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– ARTICLE –

Location, Location, Location: A viewshed analysis of *heiau* spatial and temporal relationships in leeward Kohala, Hawai'i

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ABSTRACT

Late pre-European contact Hawaiian society was agriculturally based with visible religious structures acting to legitimise and reinforce elite control and management of subsistence and surplus production. The dynamic materialization of elite management of agricultural production has been documented in the leeward Kohala field system (LKFS) by analysing the spatial distribution of agricultural alignments, trails, and the division and realignment of traditional community-based land units (*ahupua'a*). Additional studies have documented the spatial expressions and significance of religious structures (*heiau*) in relation to these land-units. In this analysis we build on these previous studies by investigating the inter-visibility of *heiau*. We document shifts in the construction of *heiau* whereby decreases in the number of structures through time led to a concomitant increase in size and total viewshed breadth. Newly constructed *heiau* were built to command large viewsheds while taking into account the location and views of pre-existing religious features. These changing patterns reflect ideological shifts and the materialization of production management instrumental in chiefly and religious control.

Keywords: Hawai'i, *ahupua'a*, *heiau,* viewshed, GIS, LiDAR

INTRODUCTION

The Hawaiian archipelago presents a unique opportunity for archaeologists to study religious authority, social cohesion and chiefly-regulated economies in one of the most isolated and diverse environments of the Pacific Islands (Kolb 1992, 1994b; Kirch 2010; Hommon 2013; McCoy 2014). Between first settlement and European contact people living in the islands developed complex managerial systems set within highly constrained political economies (Earle 2000). These developments were expressed not only in intensified agricultural practices and the associated division of increasingly territorial land units (Ladefoged & Graves 2006), but also in the construction of an array of religious structures, including a range of temples (*heiau*) (McCoy 2014).

The development of intensified fixed-field dryland agriculture began in the fifteenth century and continued into the early historic era (Ladefoged *et al.* 2008). A complex religious system–which was materialized in *heiau* or temples–manifested itself concurrently with intensive agricultural development and provided a practical avenue for negotiating social inequalities and legitimising group interests (Kolb 1994a). Many religious structures are documented in the leeward Kohala field system (LKFS) (Figure 1) and their spatial and temporal distribution studied in detail (Mulrooney & Ladefoged 2005; McCoy *et al.* 2011; McCoy *et al.* 2012). Building on the seriation of *heiau* initially developed by Mulrooney & Ladefoged (2005) and later revised by McCoy *et al.* (2011), we explore the spatial interrelationships of *heiau* and changing territorial boundaries via a GIS-based viewshed analysis with airborne LiDAR (light detection and ranging). We note how visibility from *heiau* reflects the materialization of changing socio-political relations in the pre-contact chiefdoms of leeward Kohala.

Hawaiian religious features and territorial units

Heiau are places of religious significance that were often

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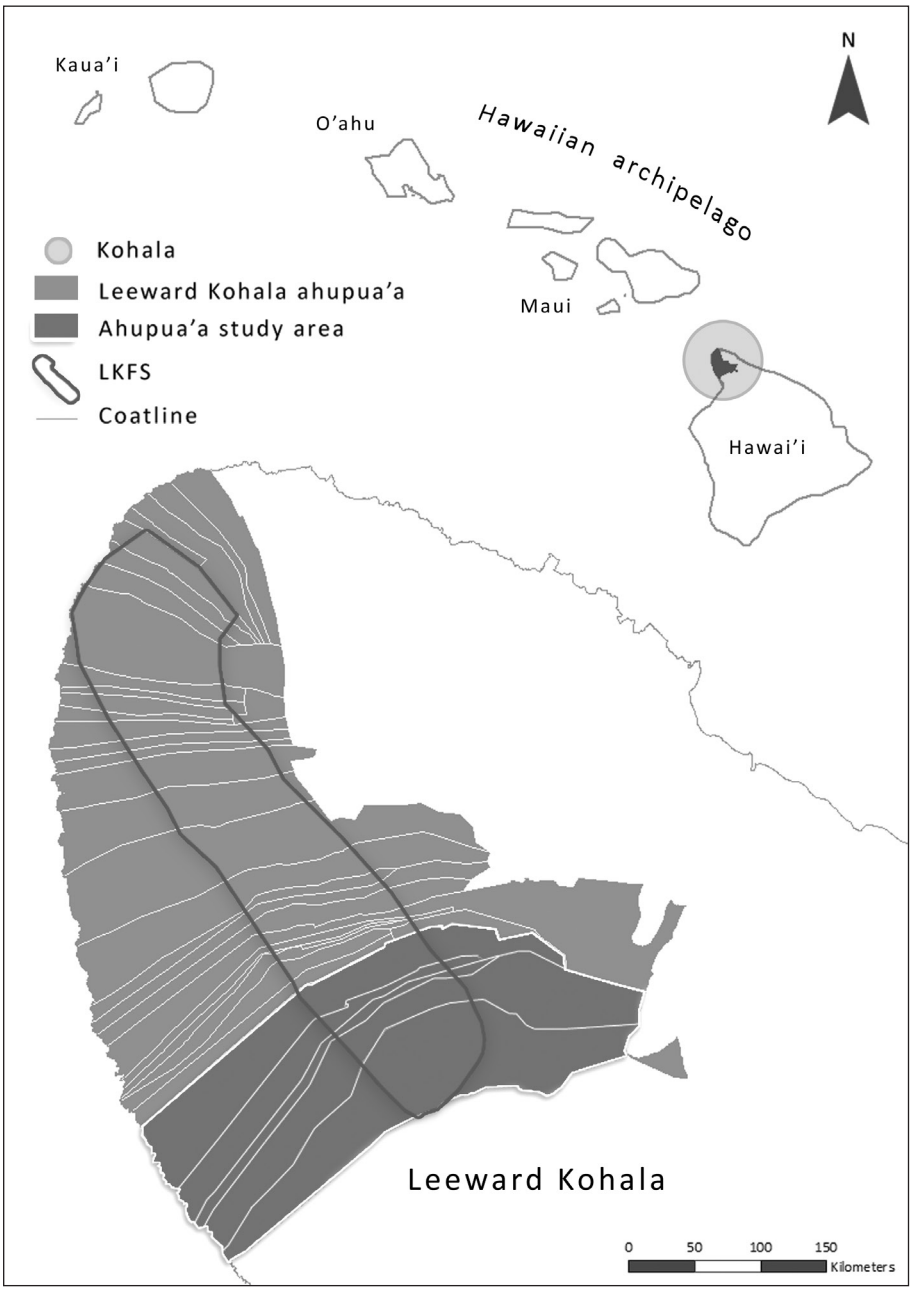

Figure 1. Hawaiian archipelago showing the location of Leeward Kohala (LK) together with a detail of the LK Field System (LKFS) extending across recorded *ahupua'a* boundary zones. The southernmost *ahupua'a* shaded in dark grey indicates the study area considered in this paper.

materialized with the construction of rock foundations, although not all *heiau* have culturally constructed expressions (Valeri 1985f; Cachola-Abad 1996; McCoy 2014). By the 15th century AD, *heiau* were constructed to physically and visually manifest the power of elites (Kolb 1994b, 1994a; Earle 2000; Kolb 2006). Many of these structures were monumental in size and were closely associated with displays of ritualistic activity, whilst a number of smaller temples acted to reinforce and emphasise the omnipresence of chiefly and religious authority throughout social and economic life in Hawaiian society (Valeri 1985; Stokes 1991).

Valeri (1985) defines two discreet types of worship at *heiau.* These correlate with a temple's form and function, providing a heuristic basis for behavioural interpretation of varying patterns in the distribution and size of *heiau* viewsheds. The first type of worship relates to productivity rituals conducted by an array of priests, commoners and chiefs (Mulrooney & Ladefoged 2005). These activities generally occurred at smaller shrines and were concerned with the production of food, the success of agricultural

harvests, the continuation of suitable rains, and the successful yields of fish as well as other collected resources (Valeri 1985; Mulrooney & Ladefoged 2005). These temples were associated with one or more specific gods and were a focus for the collection and redistribution of tribute and food-stuffs intended for the chiefly elite (Valeri 1985). They were generally small enough to accommodate a group of a few dozen people during ceremonial activity, and would have required relatively minimal labour to construct and maintain (McCoy *et al.* 2011). The number and scale of these *heiau* suggests worship at these sites was predominantly concerned with the incorporation of religious ideals into concepts of management and agricultural productivity at the familial level, creating a causative link and legitimization between religion, agriculture and management.

The second category of *heiau* is related to restricted ceremonial activities which were held exclusively by priests and high chiefs (Valeri 1985). These structures, whilst more infrequent, are the most identifiable on the landscape due to their monumental design and conspicuous placement. Valeri (1985) suggests that the primary concern regarding the construction and utilisation of this style of *heiau* was in reinforcing the infallibility of hierarchy and its legitimization through restricted religious practice. Both categories of *heiau* are associated with *ahupua'a*, linking the religious, political, territorial and agricultural aspects of society.

In the LKFS, *ahupua'a* were social and political land divisions integral to the management of production (see Figure 1). Ladefoged *et al.* (2008) demonstrated that in years of average or better rainfall *ahupua'a* had the potential to produce substantial surpluses which exceeded the needs of local populations. These surpluses were in part stored or fed to livestock (see Dye 2014; Ladefoged 2014), but a large proportion would have served as tribute to the elites of Kohala and elsewhere to fund religious and military activities.

