Visibility Analysis of Oahu Heiau

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAIʻI AT MĀNOA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

IN

GEOGRAPHY

May 2012

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Keywords: heiau, intervisibility, viewshed analysis

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Introduction

The English missionary William Ellis made an evangelical circuit of Hawaii Island in 1823. In the northern district of Kohala he observed the ruins of the heiau Pu`ukohala. He wrote:

> Although the huge pile resembles a dismantled fortress, whose frown no longer strikes terror through the surrounding country, yet it is impossible to walk over such a Golgotha, or contemplate a spot which must often have resembled a pandemonium, more than any living thing on earth, without a strong feeling of horror at the recollection of the bloody and infernal rites frequently practised within its walls.

Pu`ukohala was the major heiau of Kamehameha, who constructed the massive structure before launching his conquest of the Hawaiian Islands. Heiau feature prominently in ethnohistoric accounts of warfare and political struggle. Ellis recorded the sacrificial rites performed at Pu`ukohala:

> Tairi, or Kukairimoku, the favourite war-god of Tamehameha, was the principal idol. To him the heiau was dedicated, and for his occasional residence it was built. On the day in which he was brought within its precincts, vast offerings of fruit, hogs, and dogs, were presented, and no less than eleven human victims immolated on its altars (82).

The ritual of human sacrifice was introduced to Hawaii in the 12th century and became common at war heiau such as Pu`ukohala. In time, heiau of this design emerged as the major symbol of elite power and control. They were often of monumental construction and located on the crests of hills, sea promontories, and other topographically commanding and visually prominent locations.

Heiau relied on their visibility to project power over the common people or maka`ainana- literally, the “eyes of the land.” A spatial and statistical analysis is proposed to quantify the visibility of known heiau locations on the island of Oahu. This process relies on a spatial dataset assembled from a wide range of sources.

Chapter Outline

Chapter I contains an ethnographic and historical description of heiau and their context within pre-contact Hawaii. Their rituals, design, construction, typologies, and destruction are outlined. Heiau are examined as both symbols of power and as religious sites.

Chapter II is an overview of visibility within the Geographic Information System toolset. GIS offers mechanisms to quantify visibility and answer archaeological questions. The history of visibility analysis from its origins in the United Kingdom to its application within the field of prehistoric archaeology is briefly summarized.

Chapter III outlines the methodological process to assemble the spatial and textual dataset of Oahu heiau. Although most Oahu heiau are well documented, the assembly of various sources into one uniform compilation was essential before embarking on a statistical exploration. This chapter discusses the collocation process and questions of data accuracy, precision, and thoroughness. Metadata and field descriptions for the dataset are also included.

Chapter IV is an exploratory data analysis of the Oahu heiau dataset. Heiau function, location, and condition are examined. The values of viewsheds and intervisibility are proposed to quantify visibility. Utilizing intervisibility as a test metric, a random sampling experiment attempts to discern if visibility was a significant characteristic of heiau.

Chapter V summarizes the conclusions of the exploratory data analysis. It is realized that the fragmentary nature of the dataset raises more questions than it answers.

It is proposed that both further research and spatial and statistical analysis may offer further conclusions and, of course, research questions.

Chapter I. Hawaiian Heiau

Heiau as Symbol

The word heiau is a variation of the archaic *haiau* (McAllister 1933:8). *Hai* means "to sacrifice" and *au*, "movement or flow" (Cachola Abad 1992:12). Heiau served as places where divine power (mana) was believed to be concentrated and transferred through the acts of sacrifice and ritual between commoners, chiefs, and their gods. Like the palaces and shrines of Bronze Age Crete (Graham 1987) or Germanic *Thingplatz* (Lane 1983), heiau were the physical embodiment of the state religion where elites could establish and replenish their social status (Kolb 1994).

Within the late "Expansionist Period," around 1650 (Cordy 1974; Kirch 1985), monumental heiau were built and dedicated to the purposes of two major gods of the state religion, Ku and Lono. Oral traditions establish that in the late 12th or 13th centuries a warrior-priest from the mythical southern islands of Kahiki, Pa`oa, introduced the god of war, Ku, and the ritual of human sacrifice at Mo`okini Heiau in Kohala, Hawaii (Fornander 1969). Mo`okini is one of the first example of a war (luakini or pookanaka) heiau in Hawaii. The ethno-historian John Papa I`i records that Mo`okini was the major luakini for the district of Kohala, just as there was a major luakini heiau for each of the other five Hawaii Island districts (160).

Centuries of internecine warfare established the monumental luakini as the major archetype of heiau function in the Hawaiian Islands (Kolb and Dixon 2002; Kolb 2006). Perhaps no luakini-class heiau, besides Mo`okini, is more famous for its direct effect on this process as that of Pu`ukohala (Thrum 1908). In 1792, while Kamehameha was

campaigning in Maui, a revolt broke out on Hawaii Island. Kamehameha returned to the island, and before crushing the rebels and on the advice of his kahuna, built Pu`ukohala in Kawaihaie, Kona. The heiau was located on a hill in a dominant location above the bay. When the rebel chief Keoua arrived in Kawaihaie Bay to parley, he and his followers were in a state of "shock and awe" when they saw the massive shape of the heiau on the hill above them where before there had been none. Keoua was captured and sacrificed in the dedication of the new heiau. This confirmed Kamehameha's control over the island of Hawaii and augured a successful beginning to the conquest of the other islands.

Figure 1.Pu`ukohala, Kona**.** Image by the author.

A similar example of heiau as political symbol is told of the Maui ali`i nui, Kahekili, and Kalaniopuu of Hawaii. In 1775, before the start of the bitter war between Maui and Hawaii Islands, Kalaniopuu built a heiau "against sedition and for vengeance against the chief of Maui." When Kahekili heard this news he had his kahuna,

Kaleopu`upu`u, build the heiau Kaluli at Pu'uohala, Wailuku to alleviate this 'heiau gap.' Kaleopu`upu`u told Kahekili that the heiau was "the house of your god; open the sluice gate that the fish may enter." A year later in 1776, after the Hawaii forces had invaded Maui and maneuvered into a tactically disastrous position on the battlefield, he said to Kahekili "the fish have entered the sluice; draw in the net" (Kamakau 1992:85). The invading Hawaiian army was wiped out; their fiefdom of Hana, held since 1759 by the famous fortress of Ka`uiki, fell in 1782 when the water supply was cut off. The garrison attempted to break out but were routed and committed to the imu loa ovens for sacrifice (Thrum 1889:28). Kaleopu`upu`u later engineered the death of his elder brother, Ka`opulupulu, kahuna to Kahahana of Oahu to destabilize the island before a pending Maui invasion (Kamakau 1992:133). Oahu fell to the Maui forces in 1783, and less than a decade later, to the triumphant armies of Kamehameha.

The position of Pu`u O Mahuka, on the ridge above Waimea Bay, Oahu, allowed the site to dominate the bay and almost all of Waialua district out to Ka`ena Point. According to legend, the chief of Oahu asked his kahuna if it was propitious to invade Kauai. He responded that they must build a large heiau on the heights above Waimea so that he could ask the opinion of the gods. A large heiau was built and the kahuna lit a sacrificial fire. The wind carried the smoke to Kauai. The kahuna informed the chief that the Kauai gods had responded that it was not an auspicious time for war. In gratitude, the Oahu chief bestowed Waimea Valley to the kahuna class under whose control it remained until the end of the old religion (Kennedy 2005).

Beyond their symbolic roles and usage in ritual, luakini had a very real and terrorizing aspect- they demanded a stream of victims for human sacrifice. Although rival

Figure 2. Pu`u O Mahuka heiau, Oahu. (Hawaii State Archives)

chiefs and defeated warriors were prized for their high mana, commoners could be sacrificed for seemingly trivial transgressions against the kapu. The Mu, an ecclesiastical secret police, ferreted out the seditious. Even lesser members of the kahuna order could be sacrificed in a pinch (Thrum 1908). Kamakau writes that

> The cause of the death of some of these people in olden time was, due to the false schemers unjustly accusing many of infringing the personal kapus of the king, or violating things sacred to the gods, whereby the death penalty would apply, or forfeits ensue. Such was the fear of the people living with the chiefs in olden time. Whenever the king built a heiau pookanaka it was not released of kapu by numerous pigs, bananas, coconuts or other sacrifices and offerings, but only upon the offering up of a human sacrifice would its consecration be complete. Therefore if no culprit or captive was at hand for the purpose, then some cause would be found by one of the favorites of the chief against probably some high or ordinary chief, or maybe some intimate friend of the chief. No one was safe or could escape from those jealous fault-finders; even the power of the king could not save his 1ife.

It is very likely that when Pa`oa introduced the luakini system of human sacrifice in Kohala he did it with the point of a lance, at the head of a body of his Kahiki warriors- and that his first offerings were the victims of his invading army.

Heiau as Fortress

Warfare was a major feature of Hawaiian culture and had been endemic for several centuries before Western contact. Kamakau states that

> The race was on the decrease even before the coming of the missionaries... this was due in part to the merciless battles that had been fought in which the earth was covered with the innocent who were slaughtered... many died in the mountains, fell over cliffs, or were drowned in the sea. They were killed even when they fled to another land, those on Maui killing refugees from wars on Hawaii, or those on Hawaii killing people who had fled from Maui. Even castaways were slain... the lower class dwindled, and the upper grew more and more wicked. (1992:236)

Kamakau (1964:19) writes of a class of fortified war heiau with enclosing walls known as the pa kaua heiau. The pa kaua heiau were not unique; 'battle' hills, fortresses (pa kaua), strongholds, and refuges (pu`u honua) are also mentioned in oral traditions and contemporary historical accounts (1992:80). Kamakau records that the heiau within the complex of Honaunau were surrounded with the walls of a pa kaua heiau, twelve feet high by seventeen feet wide and one thousand feet long. The pu`u honua of all islands except Kauai and Hawaii were destroyed under the re-distribution of conquered lands by Kamehameha to his vassals (Ii 69). Kauai was never invaded and so retains its land divisions and pu`u honua. The site at Honaunau remains because as Kamakau writes, it is the "Kona chiefs that won the kingdom, or perhaps because the land is of no value."

Figure 3. Exterior and interior views of Ke'ekū Heiau, Ka`u. Images by the author.

Kukaoo heiau, in Manoa Valley, Oahu, may have served as a pa kaua heiau. Thrum records that the heiau was built by Menehune and wrested from them by the chief Kualii:

> The menehune's fort was on a rocky hill on the opposite side of the hill, just above Kukaoo. Previous to the battle, they had control of all upper Manoa. After Kualii obtained possession, he made it the principal temple fort of a system of heiaus.

McAllister observed that the heiau consisted of four low walls atop a natural elevation of about thirty feet high (McAllister 1933:79). The locations of the other fortified heiau within this redoubt are unknown.

Hodder (in Kolb 1994) suggests that major luakini heiau may have served as refuges for the chiefs from the people. Many luakini contain characteristics of pa kaua heiau; they were often monumental in size and located in visibly prominent locations such as the crest of hills or ridges in order to ensure good visibility of surrounding areas or coastline; they could be located to take advantage of natural defensive topography such as on islands, sea-bound promontories, against the back of sloping terrain, or astride or at the conjunction of ridges. Luakini heiau could also feature high single or double walls, multiple stacked terraces, and narrow entrance ways (Stokes 1991).

Figure 4. Exterior and interior views of Mo`okini Heiau, Kohala. Images by the author.

There are several examples of luakini that may have served as pa kaua heiau. Mo`okini, at the edge of Upolu Point, is enclosed by walls thirty-four feet wide by nineteen feet high (1991:173-178). Poliahu, near the Wailua River, Kauai, is situated at the top of a narrow ridge connecting the coastal plains and the upper highlands of Kapapa (Bennet 1931). Ke`ekū heiau, in Ka`u, Hawaii, a rebellious region infamous for deposing unjust rulers, is located on a peninsula surrounded on water by three sides and large double walls on the fourth. The heiau is situated to dominate one of the few suitable canoe landing sites and freshwater springs in that region.

Figure 5. A View of Karakakooa, in Owhyhee, by John Webber (1784). An engraving of the scene of Cook's 1779 visit to Kealakekua Bay. Note the heiau atop the high stone foundation at far right.

Types

Luakini were one of two major archetypes of heiau function under the state religion as noted by the historians Kamakau and Malo. Luakini served the god Kunuiakea (*Ku*) and his derivatives and was known as "the great unseen god in the dark clouds of heaven" (Kamakau 1968:7). Ku was the god of war and his rituals, or *kapu*, demanded human sacrifice at the luakini. The luakini were the only heiau where human sacrifice was allowed and they could only be built and consecrated by a high chief.

The other major archetype of heiau function was for the god Lono. Hale o Lono (or mapele) were dedicated to the success of agriculture, animal husbandry, and the "prosperity of the people" (Kamakau). Malo states that there was no strict difference between a heiau for Lono or Ku and even that "when the king wished to make crops flourish he might build a luakini." The wise ruler, according to Kamakau, would start with a luakini: "when the people and the priests saw that the services of the luakini were well conducted, then they began to have confidence in the stability of the government,

and they put up other places of worship, such as the Mapele, the Kukoea, and the Hale o Lono (1968:212)." Kamehameha built luakini in his conquest of the islands, but after his return to Kona he put the sword aside for the ploughshare and built Hale o Lono (Kirch 96). Ahu`ena heiau at Kailua Bay, Kona, was his personal heiau. I`i records that it served as a royal treasure-house and included the idols of those vanquished gods plundered from the temples of other islands (1963:123).

The ancient polytheistic religion consisted of ancestral, nature, and miscellaneous gods and each had their proscribed rituals and acolytes. There were many other types of heiau not included within the two major archetypes of the state religion (see Table 1). The kahuna class had their own heiau dedicated to healing and medical instruction, as places of refuge from crime or war, and as religious compounds and colleges. Maka`ainana heiau included those for fishing, agriculture, family, and craftsmanship. These heiau could consist of stone platforms and terraces similar to luakini or hale o Lono, usually on a much smaller scale, or a single large stone (pohaku), rock cairn, altar (ko`a), or even a hilltop, glade, forest, or other natural place perceived to be imbued with mana.

