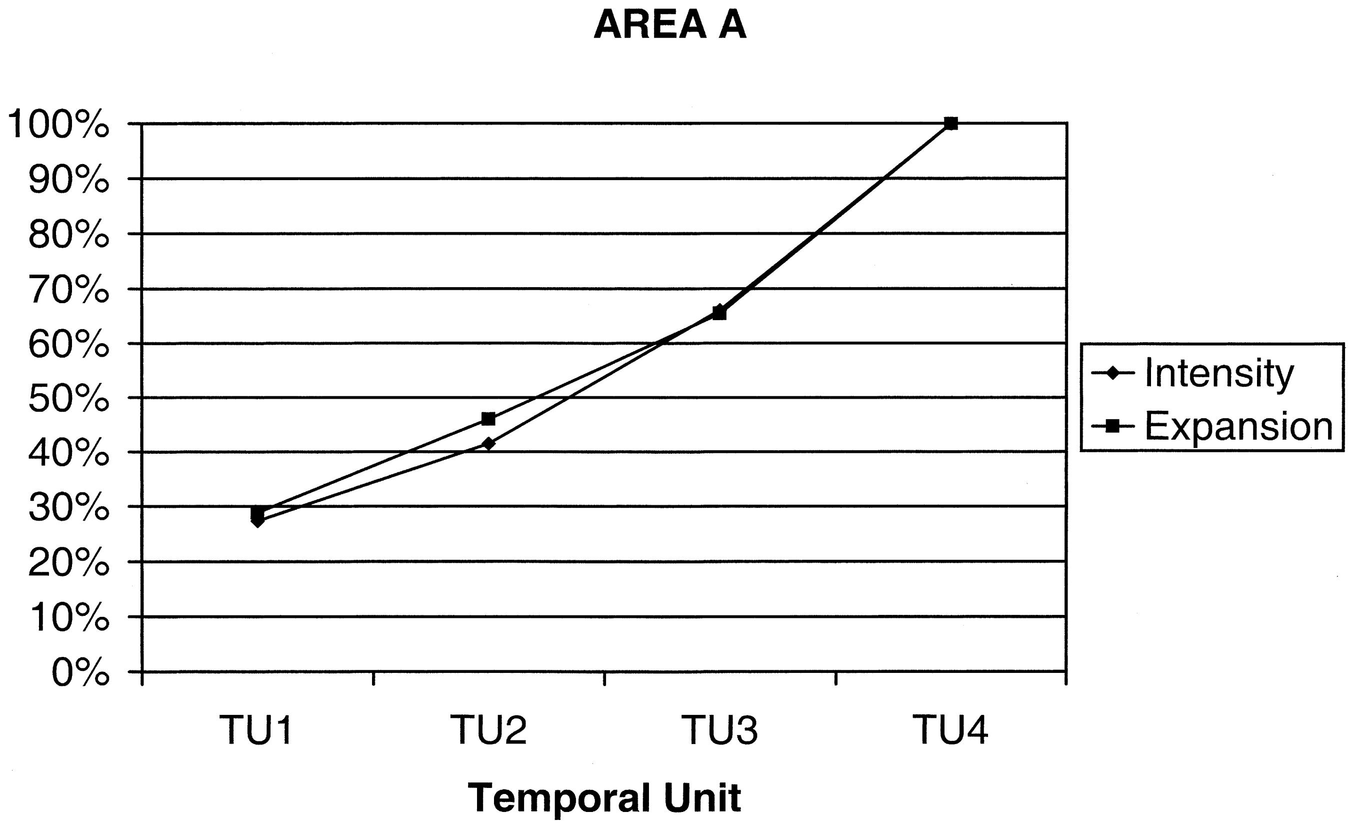

Fig. 10. The relative amount of agricultural expansion and intensity levels across four temporal units in Area A. Agricultural expansion and intensity levels are matched across temporal units.

ground surface and thus reduce the rate of evapotranspiration and erosion, and increase the availability of moisture for crop production. While the Kohala Field System has not been preserved in its entirety, the sections we have selected for study here are comparably preserved and were mapped at the same scale. Thus these walls are an excellent measure of dry land agriculture in this part of Hawai'i.