LKFS ahupua'a and heiau spatial and temporal patterning

On the basis of the names and spatial relationships between *ahupua'a* boundaries, Ladefoged & Graves (2006) identified a temporal succession for the LKFS in which the *ahupua'a* units documented in the mid-nineteenth century were part of increasingly larger geographic units as one regresses through time (Figure 2). This scheme postu-

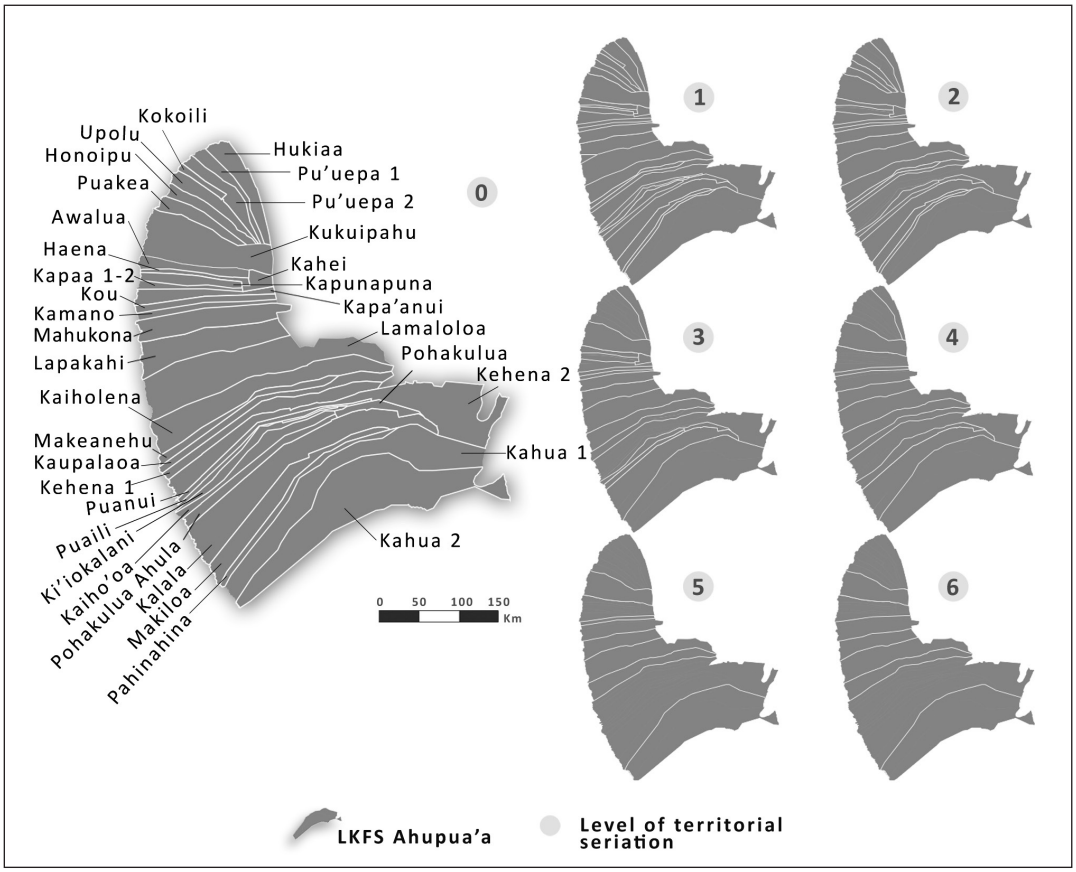

Figure 2. Ladefoged and Graves' (2006) seven levels of LKFS *ahupua'a* division (from youngest to oldest, Levels 0 to 6), based on historical and hierarchical relationships

lates a scenario in which arable land and territories were divided into smaller spatial units as time progressed. Reconstructing *ahupua'a* boundaries with reference to both USGS maps and a GPS survey of archaeologically-delimited walls and trails, a relative chronology of territorial units was deduced from the names, intersections, and overlays of the historically defined *ahupua'a* boundaries (see Ladefoged & Graves 2006 for details). This resulted in the identification of seven Levels (from youngest to oldest, 0–6) of hierarchical and historical *ahupua'a* division (see Figure 2).

According to this scheme, Level five and six represents the earliest stage of *ahupua'a* reorganisation (Figure 2). Partitioning of the oldest territories involved either the division of land with similar boundary orientations or the full bifurcation of land-units to create smaller units, from nine land-parcels during Level six to 11 units at Level five. The following Level three and four divisions consisted of the partial bifurcation of land parcels, followed by the capping and bounding of upslope terrain, with 15 parcels at Level four becoming 19 *ahupua'a* at Level three. Level three is followed by the subsequent cutting-out of sections from within previous territories (Levels two, Figure 2), producing 25 parcels of land. The more recent episodes of *ahupua'a* restructuring are evident from the shared derived names of 29 land-units at Level one subdivision. This practice of community level re-organisation eventually resulted in the creation of 35 *ahupua'a* (Level zero) that were documented in the mid-nineteenth century (Ladefoged & Graves 2006; see Level zero in Figure 2). These changes were linked to increasing population pressures, surplus production within processes of agricultural development, socio-political transformations and increasing managerial control.

Mulrooney & Ladefoged (2005) identified eight community-level *heiau* spatially associated with five *ahupua'a* in the southern LKFS (i.e., Kalala, Makiloa, Pāhinahina, Kahua 1 and Kahua 2) (Figure 3). These *heiau* were located either in the centre or on the border of each related *ahupua'a*. Mulrooney & Ladefoged (2005) performed a seriation analysis, dividing the *heiau* into four stylistic classes and, in conjunction with the territorial dynamics noted by Ladefoged & Graves (2006), defined five temporal phases. The earliest phase involved the construction of three *heiau* from seriation Groups one and two that spatially correlated to Ladefoged & Graves' (2006) Level four land division and the separation of Kalala from the area to

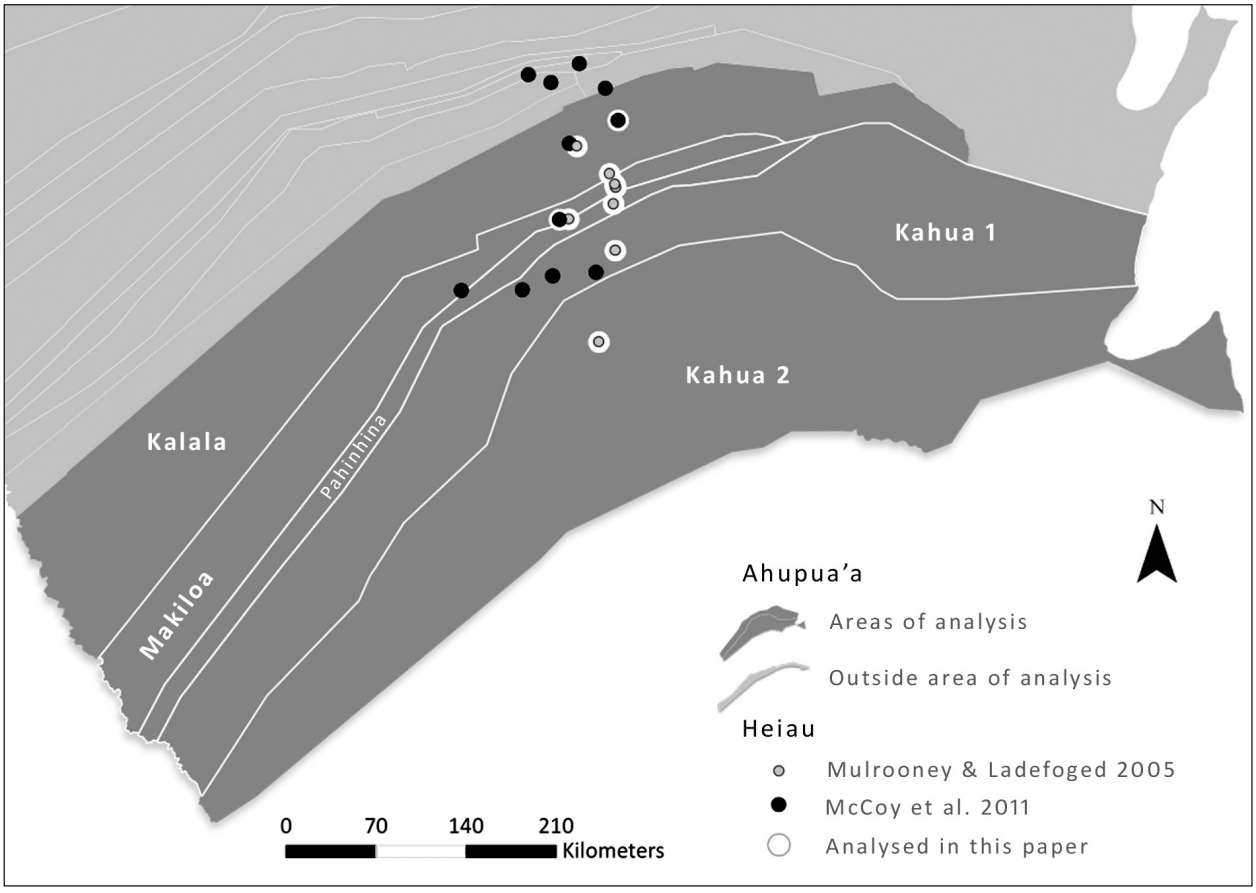

Figure 3. *Heiau* identified by Mulrooney and Ladefoged (2005) and McCoy *et al.* (2011) in the southernmost zone of the LKFS. *Heiau* symbols with white outer ring indicate temples selected for viewshed (VS) analysis in this paper.

the south (consisting of Pāhinahina, Kahua 1 and Kahua 2). The second temporal phase included the construction of *heiau* assigned to seriation Group two that was spatially correlated with the division of Pāhinahina from Kahua. Following this, the third temporal phase involved the construction of a Group three *heiau* that was spatially correlated with the cutting out of Makiloa from Kalala (also part of the Level two land divisions). The fourth phase involved the introduction of another seriation Group three *heiau* spatially correlated with the separation of Kahua 1 and Kahua 2 (Level two). The fifth and most recent phase involved the construction of two Group four *heiau* and spatial in-filling within Makiloa and Kalala. Mulrooney & Ladefoged's (2005) chrono-seriation forms a stylistically-defined temporal framework that directly couples the progressive fragmentation of community-level land-units with their respective *heiau*. This coincidence between the two independent temporal datasets boosts our confidence in the *heiau* seriation and land-division chronology.

Recently, McCoy *et al.* (2011) extended Mulrooney & Ladefoged's (2005) *heiau* analysis by increasing the sample size from eight to nineteen *heiau* across a greater range of *ahupua'a* (see Figure 3). They also refined the temporal framework of *heiau* construction in relation to land-unit organisation with the addition of radiocarbon ages derived from the basal layers of eight *heiau* (McCoy *et al.* 2011: Table 2). Of these, six were sampled from Mulrooney & Ladefoged's (2005) original *heiau* dataset. McCoy *et al.'s* (2011) architectural seriation differed from Mulrooney and Ladefoged in the attributes they considered stylistically and temporally linked. With the addition of basally linked ^{14}C determinations and a slightly different stylistic seriation, McCoy *et al.* (2011) identified four chronologically bound stylistic groups (i.e., Style A to D). While the larger sample set of McCoy *et al.* (2011) produced a more refined temporal framework spanning from AD 1474 to AD 1819, there was limited re-ordering of *heiau* from the original architectural seriation carried-out by Mulrooney & Ladefoged (2005). The reclassification of two *heiau* (the most recent Group four *heiau* [KAL-25 and MKI-122] into the earlier Style B) along with the addition of new *heiau* to the sample mark the only two differences in the seriations of McCoy *et al.* (2011) and Mulrooney & Ladefoged (2005).