Shimuzu argues that the feudal system of ancient Hawaii was in a process of social movement towards internal stratification and that this resulted in an increasing separation between commoners and elites (1980:10). This stratification in turn defined which types of heiau each class could build and worship at.

Classification	Associated Social Class	Specific Types	Description	General Types
Major	King	mao	A heiau for alii (Malo 1951)	King's private
		Kuke`ae ahuwai	For purification at the end of the Makahiki (Malo 1951)	
		Prayer	Function as indicated by name (Bennet 1932)	
		Burial		
		Luakini kaua	A war temple (Malo 1951)	Sacrificial or pookanaka
		Luakini hooululai	Dedicated for abundant harvest (Malo 1951)	
		general	A luakini for the prevention of epidemics (Ii 1973)	
	King and Chiefs	Waihau	Made to bring blessings on the population (Kamakau 1974)	
		Unuunu hoouluai	For the increase of food crops (Kamakau 1974)	
		Unu o Lono	? (Malo 1951)	Dedicated to Lono
		Mapele	For blessings on crops (Malo 1951)	
		Ipu o Lono	For increase of food crops (Kamakau 1974)	
		Hale o Lono	A thatched house enclosed with a fence of lama wood; function unclear (Ii 1973)	
		Eweai	To bring rain (Malo 1951)	Dedicated to miscellaneous gods
		Heiau loulu	To the fishing gods (Malo 1951)	
		Hale o kaili	Dedicated to the god Kailik or Kukaili moku (Ii 1973)	
		Hale hui	Dwelling for misc. gods (Ii 1973)	
		Lono puha	Dedicated to Lono puha upon recovery from an illness (Malo 1951)	
		Kolea muku	Dedicated to Kolea muku upon recovery from an illness (Malo 1951)	
	Female chiefs	Hale of Papa	Dedicated to the deity Papa for the services of female alii (Ii 1973)	
Minor	Priests	Ulu hale	Houses used in the medical arts (Kamakau 1974)	
		Hale lau		
		Moku hale		
		Dwelling places	Houses used by priests were considered minor heiau (Bennet 1932)	
		Learning places	Ecclesiastical colleges	
	Priests and commoners	Tapa beaters, women, debtors, hula, canoe builders, surf riders, love impelling	Function as indicated by name (Bennet 1932)	
	Commoners	Ko`a	Fishing shrine (Malo 1951)	
		Ku`ula	Fishing shrine dedicated to ku`ula (Malo 1951)	
		Heiau or mua	House containing family shrine for daily worship (Malo 1951)	

Table 1. Heiau Types. Compiled by Shimuzu (1980).

Ritual

Ritual created and maintained mana. The quality of the ritual served as a measure of a chief's righteousness and mandate to lead. Kamakau states that

> If the services of religion under any king were conducted in a slack or slovenly manner, it would be the general opinion that that government would pass into the hands of a king under whom the services of religion would be strictly and correctly performed. It was firmly believed that a religious king was possessed of mighty power, because it was a matter of observation that kings who were attentive to their religious duties conducted all their affairs in a becoming manner, while irreligious kings neglected the affairs of their government.

The dedication of a heiau was an important ritual and the same heiau could be dedicated multiple times. According to Malo, a chief could rededicate a heiau's purpose by contingency and from season to season. At the end of the agricultural season the annual harvest festival of Makahiki would start with a strict kapu. The high chief and his kahuna would then circumnavigate the island and extract tribute from the ahupua`a for their god. Kamakau writes that this extortion was not the tradition of the ka po`e kahiko but a practice introduced by Kamehameha and his newly-created gods. If the god was not pleased with the offerings the district would be plundered. At the end of the circuit a heiau would be dedicated, the kapu lifted, and the festival of play, dancing, and feasting begin (1968:20).

Although heiau could be dedicated as either a luakini or Hale o Lono, the rituals performed were unique to each archetype. Malo (1951:159) describes that

> There were two rituals which the king in his eminent station used in the worship of the gods; one was the ritual of Ku, the other that of Lono. The Ku ritual was very strict, the service most arduous. The priests of this rite were distinct from others and outranked them. They were called priests of the order of Ku, because Ku was the highest god whom the king worshipped in following their ritual.
>
> The Lono ritual was milder, the service more comfortable. Its priests were, however, of a separate order and of an inferior grade. They were said to be of the order of Lono because Lono was the chief object of the king's worship when he followed the ritual.

The ritual of human sacrifice is perhaps the most infamous. The early voyagers Tyermann and Bennet recorded such a ritual at a luakini heiau of Kamehameha. In 1804, Kamehameha and his army were on Oahu about to embark for the invasion of Kauai. A plague of scarlet fever swept the army, and out of eight thousand, more than two-thirds perished. Kamehameha performed a sacrifice at Papaaenaena heiau, Waikiki, to appease the gods. As Tyermann and Bennet record:

> The priests recommended a ten days' tabu, the sacrifice of three human victims, four hundred hogs, as many cocoanuts, and an equal number of branches of plantains. Three men, who had been guilty of the enormous turpitude eating cocoanuts with the old queen, were accordingly seized and led to the marae... when the slaughtering time arrived, one of them was placed under the legs of the idol, and the other two were laid, with the hogs and the fruit, upon the altar-frame. They were then beaten with clubs upon the shoulder until they died of the blows.

The historian John Papa I`i, a member of Kamehameha's court, also describes the sacrifice:

> After the fires had been lighted, the sacrificial pigs and the men were put to death. The skins of the men were scorched like those of the sacrificial pigs and laid together in a special place before the kahunas, the king, and all the others who had assembled there to worship the god idol, the group of idols, and the line of idols.

Design

Shimuzu (1980), in his architectural thesis, argued that heiau were the efforts of conscious design and the work of a designer. A specialist "architect-geomancer," the Kuhikuhi puu`one, "one who pointed out the sand heaps" would create a sand model of a proposed heiau. As Malo explains, it was his function to

> Exhibit a plan to the king, because this class of persons were thoroughly educated in what concerned a heiau. They were acquainted with the heiau which had been built from the most ancient times, from Hawaii to Kauai, some of which had gone into ruins. These kuhikuhi pu`uone knew all about these old temples, because they had studied them on the ground, had seen their sites and knew the plans of them all. They knew the heiau which a

> certain king had built, as a result of which he gained a victory over another king. That was the heiau, the plan of which the kuhikuhi pu`uone explained to the king; and if the king was pleased, he first made a sort of plan of the heiau on the ground and exhibited it to the king with an explanation of all its parts, so that he could see where fence was to run, where the houses were to stand, and where was the place for the lananuu mamao with the idols.

The kuhikuhi, also known as "one who would locate sites," was responsible for the selection of site location, though as Shimuzu laments, the appropriate criteria can only be guessed at today.

Construction

During Kalakakau's 1881 trip around the world William Armstrong described heiau to the Thai king as "simple platforms of stone surrounded by rude fences, structures hardly beyond the capacity of a beaver," much to the discomfort of Kalakaua (1913:126). After the fall of the old religion and almost a century of neglect and pillaging, most heiau were little more than scenic ruins. But in their day and under the care and attention of the kahuna, heiau were complex religious sites composed of a variety of features of which only the stone foundations survive.

Heiau were built in a wide variety of sizes and shapes. The luakini and other major heiau generally consisted of large rectangular stone platforms. Single or stepped terraces and retaining walls could be used on sloping terrain. Building material was generally basalt, although available building materials could be used such as coral and water worn stones. McAllister notes in his survey of Oahu heiau that dressed stone and mortar were not found (13).

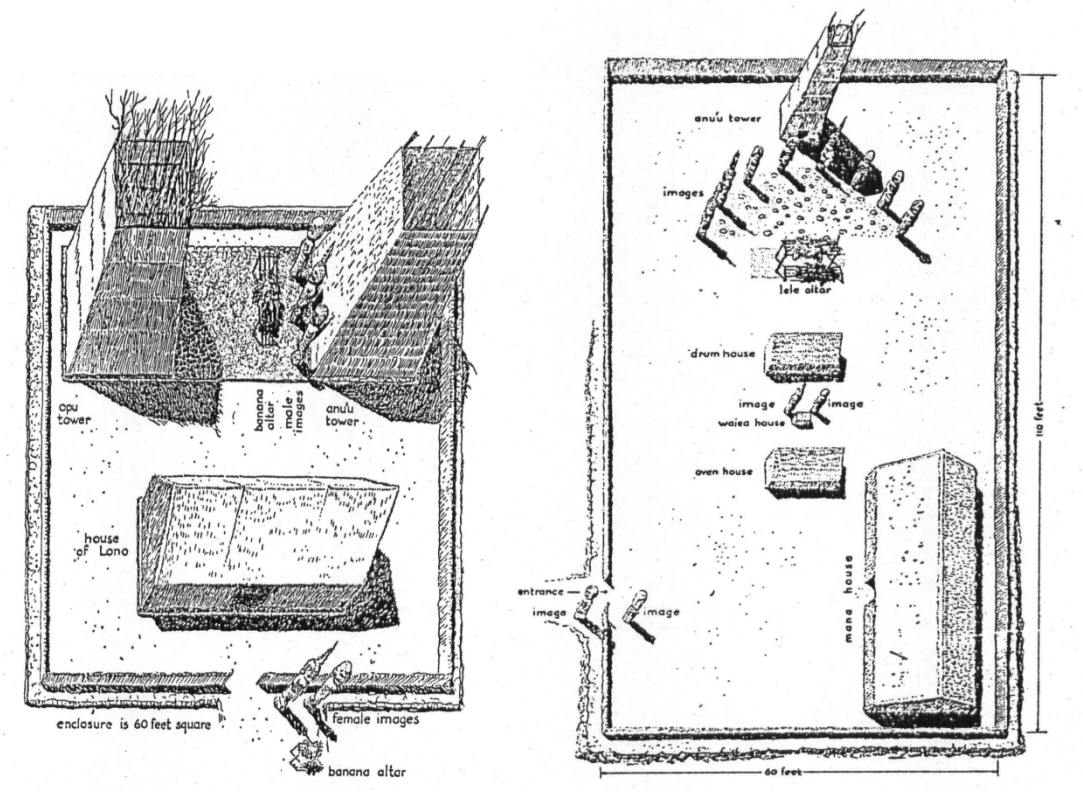

Figure 6. Illustrations of Hale o Lono and luakini heiau types. Described by John Papa I`i and drawn by Paul Rockwood.

The top of the heiau was paved, commonly with stone, but also with sand, pebbles, or earth. The paving could vary in the type of material within the same heiau. On top of the paving and within the interior were the major features of the heiau; the sacrificial altar; houses for prayer, drums, ovens, and hula; and the oracle tower.

The oracle tower (anu`u) was an obelisk usually over twenty feet in height located at the end of the platform opposite the houses. They were constructed of wooden poles and covered in white tapa cloth (Shimuzu 1980:16). Emerson writes that the oracle tower consisted of three platforms:

> The lowest was used for the bestowal of offerings. The second was more sacred; the high priest and his attendants sometimes stood there while conducting religious services. The third was the most sacred place of all. Only the high priest and king was allowed to come to this platform. (Malo 1951:176)

According to Ellis, the priest would stand within the tower as the "organ of communication from the god, whenever the king came to inquire his will... and standing immediately before the obelisk, inquired respecting the declaration of war, the conclusion of peace, or any other affair of importance (81)." Ellis notes that he frequently asked the people whether the priest and king had already privately reached some previous agreement, but they generally answered that they did not know.

The towers were a visually dominant feature: Cook observed that as they "ranged down the coast from the east in the ships, we observed at every village one or more elevated objects, like pyramids or rather obelisks and one of these... was very conspicuous from the ship's anchoring station" (Beaglehole 1967:269).

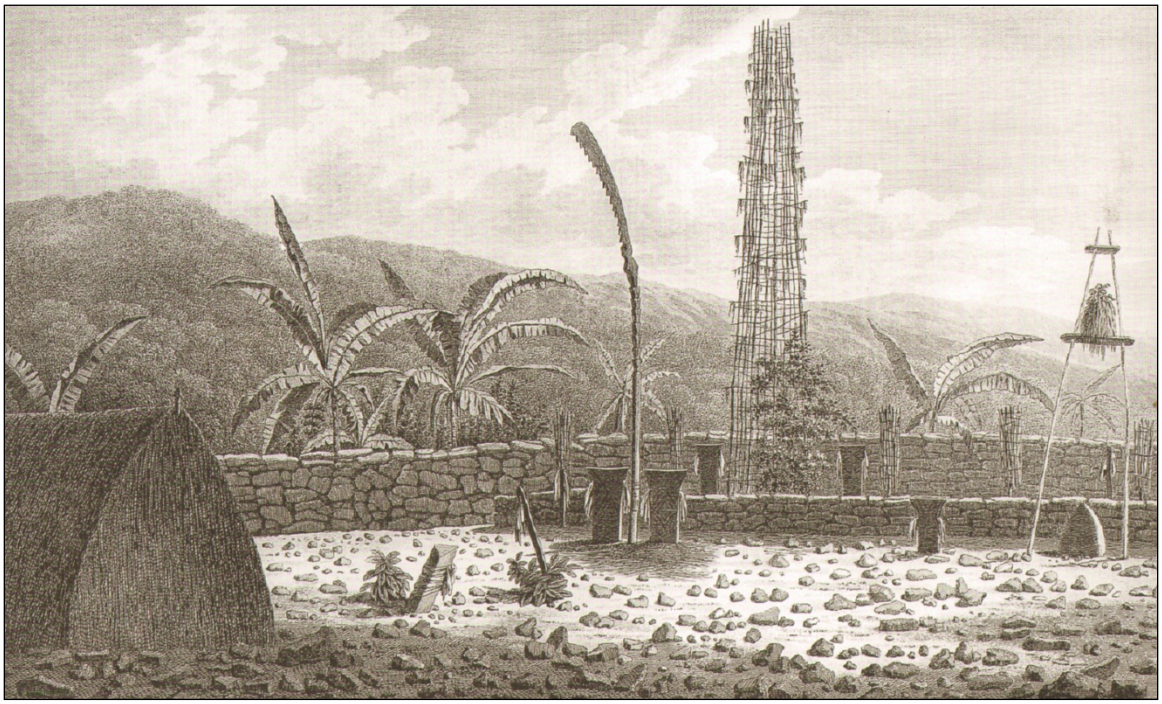

Figure 7. A Morai, in Atooi. Illustration by John Webber from Cook's 1784 expedition.