The large geographic and environmental extent and good preservation of the substantial number of walls and trails associated with the Kohala Field System makes it ideal for examining spatial variability in subsistence practices (see Ladefoged et al., [22] for a consideration of the geographic distribution of constraints for agriculture in the area). Here, we have been concerned with distinguishing spatial variation from temporal variation in dry land agricultural practices over relatively large areas. Our ability to establish change is based on identifying fine-grained relationships between trails and walls. These two architectural features can either intersect one another or, in the context of the Kohala Field System, walls can abut or end at trails (the reverse, i.e. trails ending at walls, was never noted). The explicit definition of five rules enabled us to order the walls and trails in three different localities into separate and unique chronological sequences. Given these rules, there is only one possible sequence for an area. The resolution of individual wall and trail construction phases within the sequences is, in some instances, relatively coarse. Given the likely duration of the fixed fields in Kohala—approximately 400–500 years maximum—for Areas B and C, we suspect our temporal units average ca. 100–125 years. For Area A associated with a much shorter duration of expansion, on the order of 200 to 300 years, the temporal units would average less than 100 years duration.

Comparing the sequences from the three sample areas in the field system documented two qualitatively different modes of agricultural development. In the first, agricultural expansion, that is colonization of new land for fixed field agriculture—took place before subsequent intensification. The proportion of the total area into which dry land agriculture expanded into for Areas B and C was more than double the proportion of the total length of walls constructed during the initial construction phase. In the following temporal units this was reversed with the addition of new walls outpacing new land by a factor of two or more to one. Intensification occurred more rapidly in Area C than in Area B—much of the increase in total wall length occurs in the middle temporal unit in Area C, and in the penultimate temporal unit in Area B.

The second pattern of agricultural development, in Area A, was characterized by agricultural expansion and effort occurring at a relatively similar rate of change over the duration of time represented in this relative chronology. Thus, while intensification did not occur, clearly there was agricultural change in the form of geographic expansion at a relatively constant rate of effort. On other evidence, we suspect this change—expansion of dry land farming into a new zone—occurred over a shorter absolute duration than is represented by Areas B and C.

Not only do these data and the relative ordering method we have devised enable us to distinguish spatial variability from temporal variability in agricultural development, we can place these changes within the context of other environmental differences. Less rainfall, potentially poorer soils, greater distances between upland fields and coastal settlements delayed the expansion of dry land farming in the southern-most portion of the Kohala Field System, that is, in Area A. And when expansion occurred, the labor devoted to agriculture remained fairly constant—likely because initial infrastructural investment was relatively great (i.e. comparable to that found in Areas B and C). Thus, there was limited capacity to accommodate even more intensive farming by further partitioning fields. North of this, in Areas B and C, where rainfall is more abundant and predictable and soils are perhaps more fertile, agricultural expansion occurred earlier and covered a larger proportion of the arable land. The construction of additional walls and the subdivision of existing fields within the zone of arable land—our measure of intensification—were accomplished next with perhaps Area C approaching its limit of labor inputs somewhat before Area B.

Prehistoric subsistence change in Remote Oceania usually involved quantitative shifts in the number, kind, and ranking of food resources, and the amount of effort associated with their utilization or management. The differential emphasis on expansion and increase in effort for dry land prehistoric agriculture in Hawai‘i is a good and probably representative example of the patterning of changes archaeologists working in Oceania may be able to document. Fundamental shifts in subsistence activities were relatively rare. Archaeologists must therefore focus on the relevance and quality of their data when documenting subsistence practices occasioned by more subtle but still significant temporal shifts within spatially heterogeneous island environments.

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