While constructing temporal and spatial frameworks for both *heiau* and *ahupua'a* within the LKFS has been a major focus of previous work, the manner in which the religious infrastructure assimilated the increasing visual presence of *heiau* across a steadily segmenting landscape remains to be explored. In the following we investigate the materialization of production management and the intentional construction of religious features in relation to the naturally and socially defined environment. We present an analysis of the spatial and temporal relationships between religious structures and community-level *ahupua'a* via a GIS-based viewshed analysis of *heiau* in the southern portion of the LKFS.

MATERIAL AND METHODS

We analyse the spatial and temporal patterning of ten *heiau* viewsheds. This includes the eight *heiau* originally described by Mulrooney & Ladefoged (2005) with the addition of two *heiau* recorded and described by McCoy *et al.* (2011; Table 1 and Figure 3). Our analysis is limited to the southernmost *ahupua'a* (i.e., Kalala, Makiloa, Pāhinahina, Kahua 1 and Kahua 2, see Figures 1 and 3) of the LKFS, as this is the original area that Mulrooney & Ladefoged (2005) focused on and where we have the most complete data. The southernmost *ahupua'a* differ from other *ahupua'a* in their relatively higher elevations and distance from the coast. These factors were influential in the relatively late agricultural development of the area (see Ladefoged & Graves 2008; Ladefoged *et al.* 2011), and the patterning in *heiau* viewsheds in this area might be dissimilar to that found elsewhere in the LKFS or windward contexts. In our analysis we do not incorporate several additional *heiau* described by McCoy *et al.* (2011) as these were either outside our defined study area (i.e., KOL-1, KOL-2, KHO-1 and PHK-1), or were classified by us as either functionally ambiguous (i.e., KH1-4, KH1-6, KH1-7) or small religious features (MKI-130, KAL-27) functionally distinct from the community *heiau* that form the analysed dataset.

Of the ten *heiau* selected for analysis, eight have ^{14}C ages associated with their basal layer that pre-date the construction of each overlying *heiau* by a short time (McCoy *et al.* 2011; Table 1). The seriation of the *heiau* dataset is based on nine morphological and diagnostic traits originally identified by Graves & Cachola-Abad (1996: 23), modified and used by Mulrooney & Ladefoged (2005), and adapted by McCoy *et al.* (2011). Such architectural traits include the presence of a platform, upright stones, a terrace, and/or notching (Table 1). McCoy *et al.'s* (2011) analysis resulted in the creation of four temple classes which were subsequently labelled in temporal order from A–D (see Table 1). We analyse the viewsheds of *heiau* within this temporal framework, both in relation to the dynamic fragmentation of resident and adjacent *ahupua'a*, and the community-level reorganisation that this implies. A diachronic assessment is carried out of the degree of visual impact that each temple structure and stylistic unit asserts on the surrounding landscape, and how this potentially influenced the placement of their construction, their continued use, and possible remodelling over time.

Viewshed analyses are employed in studies seeking to understand the observers' perspective both from and of the archaeological structure in relation to the wider landscape. This provides a means of assessing how visual accessibility, prominence and impact influenced past spatial structuring (see Llobera 2001, 2003, 2011 for reviews). In this paper we use this method for the first time in studies of Hawaiian religion and agriculture to assess the spatially visual interplay between *heiau* and *ahupua'a* and how this changed over time in a shifting territorial and socio-po-

Table 1. *Following McCoy et al.'s (2011) stylistic and temporal seriation, heiau included in this analysis as identified by McCoy et al. (2011) and Mulrooney and Ladefoged (2005) are listed temporally by style, with architectural attributes indicated and alternative ID numbers and temporal associations (see McCoy et al. 2011: Table 2 for details).*

Style	Heiau ID*	Original heiau ID**	Platform	Upright stones	Terrace	Courtyard	Notch	Temporal association*
D	PHH-1	H7			×			post-1680
	KAL-24^				×			post-1680
C	KH2-2^	H2			×	×		post-1647
	MKI-123^	H5		×	×	×	×	post-1647
	KH1-3^	H1		×	×	×	×	post-1647
B	MKI-125^			×	×	×		post-1522
	KAL-25	H4		×	×	×		post-1522
	MKI-124^	H8		×	×	×		post-1522
	MKI-122^	H6		×	×	×		post-1522
A	KAL-26^	H3	×					post-1474

* McCoy *et al*. 2011
** Mulrooney & Ladefoged 2005
^ *Heiau* with basally associated radiocarbon ages (see McCoy *et al*. 2011 for details)

litical system. Individual *heiau* were represented by a single, centrally positioned observer-point, set within a 1.2 m resolution digital elevation model derived from airborne LiDAR (Light Detection and Ranging) data (see Asner *et al.* (2007) and Ladefoged *et al.* (2011) for details of the LiDAR dataset). Each observer point was assessed against surrounding elevations to determine which cells of the processed area were observable from the *heiau* viewpoint (e.g., Figure 4). Here, 'viewshed' is the area of visibility from each *heiau* over the surrounding terrain. The main focus of our analysis is on the visual relationship between religious administration and the restructuring of community level agriculture within the upland field system of leeward Kohala. For this reason, the extent of each viewshed was constrained to a radius of 1 km with a maximum area of 3.14 km². Creating fixed area viewsheds of 3.14 km² enables the quantitative comparison of *heiau* viewsheds and accounts for the varying proximity of *ahupua'a* boundaries from *heiau*. A vertical offset of 3 m was allocated to each *heiau* point to overcome the effects of micro-topography

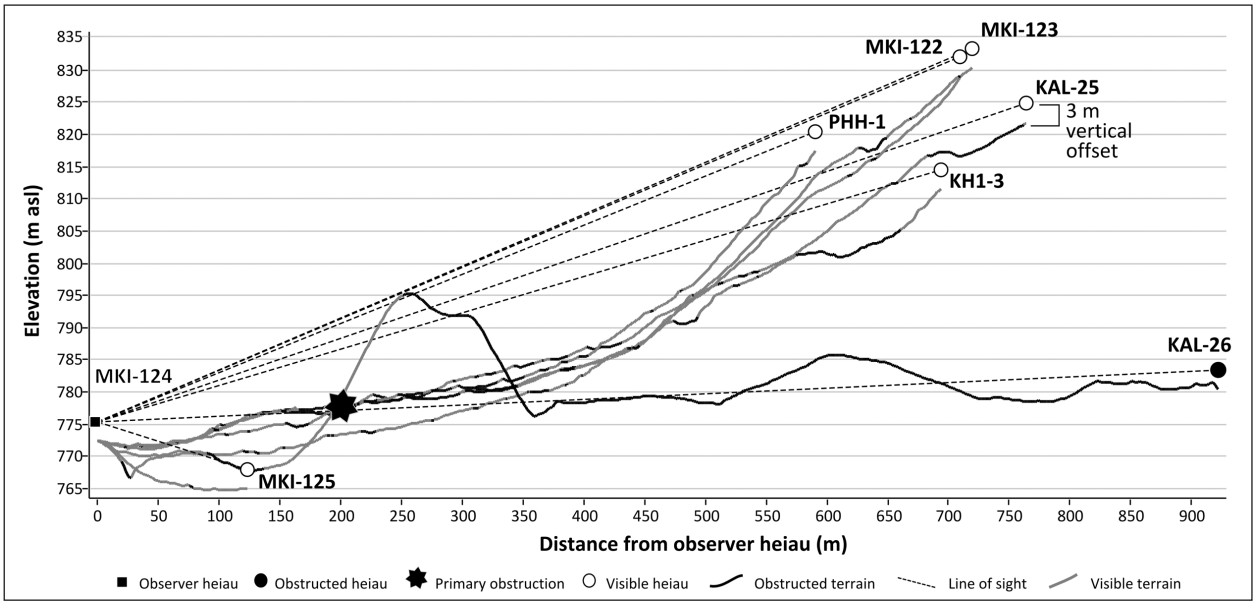

Figure 4. Line-of-sight example showing how oscillating topography using LiDAR. The set height of the archaeological structures under analysis can affect the observable viewshed of *heiau* (MKI-124) and potential inter-visibility between temples depending on their horizontal and vertical positions in the LKFS.

whilst still retaining topographic and geographic integrity. This offset also simulates the possible height of towers or other structures associated with the rock foundations of *heiau*. These measures focus the analysis to a scale that ties the ideological influence of *heiau* to production within territorial units at the community-level of organisation. To determine the inter-visibility between *heiau,* line-of-sight was calculated with observer and target points given vertical offsets of 3 m above ground level, allowing for reciprocal views between *heiau* (see Figure 4). Further to this, visual overlap and in-filling of earlier *heiau* Style groups by subsequent Styles were quantified. Visual overlap was assessed by sequentially dissolving visibility coverages of Styles that precede the group in question as well as dissolving all Style views (including the younger Style under consideration). The sum of the preceding groups and the subsequent Style was subtracted by the dissolved view of all Styles. The resulting value provides the amount of overlapping view between preceding and subsequent Styles for each relevant level of *ahupua'a* division. This overlapping provides an indication of the extent to which *heiau* were constructed to enhance their visual impact on highly productive agricultural land.

Visual in-filling of associated (level specific) *ahupua'a* was determined by calculating the amount of novel terrain in each *ahupua'a* visible to a subsequent Style, not observed by earlier Style groups. This was achieved by subtracting the overlap from the dissolved visual coverage of the most recent Style under assessment.