A wooden fence surrounded the site and large carved wooden images of gods were placed along it. Kamakau, a Christian convert, carefully notes that these graven idols were not themselves directly worshipped but "were made for adornment; to be

possessed of a spirit; and to make the house of the god attractive when he should descend from heaven." There could be anywhere from forty images per side of a luakini and some larger heiau had as many as four hundred.

Pu`ukohala heiau was the primary luakini of Kamehameha and one of the last to be built. William Ellis gives a detailed description of its features that he witnessed in 1823, only a few years after the end of the kapu system:

> The upper terrace within the area was spacious, and much better finished than the lower ones. It was paved with various kinds of flat, smooth stones, brought from a considerable distance. At the south end was a kind of inner court, where the principal idol used to be kept, surrounded by a number of images of inferior deities. In the center of this inner court was the place where the anu was erected, which was a lofty frame of wicker work, in the shape something like an obelisk, within which the priest stood as the organ of communication from the god, whenever the king came to inquire his will in any matter of importance.
>
> On the outside, just at the entrance of it, was the place of the altar, on which human and other sacrifices were offered. The remains of one of the pillars that supported it, were pointed out by the natives, and the pavement around was strewed with bones of men and animals, the mouldering re1ics of those numerous offerings once presented there. About the center of the terrace was the spot where the king's sacred house stood, in which he resided during the season of strict tabu, and at the north end, the place where the priests' houses occupied, who, with the exception of the king, were the only persons permitted to dwell within the sacred enclosure. Holes were seen on the walls, all around this, as well as the lower terraces, where wooden idols of various size and form formerly stood, casting their hideous stare in every direction.

Another luakini built by Kamehameha was Papaaenaena on the eastern slope of Leahi, Oahu. The heiau was originally built by the Maui chief Kahekili after his conquest of the island, but it may have replaced an earlier heiau known as Apuakehau. Apuakehua, also known as Helumoa, was the principal heiau of Waikiki and the seat of the island's ali`i. After his conquest of Oahu, the heiau was dedicated by Kamehameha and became his major luakini for the island (Beckett and Singer 1999). The walls of Papaaenanea could be seen from Waikiki and were described by a succession of foreign observers (in McAllister 1933:71). One visitor to the site in 1824 wrote:

> It is the largest and most perfect ruin of the idolatry of the island I have yet seen; and was the most distinguished temple of Oahu... I made its length forty and its breadth twenty yards. The walls of dark stone are perfectly regular and well built, about six feet high, three feet wide at the foundation, and two feet at the top. It is enclosed only on three sides, the oblong area, being formed by the walls being opened on the west; from this side there is a descent by three regular terraces or very broad steps... The terraces of the heiau command a beautiful prospect of the bay and plantations of Waikiki, of the plain and village of Honoruru.

Thrum notes that in 1856, the heiau was entirely demolished and its stones used for road construction in Waikiki.

Destruction

Western contact, technological change, cultural shock, and Kamehameha's conquest destabilized Hawaiian society. The 1819 succession of Liholiho to Kamehameha II provided the impetus for a broad revolution against the old order from both above and below, and even from within the kahuna class. Several months later, Christian missionaries arrived in Hawaii.

In 1823, William Ellis noted the indifference and resistance of the natives to religious instruction, and their relief at emancipation from the kapu. The governor of Hawaii told Ellis that he would build a church when the people expressed an interest in religion again, and eventually he ordered a heiau dismantled and used for its construction (2004:91).

In the 19th C., many heiau were destroyed for road-building or by the expansion of industrial agriculture and urbanization. After the 1848 Mahele, private land tenure allowed many sites to be demolished or re-used for other purposes. The American military occupation also accounted for the destruction of many sites.

Few large heiau survive, such as the luakini, but most of the small heiau are destroyed. Helenihi of Makua, one of McAllister's informants, wrote that "there were many places of worship formerly, but only the knowledge of the large chiefly structures has come down to us. The small shrines of the commoner, in which the daily wants were prayed for, are lost" (McAllister 1933:11).

Typologies

The native historians Kamakau and Malo classified heiau into the two major functional archetypes; luakini and hale o lono. As noted, even these archetypes could overlap and the only definite distinction appears to be the separation between chiefly and commoner activity.

Thrum was the editor of the Hawaiian Annual and a keen antiquarian of ancient Hawaii, especially heiau. His efforts to record sites through native informants, oral histories, and fieldwork were the first systematic attempts to classify heiau, but as he notes:

> We are at least fifty years too late in entering upon these investigations for a complete knowledge of the matter, for there are no natives now living that have more than hear-say information on the subject, not a little of which proves conflicting if not contradictory. (Thrum, 1907)

Thrum estimated that out of all heiau constructed, only one-third survived from the pre-contact era. The knowledge of their functional type was limited to one-fourth of surviving heiau, most of which were themselves partially destroyed.

McAllister and his contemporary John Stokes were two of Hawaii's first archaeologists. His landmark Archaeology of Oahu (1933) contained an island-wide

survey of heiau. Like Thrum he relied upon native informants, though now a generation later. He lamented that "classifying the heiaus remaining on Oahu into types is an arbitrary and unsatisfying procedure. Not only are there too few of these structures, but no two heiaus, furthermore, are alike." He also utilized archeological survey to measure and record sites around the island. Stokes undertook similar research under the auspices of the Bishop Museum on the island of Hawaii.

Attempts to establish a rigorous typology were undertaken by Bennet (1932). The classification of artifacts, sites, and historical epochs was a popular activity for anthropologists of the era. Bennet relied upon a descriptive classification system to define heiau function. He separated heiau based upon size and features and then compared their features to other temple sites throughout the Pacific. The sheer number of differences in architectural styles, facings, and orientation defeated any attempts by Bennet to create anything more than the most arbitrarily defined categories, although he did note architectural similarities between Hawaiian and Marquesan temple sites.

Shimizu (1980) sought to discern the hand of an intelligent creator/architect by classifying the features and components of heiau. He argued that heiau were the product of “conscious, designed” efforts due to observed architectural elaboration and style. He also noted that heiau followed consistent patterns of orientation and distribution, although these conclusions were limited without precise spatial details.

Post-modern critique against typologies, and their negative impact on culture resource management, was exemplified by Cachola-Abad (1995). She argued that determining heiau function is difficult because of the tremendous physical diversity heiau exhibit, the necessary broad and non-physical nature of an accurate definition of the term

'heiau', and problems involved in assessing their specific religious functions. According to Cachola-Abad, archaeologists are guilty of ethnographic analogy when classifying heiau while ignoring culturally-derived assessments. The source of these privileged assessments is not identified.

Chapter II. Visibility

The visibility of heiau has often been noted and thought to have played an important role in their function and location. Early Western voyagers observed heiau atop hills and in locations favorable for views from the sea. Ethnohistory records that common practice was to sight heiau on slopes outside of and above villages, and early spatial analysis (Shimuzu 1980) suggests that the majority of heiau were located in the elevation zone between the coastal plains and hills. Visibility appears to be an important attribute for heiau, but how can this assumption be tested?

History

Two early studies attempted to quantify visibility for archaeological research. In successive studies of Neolithic Orkney, Renfrew (1979) and Fraser (1983) analyzed the visibility within the landscape of prehistoric rock cairns. Their work produced a rigorous methodology that introduced concepts like field-of-view, line-of-sight, and intervisibility that were later to become integral components of visibility analysis. Archaeoastronomy also made early contributions in its explorations of planetary and sky viewsheds of archaeological sites such as megalithic monuments in Scotland (Ruggles 1984).

Systematic attempts to quantify vision first emerged in the early 1990s within the post-modern archaeological movement, although this is likely due to the development of personal computer-based GIS systems rather than any theoretical synergy. In the United Kingdom, Post-Structuralist Archaeology imported the theoretical concepts of

phenomenology to distance itself from the quantitative methodologies of its predecessor. Phenomenology was formalized by the apostate National Socialist philosopher M. Heidegger (Thomas 1993). The philosophy explored the experiential connections between landscape and its inhabitants and saw extensive application in the architecture of the Third Reich (Taylor 1974; Virilio 1994).

Phenomenology privileges the role of vision as a perceptual act. Inhabitants of past landscapes perceive their surroundings on the human scale. They are "purposeful agents within their meaningful worlds" (Tilley 1993). Bender (1993) argued that the act of vision within a landscape was "bodily-centered" and "culturally-embedded." Tilley explored these concepts within the prehistoric landscape of Scandinavia (1993;1994). He argued that megalithic monuments formed an integral component of the spatial and visual relationships between the human landscape and the "lived" environment.

Visibility analysis adopts the tenets of phenomenology while utilizing quantitative methods to explore cognitive issues (Ogburn 2006). As Wheatley (1995) states, "...visibility analysis allows an humanized form of spatial analysis" and enables the mitigation of reactionary concerns against the use of GIS within the social sciences (Gaffney and Van Leusen 1995). These concerns are bolstered, Wheatley suggests, by the tendency of visibility studies to neglect theory under the appeal to explore new methodologies. Fisher (1997), however, argues the need for even more statistically rigorous techniques, regardless of critiques of environmental determinism.

Visibility in GIS

Geographic Information Systems offer the same advantages for archaeology as it does for other fields. Wheatley (2002:18) states that GIS allows for the creation of a "dynamic and flexible environment within which to integrate, express, analyse, and explore the full range of data, both spatial and attribute." This enables a combination of data from a wide variety of sources and creates, "in effect, an environment in which to think and explore ideas." The exploration of visibility is enabled by a variety of methods within the GIS toolset.

Intervisibility is the measure of how many sites are visible from each other. Gaffney and Stanic explored the role of intervisibility for a series of ancient Greek watchtowers in Dalmatia near the town of Pharos. The towers were found to be intervisible with each other in a chain and "formed an integral system connected to the town... whereby watch was kept for any approaching danger" (1991:78).

The lack of intervisibility can also provide meaningful archaeological interpretations. Lock and Harris (1996) examined the role of Danebury barrows as territorial markers. Their analysis of barrow sites revealed a bias against visibility- it appeared that they were positioned to avoid intervisibility with each other. They argued that this placement was purposeful to enable the barrows to act as territorial markers. Within its territory only a single barrow would be visible.

Lock and Harris also utilized the concept of field-of-view in their analysis of the defensibility of English prehistoric and Iron Age hillforts. A field-of-view represents the total area visible from a site. They imagined that sites with a larger field-of-view would be more easily defendable than those with smaller. They concluded that over the course

of time, sites were located in increasingly less defendable locations as other considerations, such as access to economic resources, became more important.

Martindale and Supernant (2009) noted that a large field-of-view did not automatically guarantee a high defensibility. For their study of the defensiveness of prehistoric Northwest American coastal villages they created ratios of site visibility to accessibility. Sites with visibility in all directions and limited avenues of approach, such as a hilltop, were rated the most defensible while those with both high visibility and easy accessibility, such as an island, were deemed the least. They combined these ratios with other factors to create a defense index for each site.

Jones (2006) utilized viewsheds to determine whether Iroquois settlements were located in highly defensive locations. A viewshed is the map representation of a field-of-view from a site. Jones determined that proximity to resources was more important than considerations of defense for determining the location of Iroquois villages.

Viewsheds over the sea can also be determined for coastal sites. Fisher (1996) employed random sampling to discern whether maritime viewsheds were significant for the location of cairns. The rock cairns on the headlands and promontories of Mull Island were assumed to be part of the island's prehistoric maritime culture and their distance from the sea therefore a significant measure of their function.

Wheatley (1995) introduced a "Cumulative Viewshed Analysis" in his study of the long barrows of Stonehenge and Avebury. The Cumulative Viewshed Analysis allowed the combination of viewsheds from multiple sites to map the most visible areas within a landscape. The cumulative viewshed could then be statistically analyzed to

determine if sites were located with respect to visibility. Wheatley determined that this was indeed true for the long barrows of Stonehenge but false for those of Avebury. He suggested that the two complexes may have been built by different cultural groups. Fisher and Farrelly (1996) contended that these results may have included a methodological or topographical error, and suggested a more comprehensive cumulative viewshed analysis utilizing a larger sample and better statistical analysis (Openshaw 1991).

Lake, Woodman, and Mithen (1997) conducted a more intensive CVA on the Mesolithic sites of Islay, Scotland. They proposed to determine if sites were in the most visible locations by compiling a cumulative viewshed composed of viewsheds from every cell in the landscape. In order to accomplish this intense computational task they developed scripting and native-code algorithms for the GRASS GIS application. Although their tool for enabling CVA within GRASS greatly reduced the amount of time required, they still found that random sampling was required for large study areas.

Critique

There is a wide critique of visibility analysis. Wheatley (1995;2001;2002) outlines several of the problems and limitations of visibility analysis for archaeological study.

Methodology is one potential source of error. The calculation of visibility relies on a digital elevation model (DEM). According to Wheatley (2002), the precision and accuracy of the DEM is the most important factor as it is the virtual model upon which every analysis is conducted. However, even accurate DEMs can have a negative impact on a study dependent on its resolution. DEMs with small resolutions can simplify terrain

features (Gillings and Wheatley 2001), while more detailed DEMs can introduce terrain features that are not relevant and demand increased computational resources. Wheatley states that these errors can be avoided by using a vector DEM, such as a TIN, which allows the sample density to increase where needed.

Fisher (1991) argues that since all DEMs contain measurement errors, viewsheds should be calculated by introducing a probability of error within the DEM. This would generate a 'fuzzy' viewshed instead of a simple binary in view/out of view result. Higuchi (1993) further elaborated on the concept of the fuzzy viewshed. In his study of Japanese landscapes, he proposed that viewsheds be separated into classes based on factors such as the distance from the viewer and object clarity. Ogburn (2005) utilized fuzzy viewsheds to determine the levels of visibility for Inca storehouses from neighboring villages.

Intervisibility relies on the assumption that the act of vision is reciprocal between the viewer and the viewed. However, the visibility of a site can be impacted by its physical features and background (Fisher 1996). While a monument on a hilltop may be outlined against the sky and widely visible, one on a hillside may be more difficult to discern (Tilley 1993).

An example of this process was in the construction of the fortifications of the *Atlantikwall* along the European littoral. The documentary record provides evidence that naval observation towers in the Channel Islands were designed to act as prominent monuments (Cruickshank 1975). They were several stories in height and positioned to be both highly visible and contain wide fields of view. In contrast, army coastal artillery towers on the French mainland, while also located to retain extensive views, were themselves well hidden or camouflaged.

Temporal natural processes such as shadow, season, and weather can also affect intervisibility and the accurate calculation of viewsheds. The threat of the trees, or what Wheatley terms the 'tree factor' (2002), can hardly be estimated, although for studies in prehistoric North America we know that there are more trees today than in the past. Weather, season, time of day, and the topographical differences between the past and present landscape can also affect the accuracy of a visibility calculation. Perhaps because none of these factors can be accurately determined- beyond the introduction of further 'fuzziness'- attempts to model them in the literature are few.

A further limitation of visibility analysis is the failure to reflect the mobility of an observer. Wheatley argues that if vision is an 'embodied act' then the visibility calculations must simulate those of a real person. This should include variances in height, location, and perspective. This limitation is exacerbated by the lack of an extensive temporal analysis available within GIS applications (Peuquet 2002).

A final complaint against visibility analysis attacks the ethnographic reliance on the supremacy of vision. The modern role of vision as the primary sense may not equate to the experience of those in other cultures or eras. The ascendancy of vision may have been reinforced by Renaissance and Enlightenment art and philosophy (Cosgrave 1985). Wheatley (2002) suggests that vision be replaced with a measure of 'awareness.' Awareness would include vision, smell, and sound and in effect encompass the totality of human sensory input within a landscape.

Chapter IV. Data Methodology

The project initiated as a quantitative analysis of heiau, however, it was discovered that no comprehensive spatial dataset existed. A variety of primary, archaeological, and secondary sources were consulted to assemble an adequate dataset. The dataset is not a complete record of Oahu heiau but provides a sufficient number of sites for an exploratory data analysis.

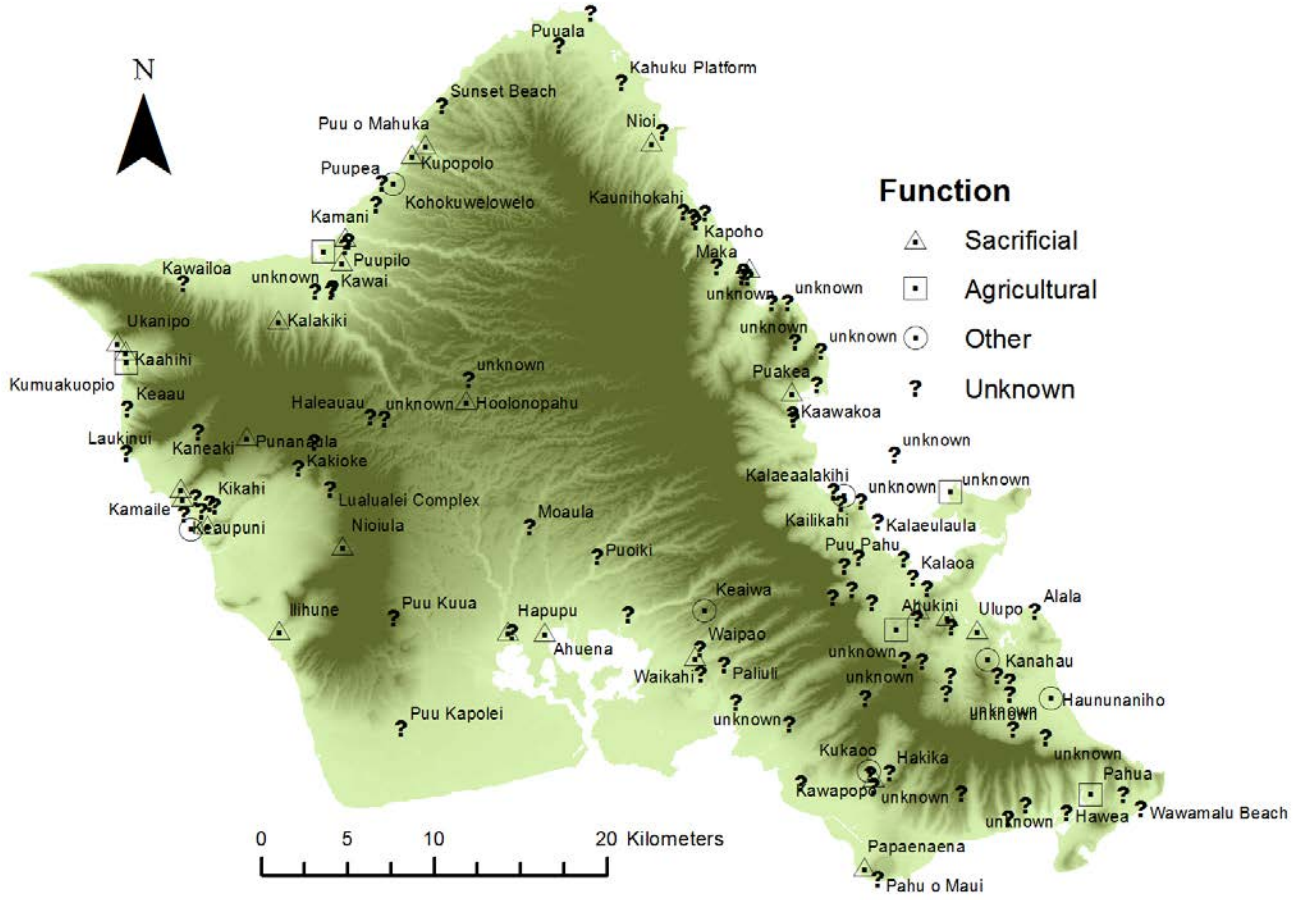

Figure 8. Map of heiau sites by function.

Data Sources

A dataset was obtained from the Office of Hawaiian Affairs (2010) courtesy of Jason Jeremiah. It was delivered as a shapefile containing approximately one hundred records. This dataset may be a partial remnant of a lost State Historic Preservation District database. According to rumor a member of their GIS staff absconded for a commercial CRM firm with a copy of their historic sites database.

The dataset itself is of dubious quality and contains many cryptic references. No metadata was included. Most of the text fields are fragmented or contain formatting errors. The site locations are in UTM Zone 4. This dataset was treated with suspicion and its contents replaced with information from other sources when possible.

Shimuzu (1980) produced a thesis for the University of Hawaii at Manoa Masters of Architecture program which is available in the Hamilton Library. The document lists Oahu heiau including tables of descriptions and site plans based on McAllister (1933). Most of this information is also provided by Sterling and Summers (1978). The study lacks precise coordinate information but does include information on district, site number (as established by McAllister), function, and status.

The Lloyd Soehren Hawaiian Place Names database (2010) represents a prodigious effort. Soehren, a professional archaeologist from Hawaii Island, researched geographic place names, Mahele Commission records, historic maps, and archives. The dataset is available for queries on the Internet but Soehren provided the entire original *dbase* files for the island of Oahu. *Dosbox*, a multi-platform *MS-DOS* emulator, was used to open the files in *dbase* and export to the CSV format. This was only necessary because

the *dbase* program separates the text fields of each record into a separate file. The Soehren dataset fields consist of coordinates (in Hawaiian State Plane format, Old Hawaiian datum, NAD1927), district, comments, and lexicology.

The State Plane coordinates were converted to UTM Zone 4N/WGS84 using the US Army Corps' *CorpsCon* conversion software, and then combined with the records of the Shimuzu and OHA datasets.

Thrum's Hawaiian Annual (1907,1908,1911) includes multiple articles about heiau and the Hawaiian culture. Thrum had an antiquarian interest in monumental sites. His research predates archaeological investigation and was based upon native informants and translations of contemporary ethnohistories. He compiled several lists of heiau by island; including their function, general location, and other notable text.

Sterling and Summers' Sites of Oahu (1978) is a contemporary update of McAllister (1933). The work lists the cultural and archaeological features of the island by district using McAllister's numbering system. The maps for each district appear to be tracings from either USGS series 1927 or 1954, and contain limited topographic detail such as contours, shoreline, hilltops, roads, district boundaries, and benchmarks. The book also contains excerpts of McAllister's descriptions, references, and sketches.

The district maps were digitized with a large-format scanner and geo-rectified in the *Global Mapper* program. Existing geo-referenced USGS topographic rasters (1992 series) from the UH-SOEST Coastal Geology Group and a shapefile of ancient ahupua`a boundaries from the State GIS website served as base maps for the process.

The applications **Google Earth and NASA World Wind** were used to virtually ground-truth the locations of existing heiau by exporting the heiau dataset as a KML format vector layer from Global Mapper.

Historic Army Corps/USGS topographic series (1936, 1952) were also used if they noted heiau, although as there is no metadata for historic features these sites are treated with suspicion. Site 124 is marked on the 1936 and 1954 Kaena quads but no other information was discovered.

Site Visits were made to a few existing sites to verify coordinate accuracy and record photographs. In general, accuracy was to found to exceed the known or estimated size of the sites or the topographic features.

Ethnographic research was not conducted in this study. A complete ethnographic exploration of heiau sites would be a fantastic but monumental complementary project. It would be interesting to compare results from ethnographic and archaeological studies- however, we are now orders of magnitude removed from the questionable knowledge of McAllister's informants.

Data Format

The data format is a semi-colon delimited text file. There are 127 records in the dataset of heiau with known locations. The file contains the following fields:

Descriptive Fields

Northing/Easting: Coordinates are in UTM Zone 4N projection/WGS 1984 datum. Four decimal places are used which gives precision to 11 meters.

Site Number: The site number is inherited from McAllister (1933) and included in Sterling and Summers (1978) and the Soehren database.

Name : The name as recorded by McAllister (1933) or given in Sterling and Summers (1978). Diacritical marks are included when known.

Location / District : The location as given in Sterling and Summers (1978) which is generally the *ahupua`a*. The district is either Ewa, Waianae, Waialua, Wahiawa, Koolauloa, Koolaupoko, or Kona. In the pre-contact era Wahiawa and Waianae districts were one but for the purposes of spatial organization were separated in the dataset.

Condition / Function : The condition (destroyed, existing, or unknown) as given by McAllister (1933), Thrum (1907), or by later observers such as Sterling and Summers (generally circa 1955).

Location Source : The bibliographic source for the spatial coordinates. If multiple sources agree then all are listed. The order of reliability (descending) is modern aerials and site visits, USGS topographic, Sterling and Summers; McAllister, Lloyd, and OHA.

Text : Text from McAllister, Thrum, or Sterling and Summers including site description, disposition, informants, and other relevant details.

Lexicology : A translation of the place name from Lloyd's database. The lexicology can provide clues to a site location and function.

Comments : Comments generated from research or site visits.

Images : Image negative numbers or sources if given in Sterling and Summers (1978).

Spatial Fields

Elevation : The elevation (in meters) of a site determined from the 10m DEM of Oahu.

Slope : The terrain slope a site is located within, in degrees from 0 to 90. This value was interpolated from the 10m DEM base map and an overlay of site locations in GRASS.

Aspect : The aspect is the direction the slope faces, in degrees true north, from 0 to 359. The aspect was also computed in GRASS. Note that sites on flat ground are given a null value.

Viewshed (Sea and Land) : Visibility was determined by creating a viewshed for each site in the application ArcGIS/Spatial Analyst using a 30m DEM of the State. The transmitter height was set at 2m above ground level. Atmospheric interference was set at .13 (the program default) and earth curvature correction enabled. Sea viewsheds were subtracted from the total using a shapefile outline of historic Oahu. Viewshed measures in square kilometers for sea, land, and as totals of both are also included.

Intervisibility : Intervisibility is the measurement of how many other sites each site can see. It was calculated in ArcGIS/Spatial Analyst with the viewshed command using a 10m DEM of Oahu. The transmitter and receiver heights were set at ground level.

Horizon Distance : The distance from a site to the horizon (in meters).

Neighbor Islands : The number of the neighboring Hawaiian Islands visible in the viewshed for each site.