It is possible that the greatest area of visibility for *heiau* will occupy the structure's local vicinity, and decrease as distance from this origin point increases. This was tested by keeping area constant, while distance from a central position was increased in varying increments. Multiple buffer rings were produced in ArcMap that radiate concentrically from each *heiau* to a maximum radius of one kilometre. Each ring zone is of equal area (0.79 km^2) while the individual rings vary in width as distance increases (i.e., individual bands equal 0–0.5 km, 0.5–0.7 km, 0.7–0.9 km and 0.9–1 km in distance, e.g., Figure 5, Table 2). This

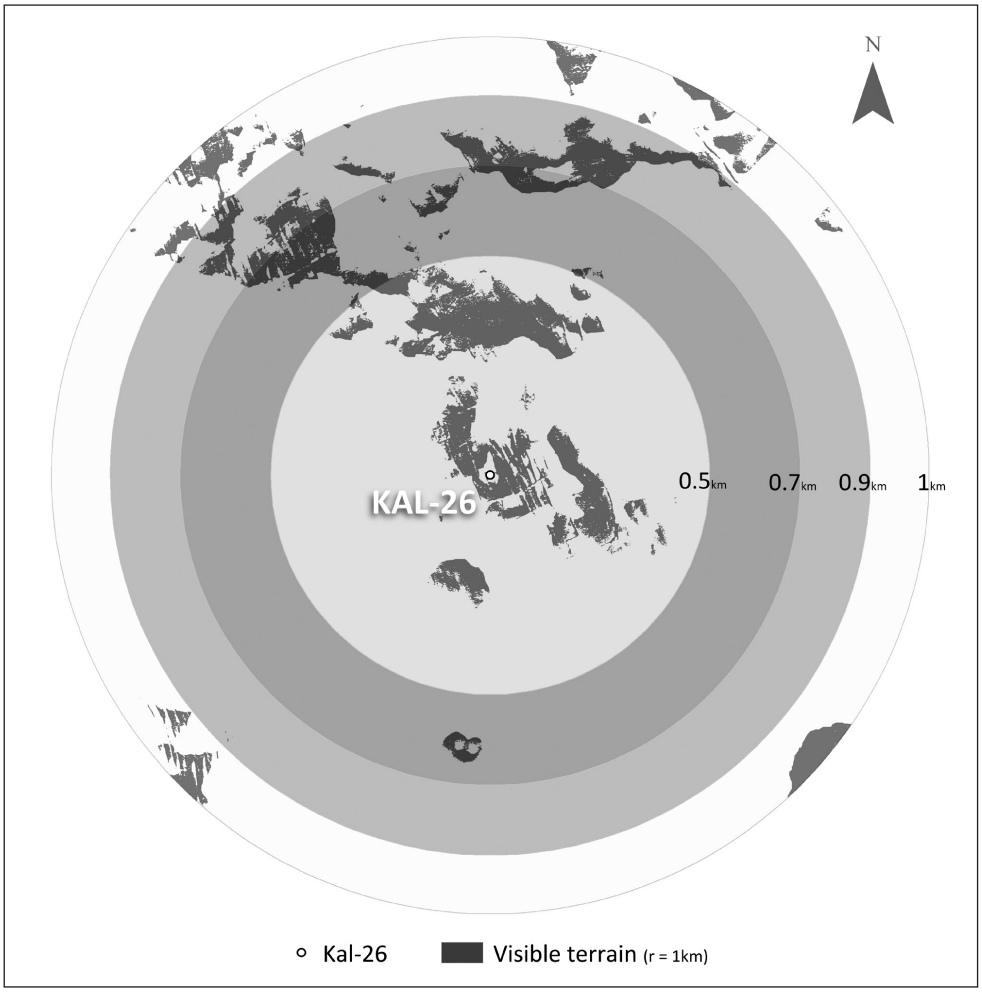

Figure 5. Multiple buffer ring example. Each ring is of equal area (0.8 km^2) and radiates out from the central position of an individual *heiau* (in this case KAL-26, Style A), to a maximum radius of 1 km (i.e., 0.5 km, 0.7 km, 0.9 km, 1 km).

Table 2. *The percentage of visibility attained by each* heiau *across four buffer rings of equivalent area (0.8 km²), incrementing in distance from the centre point (*heiau *location) out (buffer ring 1=0.5 km, 2=0.7 km, 3=0.9 km, 4=1 km).*

Style	Heiau	Buffer rings				Total (%)
		One 0–0.5 km (%)	Two 0.5–0.7 km (%)	Three 0.7–0.9 km (%)	Four 0.9–1.0 km (%)	
A	KAL-26	45	15	21	20	100
B	KAL-25	74	16	7	3	100
	MKI-122	47	26	15	12	100
	MKI-124	31	33	25	12	100
	MKI-125	27	31	27	16	100
C	KH2-2	34	28	20	18	100
	KH1-3	40	26	21	13	100
	MKI-123	48	24	18	10	100
D	PHH-1	50	19	16	15	100
	KAL-24	46	36	11	7	100

provides a means of testing whether the area of attainable viewshed decreases as the distance from each respective *heiau* increases. This also seeks to illustrate whether the variable distribution of *heiau* visibility across *ahupua'a* is simply a reflection of *ahupua'a* size, or the excursive prioritisation of *heiau* visibility into adjacent areas.

RESULTS

The results indicate that the area and distribution of *heiau* visibility between and within style types and across resident and neighbouring *ahupua'a* are highly variable. However, a notable pattern exists between the positioning of *heiau* on the LKFS landscape in relation to *ahupua'a* reorganisation through time.

Heiau viewsheds and cumulative area per heiau Style type

Table 3 shows the area and percentages of visibility individual *heiau* present within their Style groups. The earliest Style group A consists of the smallest number of *heiau* (n=1). *Heiau* KAL-26 yields the second smallest area of visibility (0.24 km²) only after Style B's *heiau* KAL-25 (0.11 km²; Table 3). Further to this, only eight per cent of KAL-26's maximum potential viewshed area (3.14 km²) is realized (Table 4, see also Figure 6). The visual coverage of KAL-26 extends northward with 54 per cent of this falling within the *heiau*'s *ahupua'a* of origin–Kalala–with a similarly large degree of observable terrain (43 per cent) further extending across into the northern *ahupua'a* of Pohakulua (see Table 5 and Figure 6). Given the large size of Kalala at the time of Style A's construction (21.54 km² during Level six land division; see Table 5 and Figure 2) and the relatively restricted extent of KAL-26's view, it would appear that the position of KAL-26 was not intend-

Table 3. *The area (km²) and percentage of visibility from individual* heiau *in each style grouping together with the total area of visibility for each style.*

Style	Heiau	Visible Area (km²)	Total (km²)	Heiau visibility per style (%)
A	KAL-26 (H3)*	0.24	0.24	100
B	KAL-25 (H4)	0.11	1.72	6
	MKI-122 (H6)*	0.44		26
	MKI-125*	0.73		43
	MKI-124 (H8)*	0.44		25
C	MKI-123 (H5)*	0.44	1.48	30
	KH1-3 (H1)*	0.59		40
	KH2-2 (H2)*	0.45		30
D	KAL-24*	0.83	1.36	61
	PHH-1 (H7)	0.53		39

Table 4. *Percentage of* heiau *visibility that exists within each of their maximum VS areas (3.14 km², radius = 1 km).*

Style	Heiau	Area of visibility (km²)	Percentage of visible VS area (%)
A	KAL-26	0.24	8
B	KAL-25	0.11	3
	MKI-122	0.44	14
	MKI-125	0.73	23
	MKI-124	0.44	14
C	MKI-123	0.44	14
	KH1-3	0.59	19
	KH2-2	0.45	14
D	KAL-24	0.83	26
	PHH-1	0.53	17

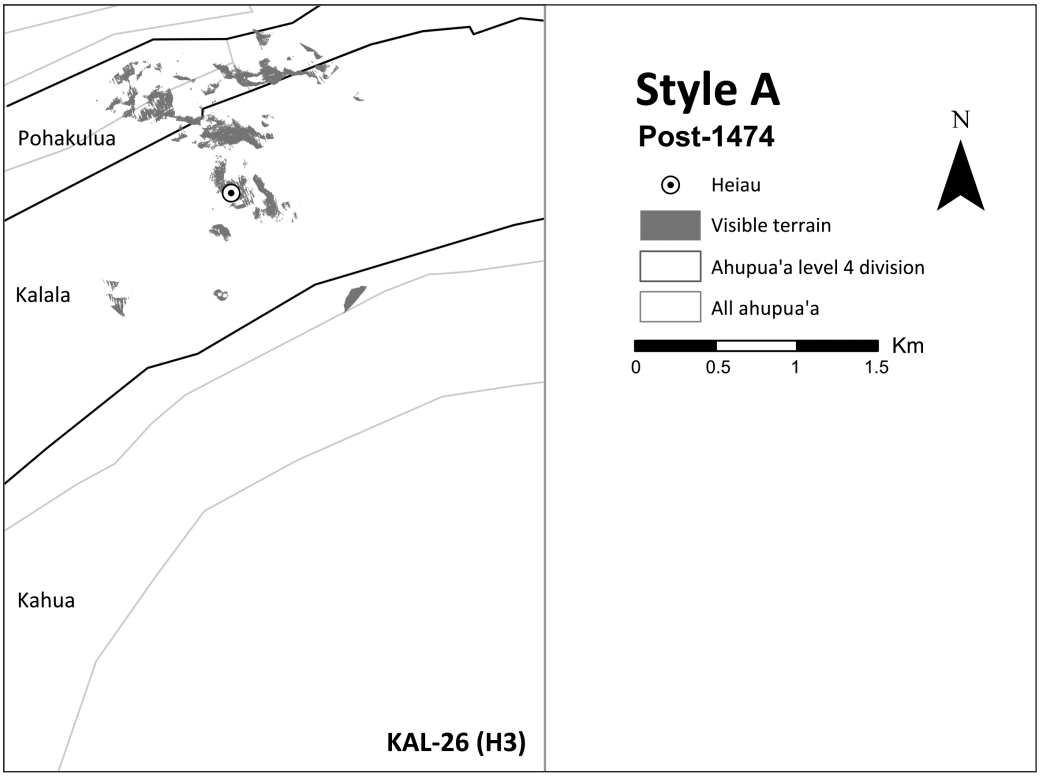

Figure 6. Style A visibility depicted against the earliest stage of *ahupua'a* organization (Level 4).

ed to maximise coverage south of Kalala, but the focus was northward, with Style A's view limited to within the local boundaries of Kalala and the immediately adjacent northern *ahupua'a* of Pohakulua Ahula (see Figure 6 and Table 5).

Style B *heiau* are concentrated on opposite sides of the Makiloa boundary (Figure 7; McCoy *et al.* 2011), which are associated with the Level two reorganisation of Kalala and Kahua into the smaller spatial units of Makiloa and Pāhinahina *ahupua'a* (Ladefoged & Graves 2006; Figure 2). This style presents the greatest number of *heiau* (n=4) as well as the largest cumulative viewshed (1.72 km^2, 36 per cent; Table 6, Figure 8), with MKI-125 accounting for the majority (43 per cent) of this cumulative visibility (see Table 3). The combined viewshed of Style B extends across all immediately adjacent *ahupua'a,* with all *heiau* obtaining variable degrees of coverage within Makiloa (see Figure 7 and Table 5b). Individually, only the visual scope of *heiau* KAL-25 falls predominantly within its *ahupua'a* of origin (76 per cent: see Table 5b) – Kalala. All Style B *heiau* located within Makiloa are inter-visible (i.e., MKI-122, MKI-124 and MKI-125). Moreover, only two per cent of Style B's total view overlaps Style A, whereas 98 per cent of Style B obtains novel visual coverage within areas of Kalala not observed by the earlier Style A *heiau* KAL-26 (Table 7 and Figure 9). As a whole, Style B's view of the surrounding level two landscape attains 99 per cent coverage of terrain not observed by earlier Style A *heiau* KAL-26, ranging further south into the newly formed *ahupua'a* of Makiloa, Pāhinahina and Kahua (Table 7 and Figure 9).