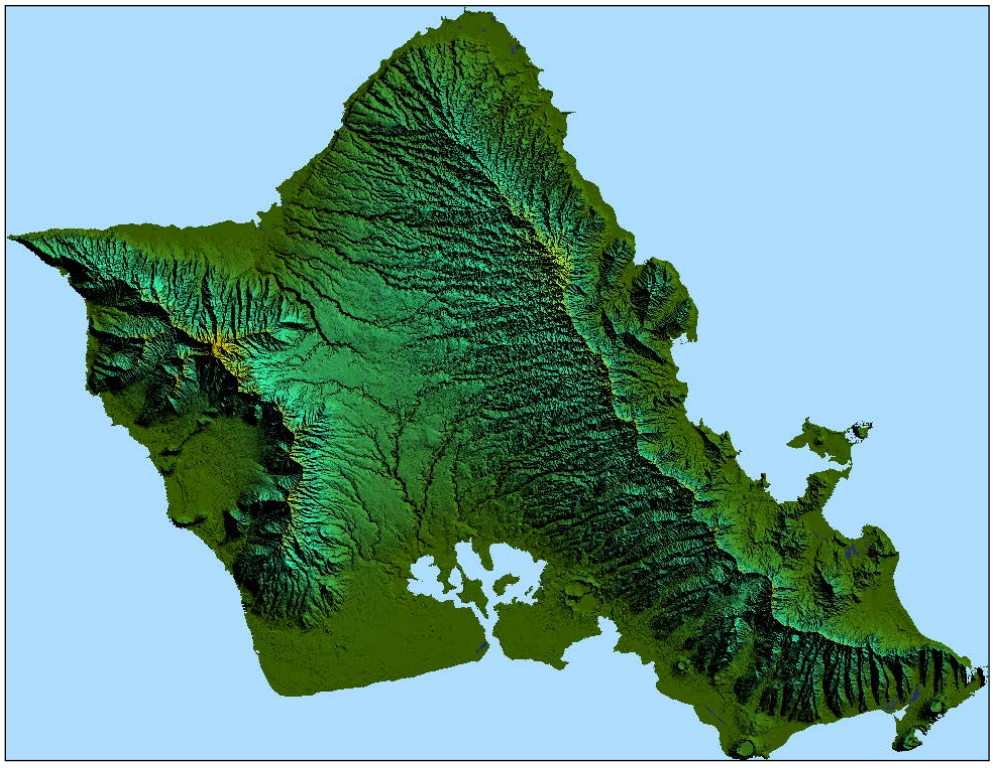

Figure 9. 10m DEM of historic Oahu.

Data Description

The dataset contains 127 heiau. Although Sterling and Summers (1978) list over two hundred heiau in their index, the dataset represents those sites for which acceptable spatial precision could be discovered. Another fifty-five heiau from the Soehren database were not included as their position could not be accurately determined beyond their general location.

The function of sites within the dataset is known for only thirty-six, or as Thrum estimated, about one-fourth (see **Figure 8**). Of the known sites, five are agricultural, eight of other classification (including one pu`u honua, two possible forts, several larger koa, a priestly university, and a heiau dedicated to healing), and twenty-five are sacrificial luakini.

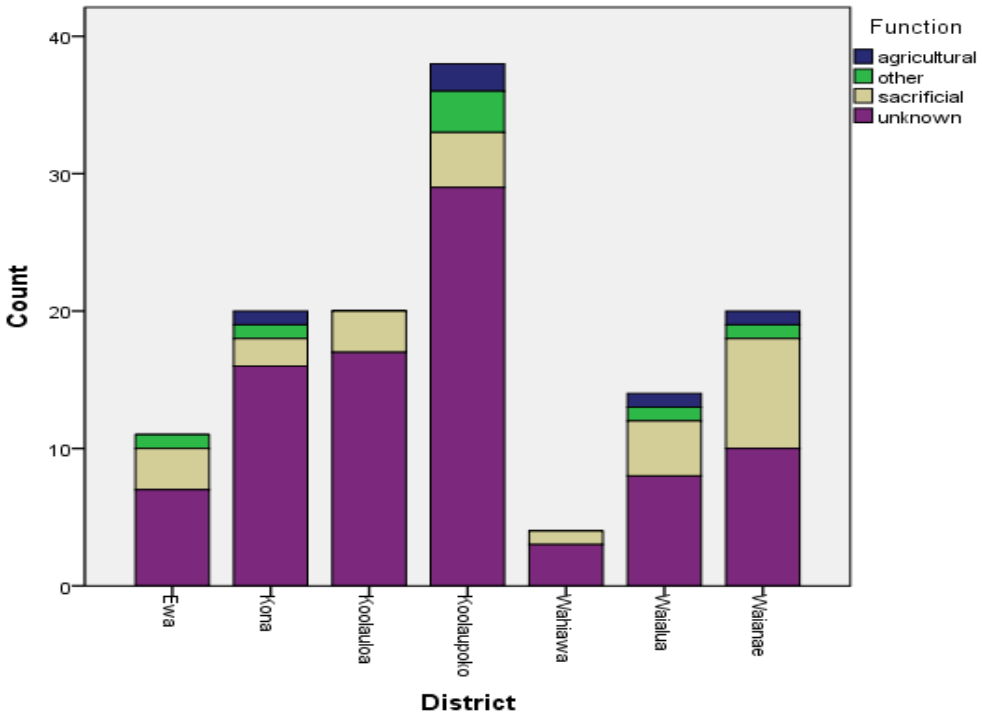

Figure 10. Heiau Function by District

Heiau are not evenly distributed around the island. Eleven sites are in the Ewa district, at least sixteen in Kona, seventeen in Koolauloa, thirty-eight in Koolaupoko, four in Wahiawa, fourteen in Waialua, and twenty-one in Waianae. The number of sites in Kona is underrepresented due to the extensive urbanization of the area.

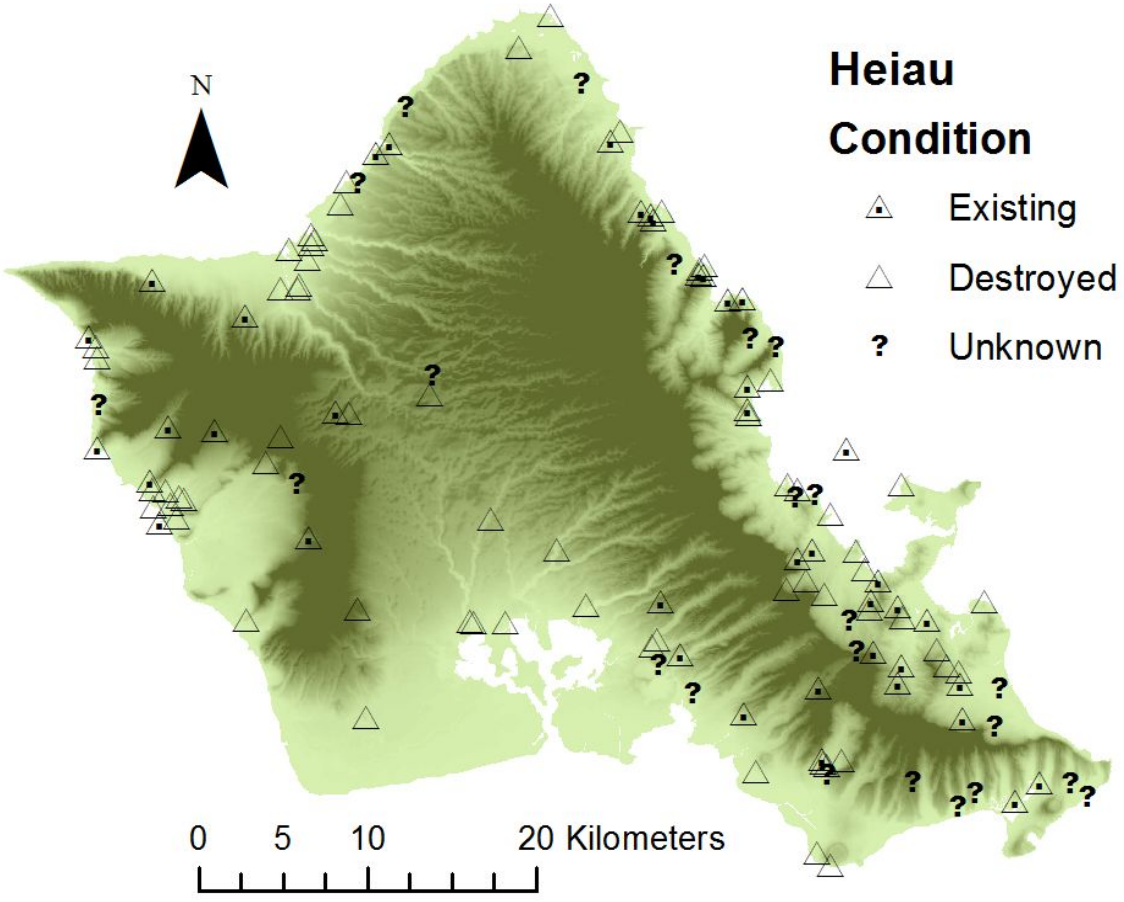

Figure 11. Existing, destroyed, or unknown heiau.

At least forty heiau in the dataset still exist. Sixty-four are known to be destroyed either within the ancient or historic eras. All districts have suffered severe losses. The status of twenty-six sites is unknown.

Table 2. Sacrificial Heiau of Oahu

Site ID	Name	Location	District	Condition	Location Source	Notes
14	Papaenaena	Palolo	Kona	destroyed	McAllister 1933:71; RM 1382. Thrum 1907:44	"At foot of Diamond Head slope." (Thrum 1907)
15	Hipawai	Manoa	Kona	destroyed	Sterling and Summers 1978:286	"On the sea side of the Manoa church. Of large size and pookanaka class, partly destroyed many years ago, then used as a place of burial. Remaining walls subsequently torn down" (Thrum 1907:45).
21	Waikahi	Halawa	Ewa	destroyed	McAllister 1933:103; Sterling and Summers 1978:10	"On the flat area on the mountain side of the road where the two gulches of Halawa meet.
26	Ahuena	Waipio	Ewa	destroyed	Sterling and Summers 1978:19	"Just seaward of the Experiment Station of the Hawaiian Sugar Planters' Association
28	Hapupu	Waikele	Ewa	destroyed	Sterling and Summers 1978:25	"The Waipahu plantation stables on the mountain side of the road across from the schoolhouse west of the town now occupy the site of the former heiau at Waikele.
32	Ilihune	Nanakuli	Waianae	destroyed	Sterling and Summers 1978:62	"A small walled heiau of pookanaka class; used about 1860 by Frank Manini as a cattle pen, for which the natives prophesied his poverty and death." (McAllister 1933)
33	Nioiula	Lualualei	Waianae	existing	McAllister 1933:110; Sterling and Summers 1978:66	"A paved and walled heiau of pookanaka class, about 50 feet squar,. in two sections; recently destroyed." (Thrum 1907:47)
35	Puu Paheehee	Waianae Kai	Waianae	destroyed	Thrum 1907:47; Sterling and Summers 1978:68	"A once walled heiau of two or three divisions, 70 feet in width, of luakini class, now in ruins; the outer portions entirely gone. Its slopes are now used as burial place for Japanese."
42	Kane-i-ka-pua-lena	Waianae	Waianae	destroyed	Sterling and Summers 1978:72	"Kane heiau, Kamaile. The approximate location in the cane was pointed out, but all the stones have been removed.
43	Kamaile	Waianae	Waianae	existing	McAllister 1933:114; Sterling and Summers 1978:73	On the State Register of Historic Places along with a complex in the area. "Kamaile heiau, on Kamaile ridge between Waianae and Makaha Valleys, an elevation about 400 feet, just above pumping station.
44	Punanaula	Waianae	Waianae	existing	McAllister 1933:116	"Located on a ridge at tie foot of Kawiwi, this heiau commands an impressive view of waianae and Lualuelei valleys.
49	Kaahihi	Makua	Waianae	destroyed	Sterling and Summers 1978:85	"Though the stones from the heiau have been removed, the site is still in evidence, for the heiau was built on a mound of earth 25 feet or more in height and approximating 100 feet square.
50	Ukanipo	Makua	Waianae	existing	McAllister 1933:124; Sterling and Summers 1978:85	"The present remains indicate a heiau of elaborate construction, not so much in size as in appearance.
53	Kalakiki	Kamananui	Waialua	existing	McAllister 1933:129; Sterling and Summers 1978:103.	On the State Register of Historic Places. "located on the crest of the ridge, with a slope on all except the mountain side, a large front terrace is about all that remains of the structure.

Table 1. (Continued) Sacrificial Heiau of Oahu

60	Hoolonopahu	Wahiawa	Wahiawa	destroyed	McAllister 1933:137; Sterling and Summers 1978:141	"A heiau which functioned in connection with Kukaniloko, the birthplace of alii. Here were kept the sacred drums of Opuku and Hawea which announced the birth of an alii. Nothing now remains of the temple.
61	Hekili	Paalaa	Waialua	destroyed	McAllister 1933:140;Sterling and Summers 1978:112	"At Palaa-uka, near the twin bridge, below the road; of luakini class and place of refuge; long since destroyed" (Thrum, 1907. p.47). " The site is said to be occupied by the Buddhist temple.
65	Kamani	Paalaa	Waialua	destroyed	McAllister 1933:141;Sterling and Summers 1978:115	"At the location of the present Haleiwa Hotel."
68	Kupopolo	Kawailoa	Waialua	existing	McAllister 1933:144; Sterling and Summers 1978:123-125; USGS 1952.	On both the State and National Register of Historic Places. "On the Waialua side of Waimea point.(Thrum, 1907, p. 48). (Shimuzu Appendix B)
69	Puu o Mahuka	Pupukea	Koolauloa	existing	Sterling and Summers 1978;aerials; site visits	On the State Register of Historic Places; also a National Landmark.
73	Nioi	Laie	Koolauloa	existing	Sterling and Summers 1978:158	On the State Register of Historic Places.
82	Kaumakaulaula	Punaluu	Koolauloa	destroyed	Sterling and Summers 1978:167	"Sea side of the government road, Punaluu."
88	Puakea	Hakipuu	Koolaupoko	existing	McAllister 1933:168-170; Sterling and Summers 1978:185	"A large three-terrace structure. Almost all of the stones have been removed for road building, but enough of the earth foundation and occasional walls remain to indicate its former size and features."
103	Kawaewae	Kaneohe	Koolaupoko	existing	aerials;McAllister 1933:179.	On both the National and State Registers of Historic Places.
106	Pahukini	Kailua	Koolaupoko	existing	aerials;McAllister 1933:182; Sterling and Summers 1978:228	On both the National and State Registers of Historic Places.
109	Ulupo	Kailua	Koolaupoko	existing	aerials;USGS 1994; Sterling and Summers 1978:233-34	On both the National and State Registers of Historic Places.

Table 3. Agricultural Heiau of Oahu

Site ID	Name	Location	District	Condition	Location Source	Notes
4	unknown	Kaneohe	Koolaupoko	Unknown	Sterling and Summers 1978:220	".. And further mountainward, the remains of a 'heiau' or heathen temple, topped the crest of a little rise that overlooked an ancient trail which skirted windward Oahu…" (Sterling and Summers 1978:220)
9	Pahua	Maunalua	Kona	Existing	Sterling and Summers 1978:264-65	"Pahua heiau, near the the end of the ridge dividing Kamilonui and Kamiloiki valleys. This heiau is 68 by 40 ft in extent and is primarily a built-up rock terrace with several low division walls. It was one of the smaller heiaus, probably of the husbandry class."

Table 2. (Continued) Agricultural Heiau of Oahu

47	Kumuakuopio	Makua	Waianae	Destroyed	McAllister 1933:123; Sterling and Summers 1978:83	"Size about 46x80 feet of husbandry class" (Thrum 1907:46). "The site is on the mountain side of the present church and is known by the natives, though nothing remains of the heiau except a sand platform…"
62	Kapukapuakea	Paalaa kai	Waialua	Destroyed	Sterling and Summers 1978:112	"East end of Kaiaka Bay, on the sea side of the railroad track. The site is remembered and pointed out, but nothing remains of the heiau. (McAllister 1933; Sterling and Summers 1978:112-113)
108	Unknown	Heeia	Koolaupoko	Destroyed	McAllister 1933:184; Sterling and Summers 1978:202	On the elevation overlooking Kaneohe Bay. "A large heiau on which became the site of a Catholic church. The ruins within the enclosure are those of the church, but the surrounding walls have the appearance of greater age." (McAllister 1933).

Digital Base Map

A composite Digital Elevation Model (DEM) was created from data available on the *National Geospatial Data Website.* A 10-meter resolution DEM of the island of Oahu was combined with a 30-meter resolution DEM of the State from Hawaii to Kauai islands and re-sampled at 30-meters. This was done to correct errors within the 30-meter DEM of Oahu. In order to avoid any edge effects when computing viewsheds, it was important to include neighboring islands and ocean areas and around Oahu. In the resulting composite DEM, areas at sea level and the sea itself contain values of zero. Every other 30-meter cell contains an integer elevation value. The composite DEM was approximately 1.4 GB in size.

For finer details A 10-meter resolution DEM of historic Oahu was created by cropping a contemporary 10-meter DEM of the island with a 19th C. historic coastline shape file from the State of Hawaii GIS database. This modified DEM was used for computing intervisibility.

Chapter IV. Statistical Analysis

Exploratory Data Analysis

Exploratory Data Analysis (EDA) is an inductive examination of statistical data (Tukey 1977). EDA encourages the exploration of data through a variety of statistical techniques in the intent to discern internal 'existential' relationships (Cowgill 1968). These relationships can then be tested with a confirmatory statistical analysis. An EDA was attempted to explore questions of visibility for Oahu heiau. These questions included:

Are heiau located in areas to ensure broad views of surrounding landscapes?

Are these broad views mostly of sea or land?

Are there any differences in the size of views by the functional archetype of a site? Or by district?

What role does intervisibility play in heiau location?

Viewsheds

A viewshed is an area of terrain visible from a geographic location within a GIS. The viewshed is computed by determining the visibility of each cell within the digital elevation model raster to a specified location using a line-of-sight profile. Cells that are visible from the specified location are given a value of 1 and all others are given a value of 0 in the viewshed output raster.

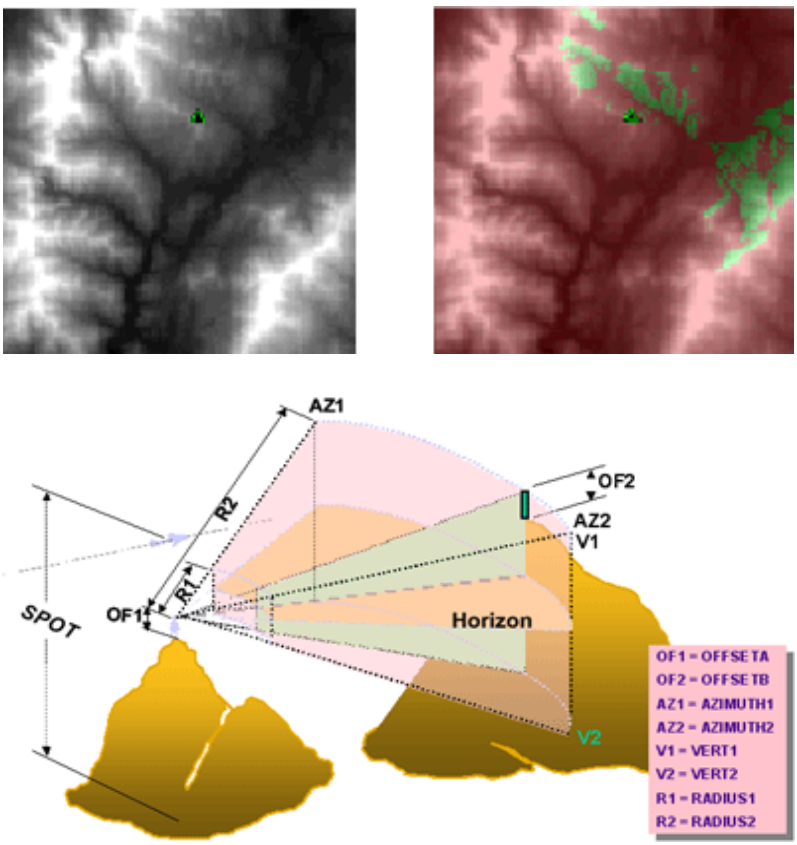

Figure 12. Viewshed calculation. A vector shapefile is overlaid a digital elevation model raster and a single location selected (top left). The viewshed calculation results in a raster with visible cells shaded green (top right). The parameters available to the viewshed tool within the ArcMap application (bottom). (ESRI 2010)

Once a viewshed raster has been generated, raster algebra can be used to separate sea and land terrain viewsheds. For example, the viewshed of Pu`u o Mahuka in the district of Kololauloa was calculated on a 10m DEM of the island of Oahu. The site is located atop a coastal bluff above Waimea Bay, and because of its high elevation has substantial views both seaward and including the Waianae range of the neighboring Waialua district (see Figure 14). When recalculated using a 30m DEM of the major Hawaiian Islands, the sea viewshed also includes the higher elevations of the island of Kauai more than 100 kilometers away. A map (Figure 13) of the island of Oahu shows, unsurprisingly, that most sites have generally large sea and small land viewsheds.

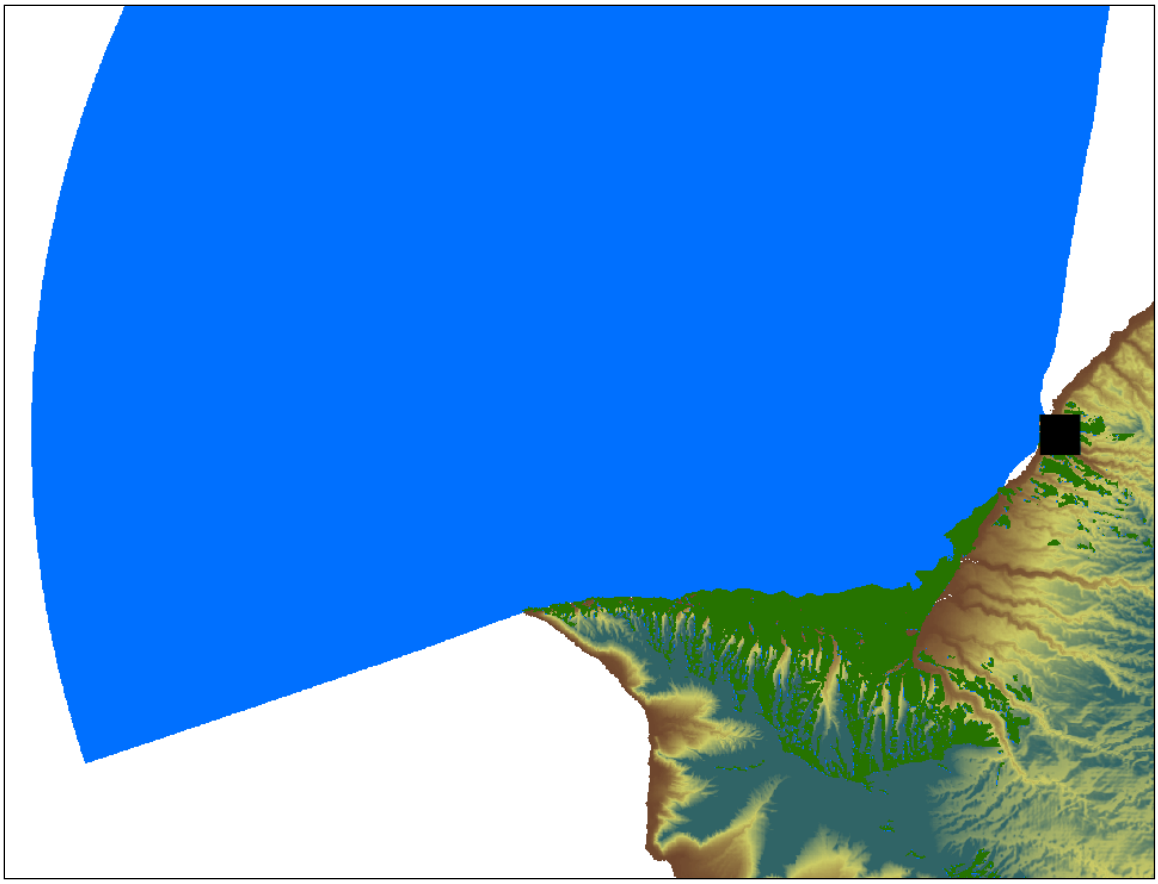

Figure 13. Sea (blue) and land (green) viewsheds of site Pu`u O Mahuka, Kololauloa district.

Pu`u O Mahuka, a noted luakini class heiau, has a relatively large viewshed compared to other sites, probably due to its elevation and location. As a group, luakini (25 sites) have relatively large viewsheds compared to sites with other functions. Sites of unknown function (90) have a slightly smaller mean viewshed while sites of 'other' function (7) have the largest. Agricultural sites (5) have a small mean viewshed. The large size of the unknown function group only allows tenuous conclusions but it is interesting to note the definite difference in mean viewsheds between the luakini and agricultural groups.

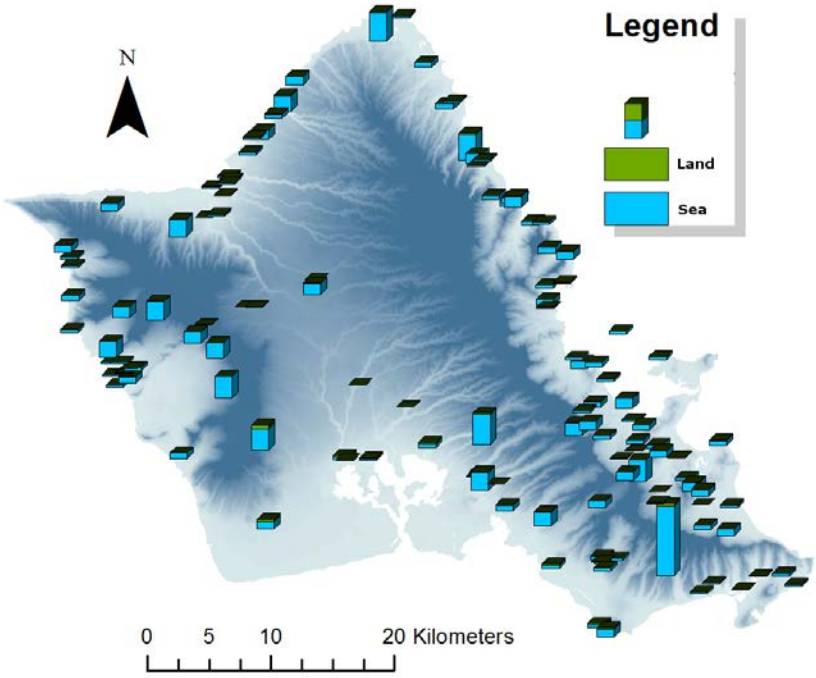

Figure 14. Land and Sea Viewsheds of Oahu Heiau. Vertical bars represent relative sizes of land and sea viewsheds from heiau sites.

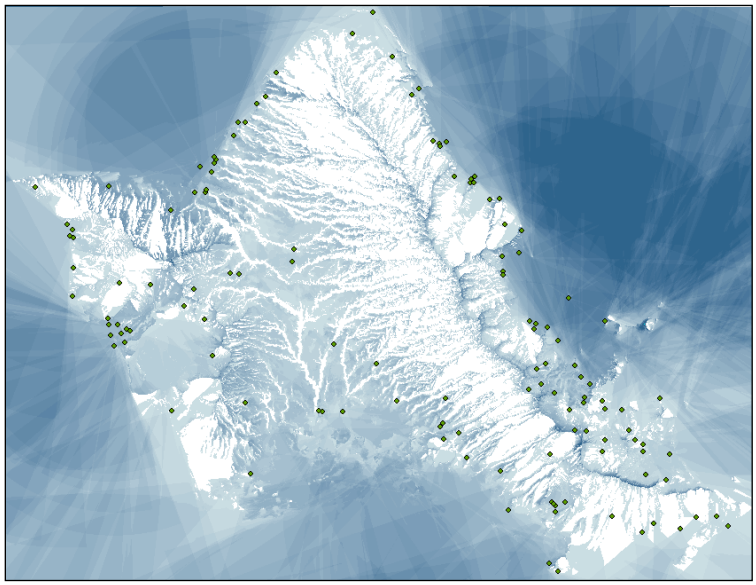

Figure 15. Viewsheds of Oahu heiau. Darker blue areas represent overlapping viewshed arcs.