After Style B, Style C (Figure 10) has the second largest cumulative viewshed in the dataset (1.48 km^2; see Table 6, Figure 8). However, Style C *heiau* (n = 3) are less variable in visual coverage, sharing relatively similar amounts of visibility between *heiau* (Table 3 and Figure 10). For instance, while KH1-3 attains the largest coverage of observable area in this style (0.059 km^2, 40 per cent), it accounts for only 10 per cent more visibility than MKI-123 (30 per cent, 0.044 km^2) and KH2-2 (30 per cent, 0.045 km^2: see Table 3). Due to the position of KH2-2 and KH1-3 within Kahua 1 and 2, Style C is linked with Level zero *ahupua'a* reorganisation during which time Kahua was divided into Kahua 1 and 2 (see Figure 2). Their central positions within the southern *ahupua'a* expand the visual range of previous Styles, while MKI-123's position within Makiloa adds to the increasing density of *heiau* within this land-unit that began with Style B. When the percentage of visual overlap and 'in-filling' between Style C and the earlier Styles A and B are quantified, a historical connection is suggested in addition to the general southward expansion of novel viewshed into newly formed territories (see Table 8 and Figure 11). This expansion is exemplified by Style C's visual incursion into the southernmost Level zero *ahupua'a*, with 86 per cent of Kahua 1 and 98 per cent of Kahua 2's terrain captured with only minimal visual overlap (i.e., Kahua 1, 14 per cent overlap and Kahua 2, two per cent overlap: Table

Table 5. *Series of tables arranged by Style and associated* ahupua'a *division level presenting the total area of each* ahupua'a *(km²) and the percentage of viewable terrain individual* heiau *obtain in each* ahupua'a *during time of temple construction. Shaded cells indicate the origin* ahupua'a *of each* heiau. *Cells framed by a dark grey border for each* heiau *indicate the most visible* ahupua'a.

	Ahupua'a (Level 2)	Area (km²)	KAL-26 (%)
	Pohakulua	7.92	43
Style A	Kalala	21.54	54
	Kahua	41.60	4
	Total	**71.06**	**100**

	Ahupua'a (Level 2)	Area (km²)	KAL-25 (%)	MKI-125 (%)	MKI-124 (%)	MKI-122 (%)
	Kaihooa	3.39	0	0	0	0
	Pohakulua Ahula	3.15	0	0	0	0
	Pohakulua	1.38	0	0	0	0
Style B	Kalala	15.10	76	28	0	16
	Makiloa	6.44	21	12	8	21
	Pāhinahina	2.78	2	18	29	27
	Kahua	38.82	0	42	63	36
	Total	**71.06**	**100**	**100**	**100**	**100**

	Ahupua'a (Level 0)	Area (km²)	MKI-123 (%)	KH1-3 (%)	KH2-2 (%)
	Kaihooa	3.39	0	0	0
	Pohakulua Ahula	3.15	0	0	0
	Pohakulua	1.38	0	0	0
	Kalala	15.10	18	5	0
Style C	Makiloa	6.44	22	15	0
	Pāhinahina	2.78	27	12	0
	Kahua 1	16.08	32	55	3
	Kahua 2	22.74	0	14	97
	Total	**71.06**	**100**	**100**	**100**

	Ahupua'a (Level 2)	Area (km²)	KAL-24 (%)	PHH-1 (%)
	Kaihooa	3.39	1	0
	Pohakulua Ahula	3.15	3	0
	Pohakulua	1.38	7	0
Style D	Kalala	15.10	78	8
	Makiloa	6.44	7	19
	Pāhinahina	2.78	4	20
	Kahua	38.82	0	53
	Total	**71.06**	**100**	**100**

8 and Figure 11). Visual overlap of Style C with respect to Style B increases notably towards the north from Kahua 1 to Kalala, reinforcing a historical connection with earlier religious structures and their associated agricultural lands. In summation, Style C yields higher percentages of visual coverage over novel terrain (87 per cent) compared to internal overlap in visibility (13 per cent) and is visually linked to Style B as well as all Level zero *ahupua'a* (Table 8 and Figure 11). This continues the apparent trend of retaining a historical association between preceding *heiau*, their related *ahupua'a* and newly established territories. It also visually expands the network of socio-political and religious influence by constructing temples in locations that capture a greater visual range over newly formed agricultural land units.

The youngest Style, D, accounts for both the second smallest number of *heiau* (n=2) and cumulative viewshed (28 per cent) after Style A (Table 6, Figure 8), with KAL-24

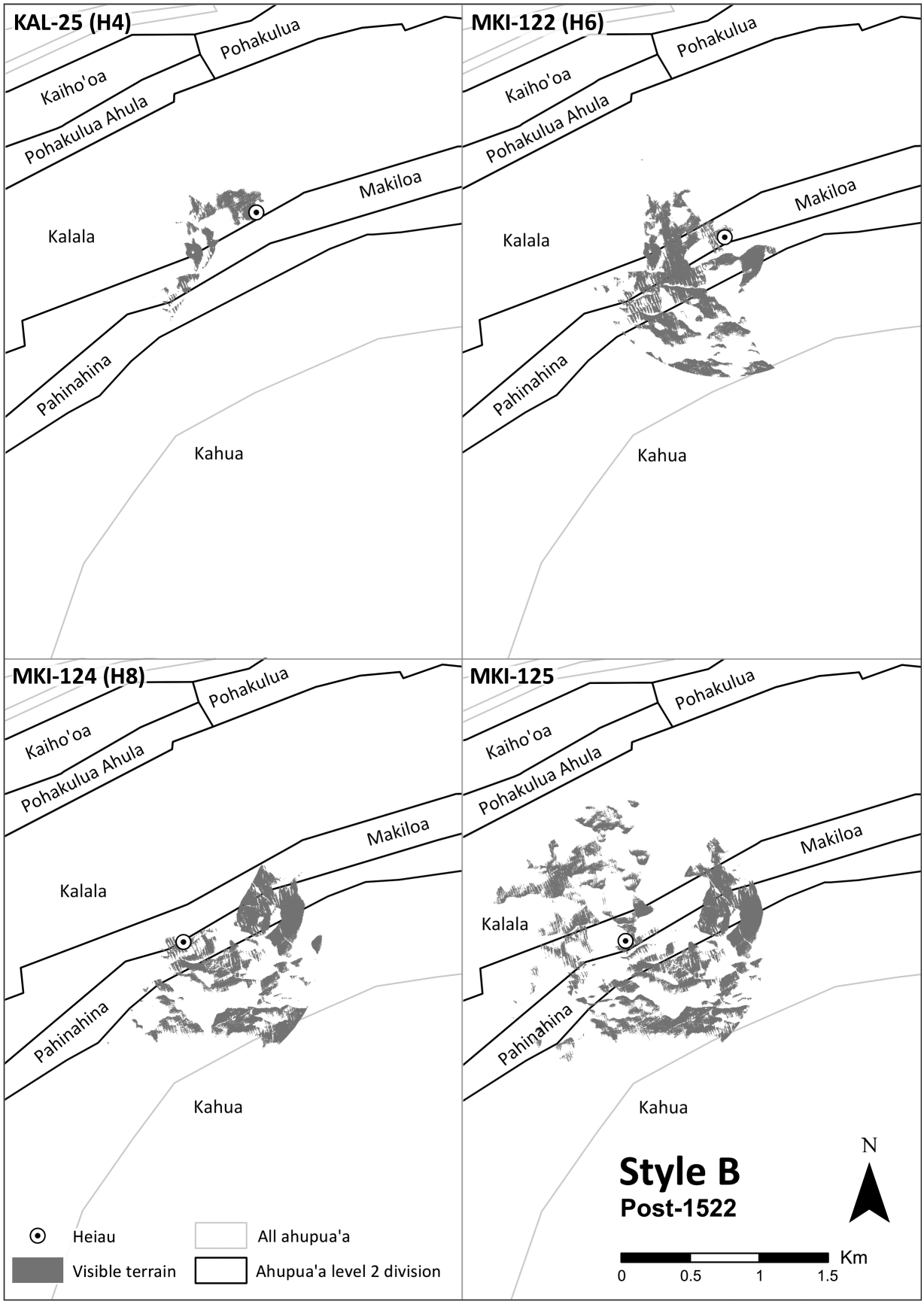

Figure 7. Style B visibility depicted against the Level 2 *ahupua'a* organization.

Table 6. *Average and cumulative visibility per Style and the percentage of visible coverage each Style obtains of the entire sample sets viewable terrain.*

Heiau style	Heiau no.	Average visibility (km^2)	Total visibility (km^2)	Style visibility in entire VS (%)
A	1	0.24	0.24	5
B	4	0.43	1.72	36
C	3	0.49	1.48	31
D	2	0.68	1.36	28
Total			**4.80**	**100**

Table 7. *Comparison between the percentage of Style B visibility overlapping previously observed Level 2 territory of Style A and the percentage of novel terrain visible to Style B, 'in-filling' areas of Level 2* ahupua'a *not observed by Style A.*

	Ahupua'a	Overlap (%)	In-filling (%)	Total (%)
Style B (Level 2)	Kalala	2	98	100
	Makiloa	0	100	100
	Pāhinahina	4	96	100
	Kahua	0	100	100
	Total	**1**	**99**	**100**

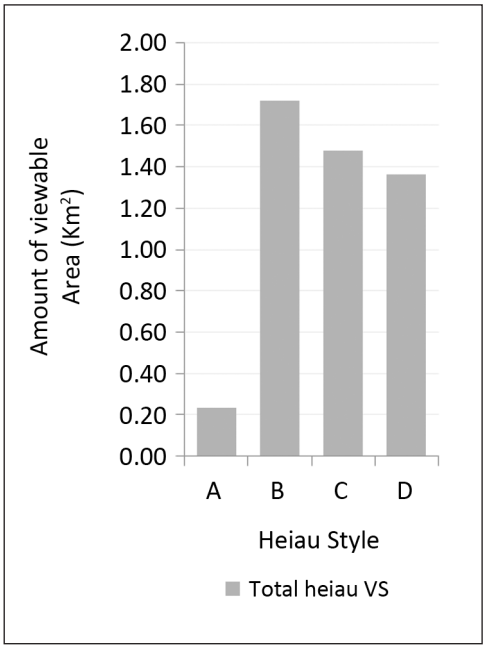

Figure 8. Cumulative total of *heiau* visibility for each *heiau* style.

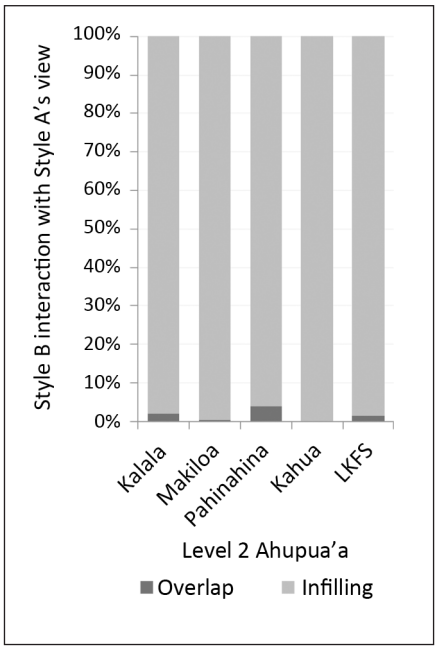

Figure 9. Hundred percentage stacked column graph depicting the percentage of Style B's total view that overlaps individual *ahupua'a* terrain already visible from Style A *heiau* (KAL-26) as well as areas of *ahupua'a* infilled by Style B's visibility coverage that are not observed by Style A.

representing 61 per cent of *heiau* visibility within this style (Table 3 and Figure 12). Kal-24 and PHH-1 are spatially disparate compared to *heiau* in Styles B and C, with KAL-24 located northeast and upslope of PHH-1 (Figure 12). Kal-24 presents a viewshed that is predominantly concentrated (78 per cent) within the boundaries of Kalala (Table 5) and, despite its extensive visual coverage (0.83 km^2; Table 4), attains limited inter-visibility with other *heiau* (i.e., with a 3 m vertical offset Style A's KAL-26 is the only *heiau* visible from Kal-24). This pattern is exemplified in Table 9, which shows that 90 per cent of Style D's visual coverage in Kalala is of novel terrain not previously observed from *heiau* in Style's A, B or C (also see Figure 13). Taken together, this suggests that the primary function of KAL-24 was to capture areas under-exploited by previous styles, thereby expanding visibility across Kalala's later subdivisions rather than attain a visual link with preceding *heiau*. In contrast, PHH-1 was constructed close to Style B and C *heiau* in a relatively central position within Pāhinahina and presents a viewshed distribution that extends across the north-south axis of Pāhinahina and neighbouring *ahupua'a* (i.e., Makiloa and Kalala, and Kahua; see Figure 12, Table 5d). Kahua is the most visible *ahupua'a* from PHH-1, capturing 53 per cent of its total viewshed (Table 5d). Within PHH-1's viewshed radius, only the northernmost *heiau* KAL-26 and KAL-25 are visually blocked from its position due to their low-lying positions together with topographic obstruction. The high levels of inter-visibility between PHH-1 and *heiau* of preceding Styles B and C are indicated by the percentage of overlap in the neighbouring *ahupua'a*

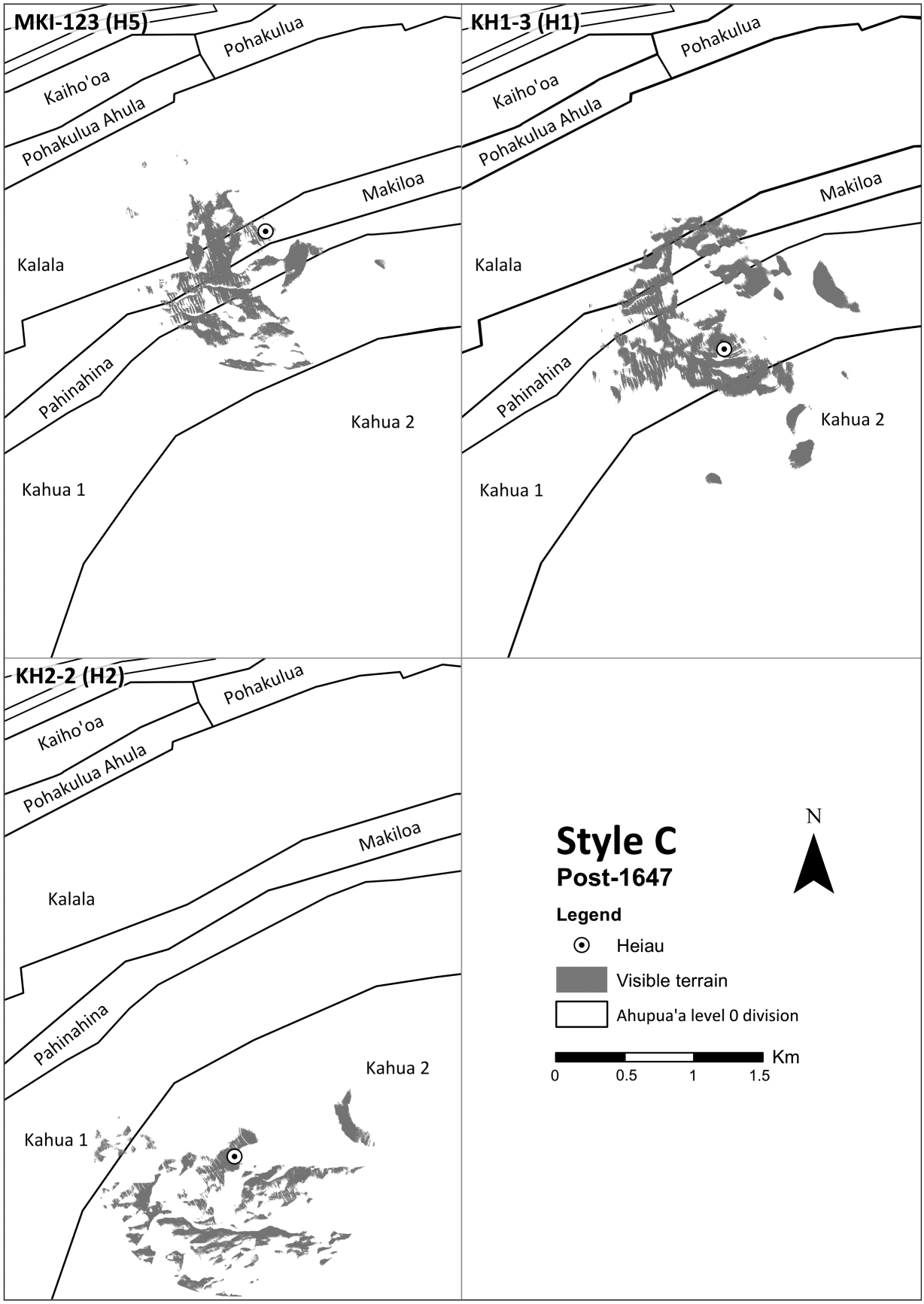

Figure 10. Style C visibility depicted against the Level 0 *ahupua'a* organization.

Table 8. *Comparison between the percentage of Style C visibility overlapping the previously observed territory (Level 0) of Style A and B and the percentage of novel terrain visible to Style C, 'in-filling' areas of Level 0 ahupua'a not observed by the combined earlier Styles A and B.*

	Ahupua'a	Overlap (%)	In-filling (%)	Total (%)
Style C (Level 0)	Kalala	89	11	100
	Makiloa	84	16	100
	Pāhinahina	86	14	100
	Kahua 1	60	40	100
	Kahua 2	3	97	100
	Total	**45**	**55**	**100**

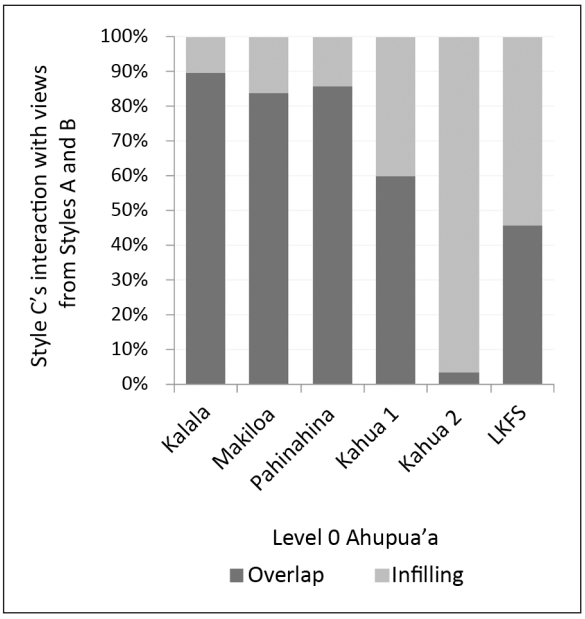

Figure 11. Hundred percentage stacked column graph depicting the percentage of Style C's total view that overlaps individual *ahupua'a* terrain already visible from Style A and B *heiau* (KAL-26) as well as areas of *ahupua'a* infilled by Style C's visibility coverage, not observed by preceding Style groups.

of Makiloa (59 per cent), Pāhinahina (82 per cent) and Kahua (88 per cent, see Table 9 and Figure 13). The expansive view that PHH-1 commands (0.53 km^2) of terrain that extends between its point of origin and each viewable *heiau*, suggests the prioritisation of a strong visual link between this temple structure and Pāhinahina's preceding parent *ahupua'a* (Kahua and to a lesser degree Makiloa) and neighbouring *heiau*. These contrasting viewsheds are reminiscent of Style C's *heiau* configuration, with isolated maximising coverage yielded by KH2–2 and the overlapping visual distributions and central positions of MKI-123 and KH1–3. Together, the *heiau* viewsheds of Style C and D expand the network of inter-visibility initiated by Style B across the southern *ahupua'a* of LKFS.

Style D *heiau* PHH-1 is related to the formation of Pāhinahina from Kahua, which is associated with the second level of territorial grouping presented by Ladefoged & Graves (2006). However, if the timing of this association as well as the territorial division itself proves to be correct (see Figure 2), then the construction of the youngest Style D *heiau* would relate to the same divisional series associated with Style B, which occurred prior to Style C's Level zero *heiau* construction. As the scheme presented by McCoy *et al.* (2012) establishes a direct link between architectural seriation and radiocarbon data, it likely represents the most accurate temporal organisation of *heiau* groupings that we currently have at hand, suggesting that the *ahupua'a* sequence initially proposed by Ladefoged & Graves (2006) is in need of refining. Here we argue that the timing of the partitioning of Pāhinahina from Kahua be shifted to Level zero reorganisation. The spatial position of PHH-1 within Pāhinahina and the temporal placement of Style D after the construction of Style C *heiau* suggests that Pāhinahina also formed after Kahua's division into two land-units, Kahua 1 and Kahua 2. This would associate Style D with the same land division level as Style C post-dating this group rather than preceding it. This more refined sequence is reflected in the spatial pattern of visual overlap and infilling, where PHH-1 visibility mainly overlaps previous Style viewsheds in Pāhinahina (84 per cent) and Kahua 1 (91 per cent; see Table 10 and Figure 14), suggesting visual connection between this temple, Style C and the parent *ahupua'a* Kahua 1.