How do site viewsheds compare by districts? There appears to be some variation, perhaps caused by topographic differences in the characteristic terrain type. Ewa sites (11) feature large viewsheds across the expanse of Mamala Bay, although the proportion of the total viewshed is small. Waialua contains a roughly similar number of sites (13) but a much smaller mean viewshed. This may be because heiau that would have been located on coastal bluffs within the western ahupua`a such as Kawaihapai, Kealia, and Kaena are not well represented. Koolaupoko (36) contains the highest number of sites but also has a low mean viewshed, perhaps because sites tend to be located within the narrow valleys or low coastal strip particular to the region. Waianane (20) and Koolauloa (21) districts share similar means and proportions. Wahiawa (4) is under-represented in the dataset but its viewsheds are limited by its location.

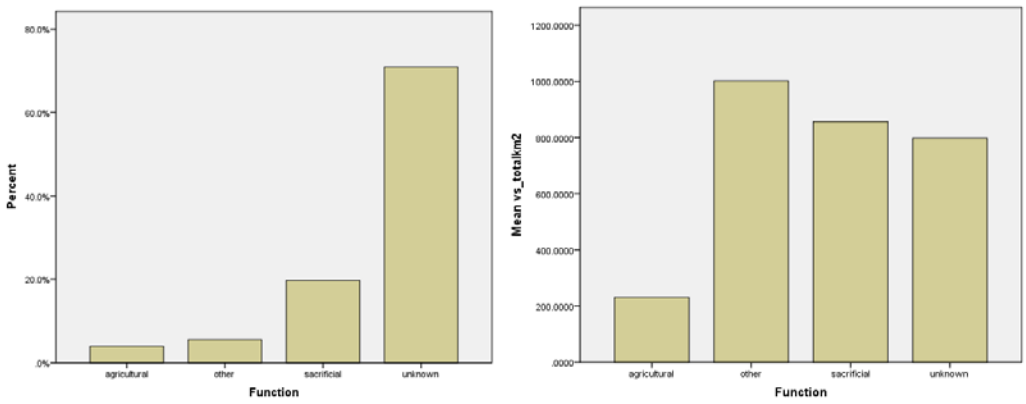

Figure 16. **Distribution of Viewsheds by Function Type.** Histograms of the proportion of heiau in each function type category and their mean viewsheds by function.

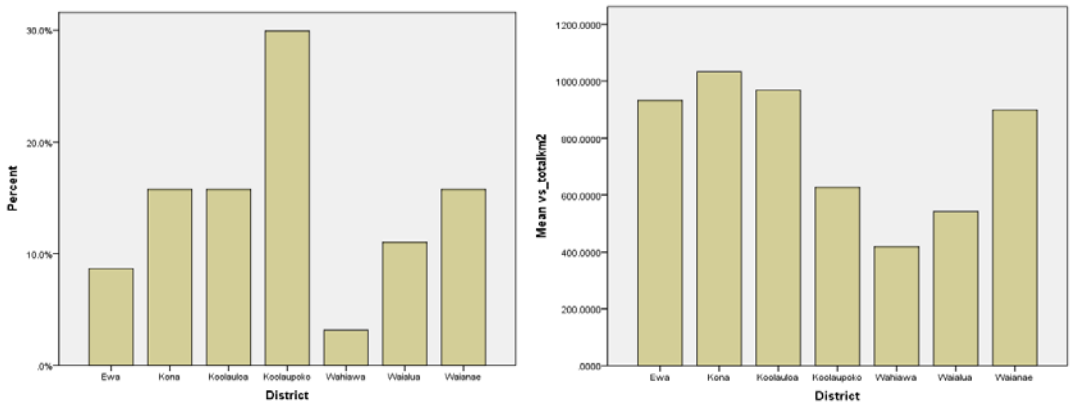

Figure 17. Distribution of Viewsheds by District. Histograms of the proportion of heiau within each district and their mean viewsheds by district.

How is the size of viewsheds distributed? Histograms of total, sea, and land viewsheds show similar distributions and that the majority of viewsheds are smaller. Although their distribution is similar, does the size of viewsheds vary between sea and land terrain?

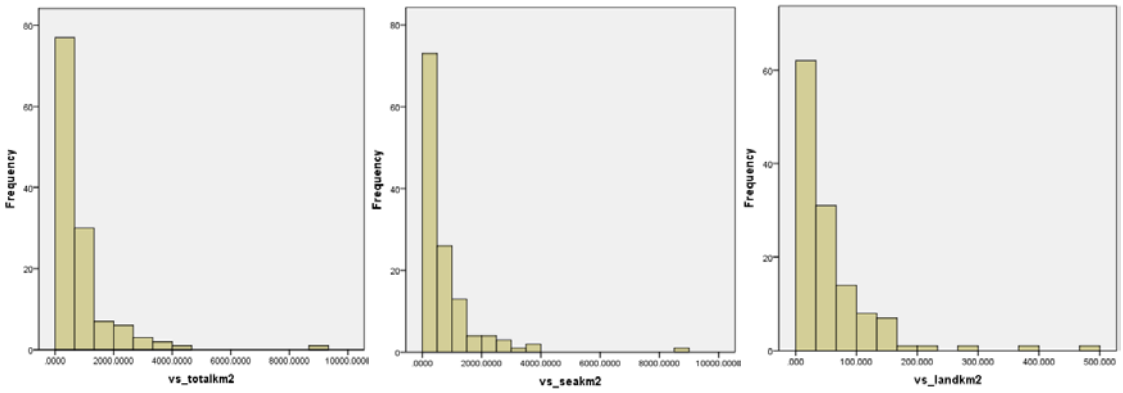

Figure 18. Histograms of Total, Sea, and Land Viewsheds.

In every district sea viewsheds are vastly larger than land viewsheds. Terrain differences may impact the ratio between sea and land viewshed sizes. Ewa, Kona, Waialua, and Wahiawa districts, which consist of broad plains and upland areas, feature larger proportions of land viewsheds. However, Waianae district also contains large

upland valleys but still features a smaller sea to land viewshed ratio. Sites within Wahiawa district, furthest removed from the coast, have the largest proportion of land viewsheds, but the location of individual sites is most likely the largest determinant rather than sweeping geographical generalizations. If anything, it is apparent that viewshed as a measure of visibility does not provide a concise mechanism to base conclusions upon. What can?

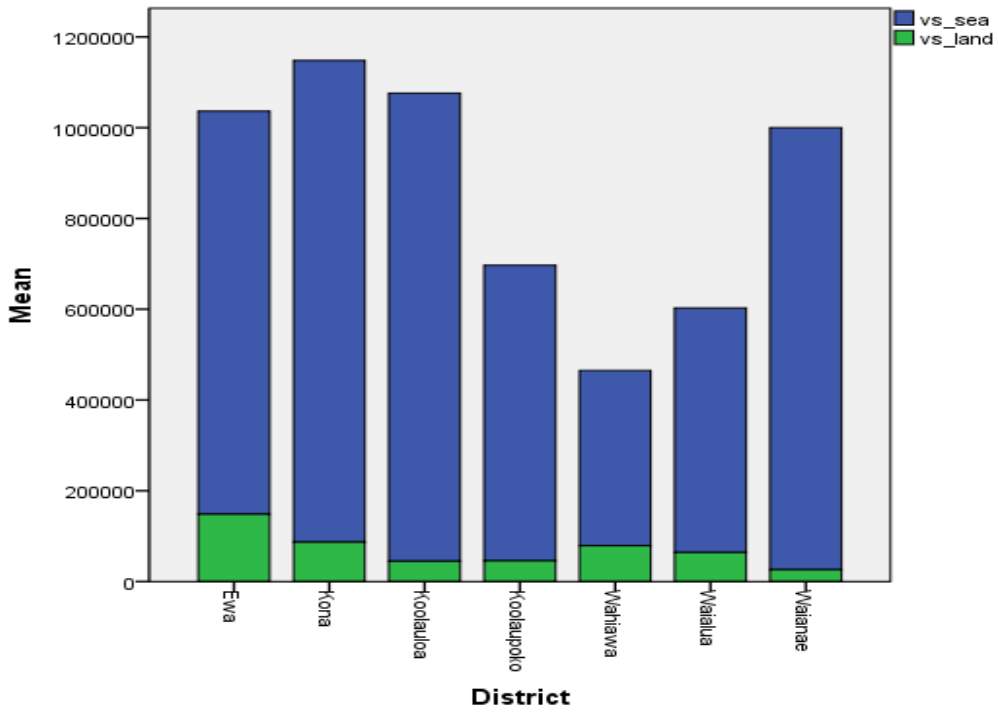

Figure 19. Sea and Land viewsheds by District. Mean sea and land viewsheds of heiau by district.

Intervisibility

Intervisibility can function as a quantifiable measure of visibility. The intervisibility value is the number of defined locations visible from a specified position. In this case, it is the number of other heiau visible from each site, not including itself. The calculation of intervisibility is similar to the viewshed tool in a GIS but is done iteratively

for a sequence of geographic locations. The output raster records the intervisibility value as an integer in each cell.

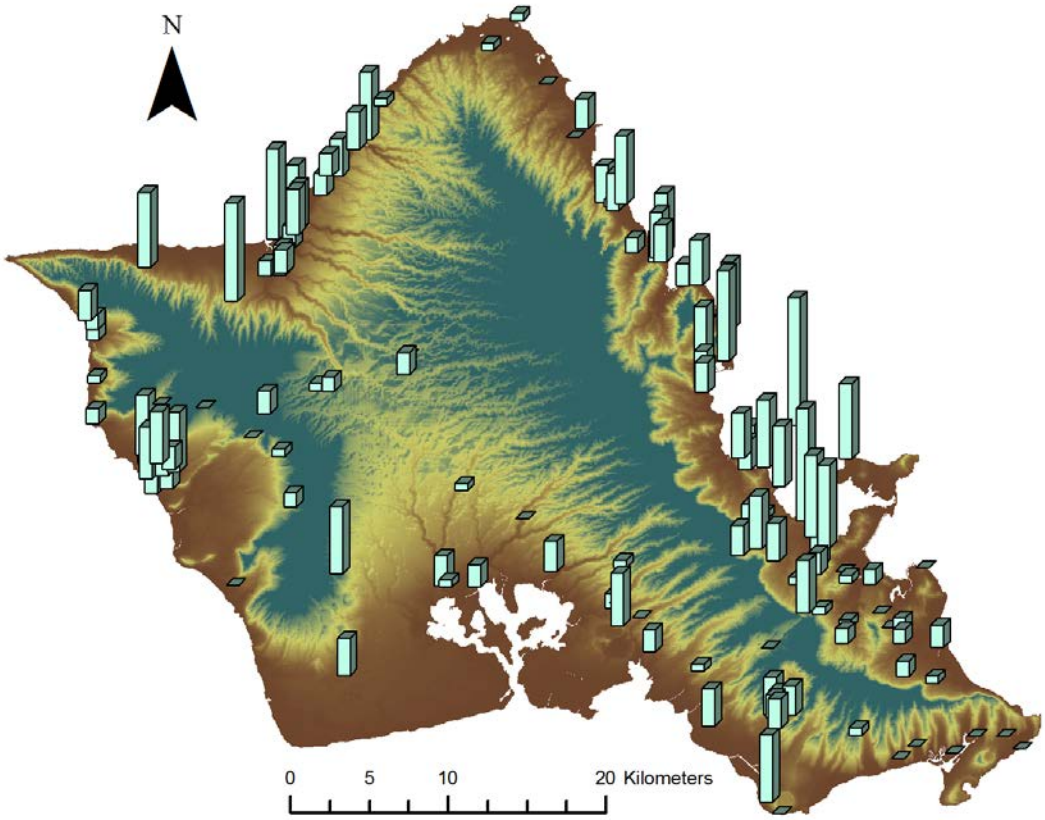

Figure 20. Relative intervisibility of Oahu heiau.

Using intervisibility as a function of visibility offers several advantages. As a single integer value the computational process to analyze large sets of data is much simpler than an unwieldy viewshed raster. The GIS calculations are also much faster and allow greater precision. For example, the viewsheds in this study were generated on a 30m DEM of the entire State of Hawaii. This was done to avoid edge effects and incorporate the vast sea viewsheds, as well as record visibility to outlying islands. The problem of using such a massive raster meant a large increase in computing time and a loss of precision when calculating visibility at the resolution of 30m per cell.

The intervisibility calculations allowed the use of the 10m DEM of the island of Oahu because sea visibility is not required and there is no danger of edge effects. This resulted in a faster computational cycle and the ability to perform multiple intervisibility analyses.

Charts of mean and the percent of total intervisibility by district show that generally the higher number of sites within a district the higher the intervisibility values, regardless of terrain differences.