Presented as a series of viewshed interactions, Figure 15 qualitatively emphasises the degree of visual overlap between all *heiau* Style groups. High levels of overlapping visibility are concentrated centrally due to the number and proximity of *heiau* in this area. It would appear that the construction site for *heiau* (i.e., MKI-122, -123, -124, -125, KH1–3 and PHH-1) was selected, in part, to express a localised visual presence while also contributing to the superimposition of previously established relationships between *heiau* and *ahupua'a* over time. Such a network of inter-visibility would reinforce the link between these community-level territories, legitimising socio-political hierarchy while reinforcing religious infallibility in an area with small managerial land units.

When all style viewsheds are assessed together across the landscape, an almost continuous network of inter-visibility is observed, beginning to the north of Kahua 1 and stretching across the southernmost *ahupua'a* of the LKFS landscape (e.g., Figure 15). It is worth noting that only five of the assessed *heiau* have their greatest area of visibility in their *ahupua'a* of origin, whilst the other five occupy adjacent areas (Table 5). In the case of Style B, the apparent prioritisation of observable land in adjacent *ahupua'a* could be interpreted as a reflection of the relatively narrow and generally smaller areas that make up the origin *ahupua'a*

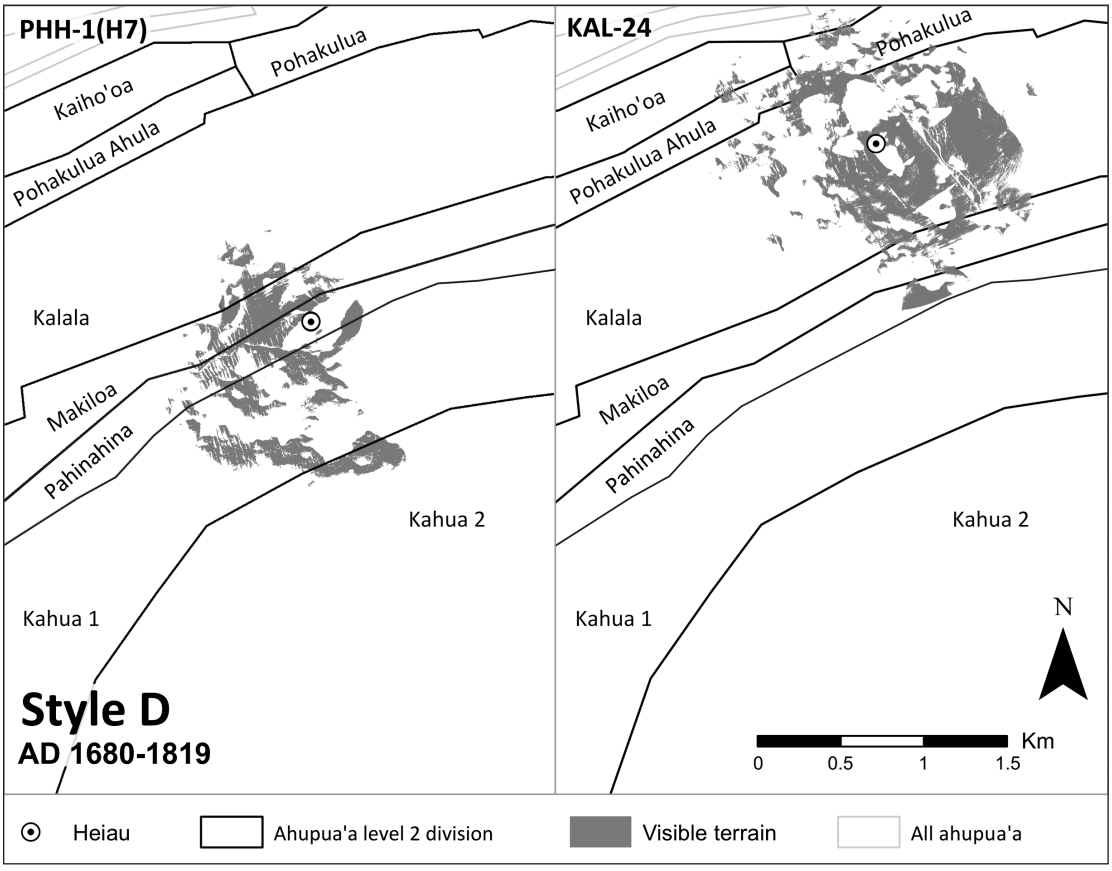

Figure 12. Style D visibility depicted against the Level 2 *ahupua'a* organization.

Table 9. *Comparison between the percentage of Style D visibility overlapping the previously observed territory (Level 2) of Style A, B and C and the percentage of novel terrain visible to Style D, 'in-filling' areas of Level 2* ahupuaʻa *not observed by the combined earlier Styles A, B or C.*

	Ahupuaʻa	Overlap (%)	In-filling (%)	Total (%)
Style D (Level 2)	Kiiokalani	6	94	100
	Kaihooa	27	73	100
	Pohakulua Ahula	8	92	100
	Kalala	10	90	100
	Makiloa	59	41	100
	Pāhinahina	82	18	100
	Kahua	88	12	100
	Total	**39**	**61**	**100**

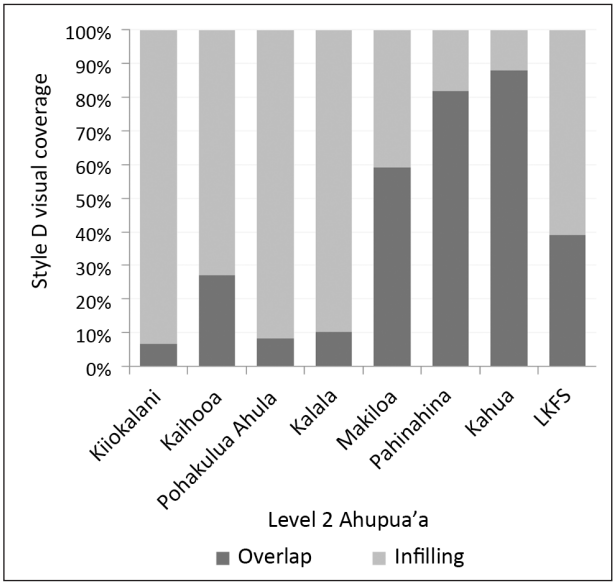

Figure 13. Hundred percentage stacked column graph depicting the percentage of Style D's total view that overlaps individual Level 2 *ahupua'a* terrain already visible from Style A, B and C *heiau* (KAL-26) as well as areas of *ahupua'a* infilled by Style D's visibility coverage, not observed by preceding Style groups.

Makiloa (6.44 km²) and neighbouring Pāhinahina (2.78 km²) compared to Kalala (15.10 km²) and Kahua (38.82 km²) (see Table 5b and Figure 7). However, when viewsheds are evaluated by means of incremental buffer rings, with area kept constant with increasing distance from each respective *heiau* (i.e., each ring zone [0–0.5 km, 0.5–0.7 km, 0.7–0.9 km, 0.9–1 km] equates to the same area of

Table 10. *Comparison between the percentage of Style D visibility overlapping the previously observed territory (Level 0) of Style A, B and C and the percentage of novel terrain visible to Style D, 'in-filling' areas of Level 0 ahupua'a not observed by the combined earlier Styles A, B or C.*

	Ahupua'a	Overlap (%)	In-filling (%)	Total (%)
Style D (Level 0)	Kiiokalani	6	94	100
	Kaihooa	27	73	100
	Pohakulua Ahula	31	69	100
	Pohakulua	41	59	100
	Kalala	10	90	100
	Makiloa	59	41	100
	Pāhinahina	84	16	100
	Kahua 1	91	9	100
	Kahua 2	74	26	100
	Total	**41**	**59**	**100**

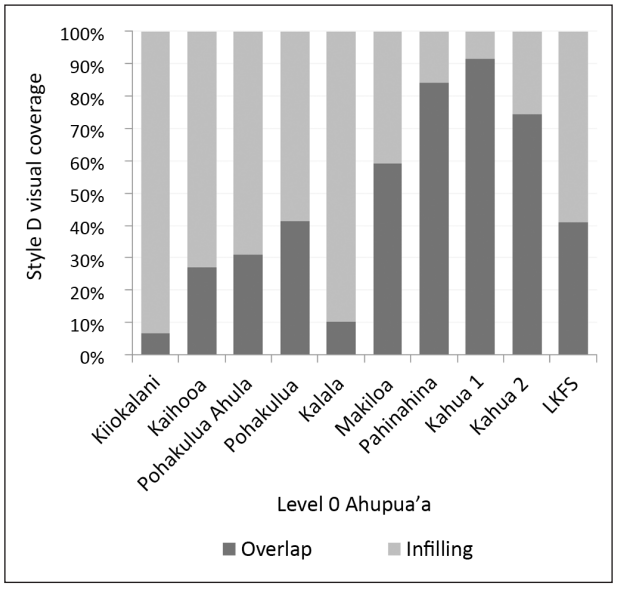

Figure 14. Hundred percentage stacked column graph depicting the percentage of Style D's total view that overlaps individual Level 0 *ahupua'a* terrain already visible from Style A, B and C *heiau* (KAL-26) as well as areas of *ahupua'a* infilled by Style D's visibility coverage, not observed by preceding Style groups.

0.8 km²; Figure 5; Table 2), an unexpected pattern is observed. Contrary to the expectation that visibility will decrease as distance increases (see *Material and methods*), the viewsheds of Style B *heiau* MKI-124 and MKI-125 yield distributions that increase with distance away from the observer, predominantly between buffer rings one and three (0.5–0.7 km, within ring two, Table 2). This spread of viewable terrain suggests a need to establish a visual link with neighbouring territories.

The combined viewshed expressed by each Style presents a biased pattern over time (see Table 6, Figures 8 and 16), with the amount of observable terrain reflecting the number of *heiau* within each Style. However, analysing the data in terms of average view per *heiau* within a given Style changes the observable pattern, indicating an increase in average viewable area over time (Table 6 and Figure 16). This is evinced by Style B which, while presenting the largest number of *heiau* in the dataset (see Table 2), also showcases the second smallest average viewshed per *heiau* (0.43 km²) (see Table 6, Figure 16). With the exception of Style A, the overall pattern shows a negative correlation between the number of *heiau* and the average size of observable area per *heiau* (Figure 16). This result suggests that over time the positioning of *heiau* in the LKFS landscape was conducted with a mind towards maximising visibility over a greater area.

DISCUSSION

Visibility from and between *heiau* in relation to surrounding agricultural divisions provides insight into changing approaches in construction and site selection. This includes the way communities interacted with *heiau* and how *ahupua'a* ties were reiterated through the genealogical inter-linking of various temples. Even though limited sample size presents a statistically insignificant result, a measurable increase in the average levels of viewable area over time is nonetheless observed (see Figure 16). Particularly, the minimal viewshed displayed by the oldest *heiau* (KAL-26) compared to the expansive views commanded by later temple structures (see McCoy *et al.* 2011:936, Figure 5). This potentially reflects a concerted change in the positioning strategy of *heiau* in response to changing socio-economic contexts with the LKFS. The patterning of *heiau* visibility supports McCoy *et al.'s* (2011) observed shift from the relatively familial positioning and construction of Style A *heiau* to the more exclusive and authoritative structures in Style B. This latter strategy is clearly reflected in the network of visual superimposition and interlinking of *heiau* both within Style B as well as between this and later styles. An idea corroborated by the relatively small amount of viewable area per *heiau* within this style compared to Styles C and D, which demonstrates that the focus of these *heiau* was not to add large portions of viewable terrain to the network, but rather to create a consolidated network of socio-political influence and economic redistribution. From this we suggest that temple construction during this time was aimed at enhancing agricultural productivity within Makiloa while extending religious and socio-political standing in adjacent territories. *Heiau* construction within Makiloa, together with visibility extending out into adjacent *ahupua'a,* would have given Makiloa a high level of socio-political and religious prominence across the southern LKFS as *heiau* constructed within this land-

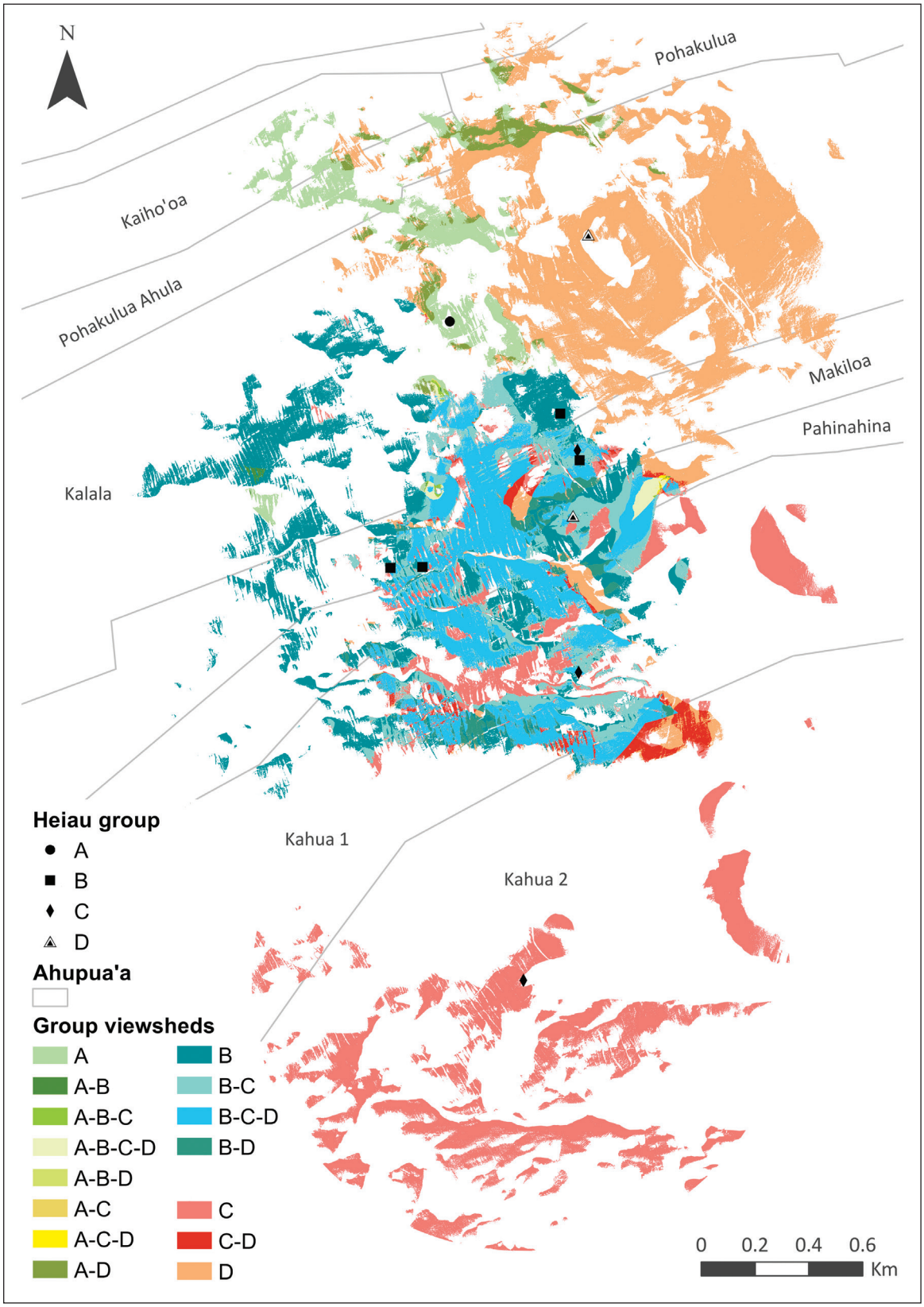

Figure 15. A Cumulative representation of visual overlap between different Style groupings across the LKFS case area. Overlapping visibility between Style viewsheds are depicted as gradients of specific colours: Green to yellow represents overlap interaction between Style A visual coverage and all forthcoming styles; Blue represents Style B and its interaction with Style's C and D; Variants of red equate to Style C through to D.

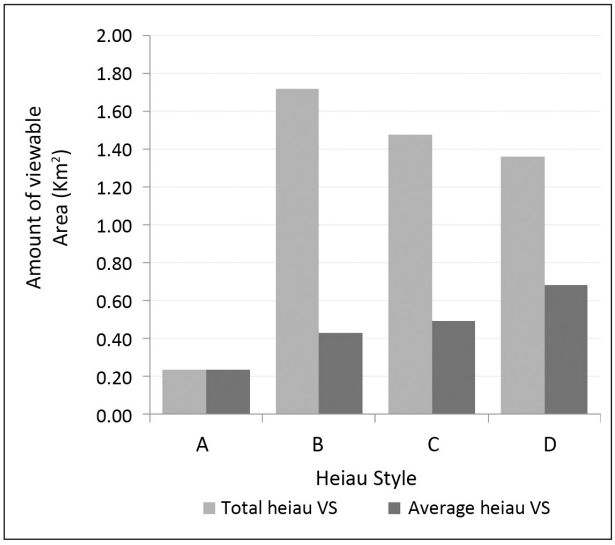

Figure 16. Average area visible compared to the cumulative total of *heiau* visibility for each *heiau* style.

unit were the most visually accessible. Visual prominence maintained old *ahupua'a* ties while visually influencing new, neighbouring communities, reinforcing religious-based chiefly authority and resource management north and south of this relatively small territory.

Subsequent *heiau* construction is emblemized by Styles C and D, which are characterized by an associated mixture of infilling and the capturing of novel terrain as *ahupua'a* were divided into ever smaller parcels of land. Together, Style C and D demonstrate a shift away from the smaller, more localised management of community structures and agricultural resources towards a broadly economical mode of socio-geographic engagement, in which larger average views were achieved with fewer structures (Table 6 and Figure 16). This suggests that these later temples were constructed to serve as legitimizing foci for high level officials of relatively discreet managerial areas, and in addition, that these units of administration were formed over a large area. Kirch (2003:106) suggested similar patterning amongst the Kahikinui *heiau* which were positioned in places of prominence in order to command sweeping views across open territory, thus better exercising the visual expression of chiefly concerns over vast expanses. Whilst the southern LKFS *heiau* are not able to claim such dramatic views, the placement principle for these later *heiau* becomes evident as *ahupua'a* are more intensively subdivided into smaller land parcels. As the number of minor chiefs grew with the increase in smaller *ahupua'a* the importance of attaining unified control over resources by the ruling polity would have become more pertinent.

The variability in size between *heiau* is linked to varying levels of worship, with smaller structures characterised as hubs of economic redistribution and/or community-level religious interaction, while the larger structures were reserved for the symbolically-charged religious ceremonies of the elite (Kolb 1992). The visual pattern presented here supports this correlation which, along with Valeri's (1985) two discrete kinds of worship, posits a general increase in temple size that is in turn reflected in the placement and visual impact of *heiau* in areas subject to intensive restructuring and reduction in parcel size over time (McCoy *et al.* 2011:936, Figure 5). Earlier Styles concentrated visibility locally (i.e., Style A *heiau* KAL-26 and Style B *heiau* KAL-25), indicating a familial focus in local productivity within large land parcels. This shifted to an apparent concern for the legitimisation and reinforcement of political and religious ambitions within the chiefly hierarchy, as is suggested by the increase in visual superimposition of temples over the same agricultural terrain already visible from previously constructed *heiau* (i.e., Style B, C [KH1–3 and MKI-123], and D [PHH-1]). As McCoy *et al.* (2011:934) note,'…the average size of temples changes little over the sequence; however, the maximum end of the range increases in Styles C and D. According to Kolb's (1997) size classes the change in size would represent the introduction of polity scaled temples'. The more recent construction of larger *heiau* (Styles C to D) appears to reflect the prioritisation of visual monumentality over familial interconnectivity by maximising visibility over a larger range via smaller numbers of *heiau*. While these later styles show a decrease in inter-visibility within their stylistic groups, they still retain a visual link with preceding *ahupua'a*. This suggests that a historical connection continued to be fundamental in the positioning and construction of *heiau* relative to resident and neighbouring *ahupua'a*. Nonetheless, the nature of religious influence and the means by which this was employed visually to link chiefly authority with resource control and prosperity shifted to a more dominant system of hierarchy over the community, at the visually monumental level.

CONCLUSION

Visibility analysis of each *heiau* within McCoy *et al.'s* (2011) relative temporal framework refines our understanding of the relationship and timing between *heiau* placement and the reorganisation of surrounding *ahupua'a*, while further elucidating the degree of inter-visibility between *heiau* through time. The positioning and visual impact of *heiau* in the southern *ahupua'a* of the LKFS demonstrates the construction of a complex system of management, which in its early form was operable at the level of a small community. As agricultural production intensified, chiefly interest and investment at a more intensive scale became necessary and developments in agricultural practice, social division and legitimizing structures were introduced. The formation of *ahupua'a* boundaries was linked through a network of inter-visible structures. The placement of these later *heiau* is such that the subsistence economy as well

as chiefly and religious authority was visually operable at an individual community level but also at a more centralized scale. Over time *heiau* decreased in number per style type, while experiencing a concomitant increase in size and total visual breadth. In this sense, dominion over the observable terrain of leeward Kohala was attained via the creation of a monumental architecture that commanded wide views over surrounding *ahupua'a* while expanding the visual network already in place. These structures legitimized production management and social inequality through demonstrating chiefly and religious control prominently on a landscape that had undergone multiple phases of agricultural reorganisation at the community level.

Acknowledgments

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