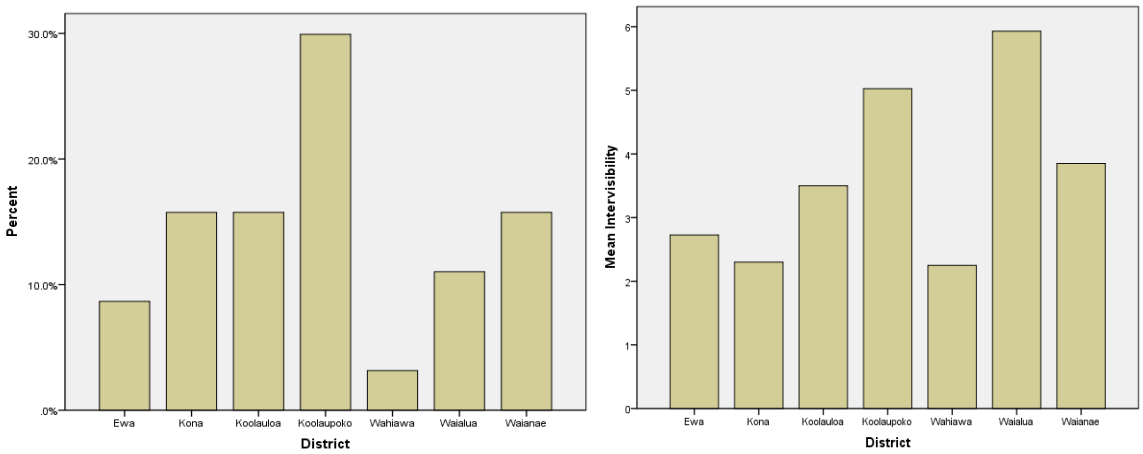

Figure 21. Distribution of Intervisibility Values by District. Proportion of heiau intervisibility values and mean intervisibility for each district.

When compared by function type, the proportion of intervisibility values within the dataset roughly follow the number of sites within each group. Mean intervisibility values are mostly similar regardless of function type.

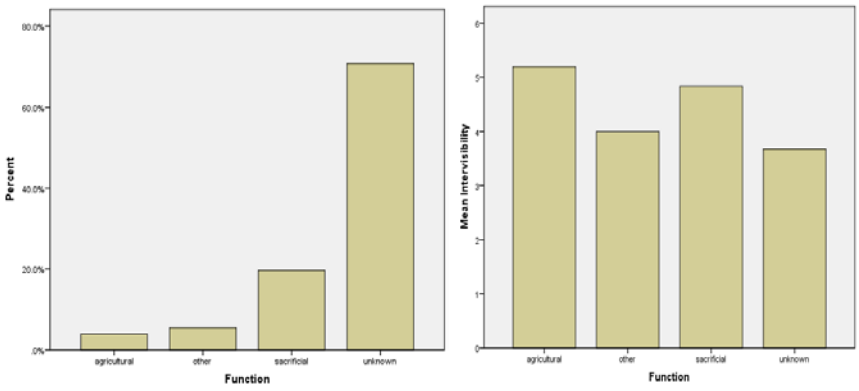

Figure 22. Distribution of Intervisibility Values by Function. Proportion of heiau intervisibility by function and mean intervisibility for each function type.

Assumptions about the visibility of luakini versus agricultural heiau are belied by Figure 22. Agricultural sites have both low and extremely high intervisibility values, while luakini fall roughly in the middle. The disproportionate number of sites with unknown functions makes an attempt to draw conclusions about visibility by function groups impractical.

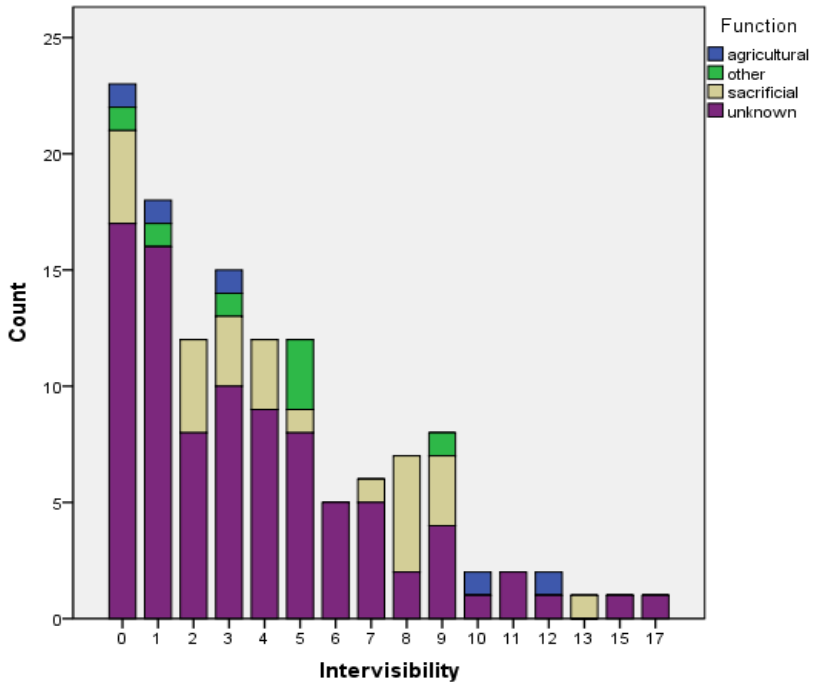

Figure 23. Intervisibility by Function. Number of heiau with intervisibility values of 0 to 17, detailed by function type.

How does intervisibility relate to viewsheds? It appears that viewshed sizes are not directly affected by intervisibility. Both large and small viewsheds can result in high intervisibility values:

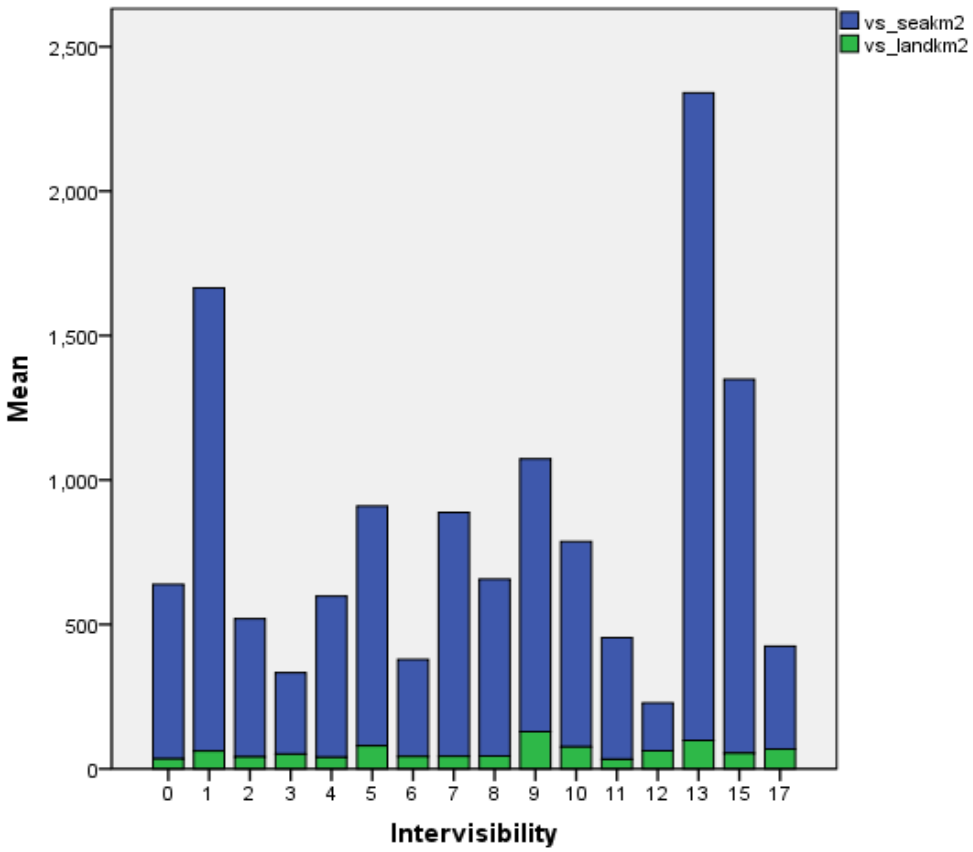

Figure 24. Viewshed by Intervisibility Values. Mean viewshed of heiau for intervisibility values from 0 to 17.

Significance of Intervisibility

The Cumulative Viewshed Analysis proposed by Wheatley (1995) utilized the Kolmogorov-Smirnov one-sample test. This process allowed the comparison of a sample's distribution against that of the entire population. Wheatley argued that the one-sample test provided a more precise test as no further information was introduced into the analysis.

It was found to be impractical to perform a one-sample Kolmogorov-Smirnov test on a raster of the entire island (see Figure 8) due to the large extent of the dataset. A two-sample test was adopted instead. When combined with a random-sampling methodology, the two-sample test allowed the iteration of multiple tests to determine whether intervisibility was a significant factor in the location of heiau. Two hypotheses were assessed:

> **H0**. The null hypothesis, that site locations are randomly distributed in the landscape.
>
> **H1**. The alternate hypothesis, that site locations are not randomly placed within the landscape but were located with respect to intervisibility.

Random Sampling

Random sampling was introduced for use in a two-sample Kolmogorov-Smirnov analysis. In order to establish a default test case a number of random sites equivalent to the total number of heiau sites were selected within the boundaries of the historical Oahu coastline polygon using a function within the Quantum GIS application. A viewshed analysis was then computed within ArcGIS which gave the intervisibility value for each

site. Site height and observer offsets of zero meters above ground level were used to avoid any assumptions about site structure height and to avoid problems associated with background-foreground object visibility.

The intervisibility value was then compared against those of the existing heiau sites using the Kolmogorov-Smirnov two-sample analysis. The results from this test indicated that there was indeed a difference (significance of .009, α=.05, N=128) between the intervisibility of actual heiau sites and random sites distributed across the entire island.

This was not entirely surprising given that the random point selection process chose many more points from the larger central Wahiawa/Kunia uplands area of the island than were contained in the dataset. The lack of heiau in this area is either due to the destructive effects of historic large scale industrial agriculture or reflects a genuine lack of settlements in this region. In compensation for the effect this may have had on the statistical analysis, stratified random sampling methods were derived based on the topography of the island.

Stratified Random Sampling

Fisher (1996) utilized stratified random sampling in his study of the Bronze Age cairns of Mull Island, Scotland. Cairn sites were divided into bands based on distance from the shoreline. The bands were delineated using Evans' (1976) median method. A number of random points equal to the number of existing cairns within each band were selected and their mean viewshed compared against the cairn viewshed. For the purposes

of this study, stratified sampling was used in three test cases to assess the validity of the null and alternate hypotheses:

1. By the elevation of a site above sea level.
2. By the distance from a site to the coast in a straight line.
3. And by the distance from a site to the coast along a flow path.

Random Sampling by Elevation

Shimuzu (1980) created a topographical chart of heiau distribution by elevation. He separated the island of Oahu into four zones; coast, plains, the physiographic 'edge', and the dissected uplands, cliffs and valleys (Figure 6). This is roughly similar to Malo's categorization of land divisions by the kahakai (coast), kula (plains), mau (uplands), and mauna (mountainside).

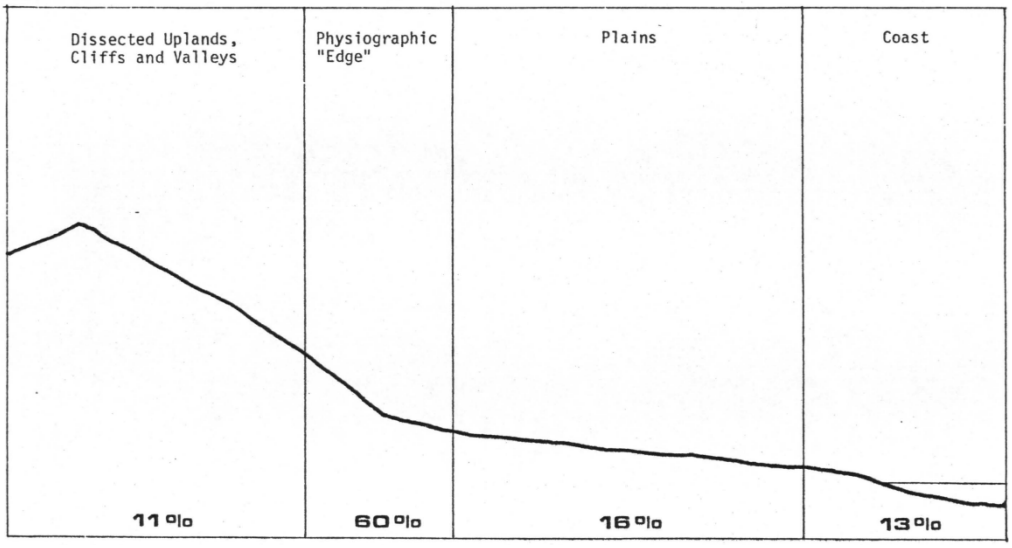

Figure 25. Heiau distribution: Rough percentage of heiau within each elevation zone (in Shimuzu 1980).

Using the Jenks distribution natural breaks method (Jenks 1967) within ArcMap, heiau were divided into four zones by elevation. Random sites equivalent to the number of heiau in each zone were selected. This resulted in a map of random locations much more similar to the heiau dataset. A batch visibility analysis was then computed to

determine the intervisibility of each random site. These values were compared against the intervisibility values of heiau sites using the Kolmogorov-Smirnov two-sample test. The results again rejected (significance of .044, $\alpha = .05$, N = 128) the null hypothesis and supported the observation that heiau sites were located with respect to visibility.

Random Sampling by Distance to Coast

The distance to the coast from each heiau was utilized to delineate zones for the selection of random points. Like those selected for elevation, this also resulted in a distribution of random points that better matched the actual heiau dataset than the random points taken from the entire island. The intervisibility values from the random sample were then computed and compared against known sites using a Kolmogorov-Smirnov two-sample test. The results (significance of .156, $\alpha = .05$, N = 128) supported the null hypothesis and suggest that there is no significant difference between random sites selected by coast-distance and those of the dataset.

This statistical analysis failed to validate the assumptions of H1. Conversely, the test reveals that the distance of a site from the coast could be an important factor in heiau location. This could form the basis of further analysis to examine this relationship.

Random Sampling by Flow Distance

A final coast-distance analysis was conducted. In order to more accurately measure the distance between a heiau and the coast the measurement of flow distance was recorded. Flow distance also relates to the human experience within the landscape by recognizing interrupting terrain features such as ridges and hills.

The flow distance random sampling method was chosen to determine heiau site locations within their respective ahupua`a district (see Figure 13). Ahupua`a boundaries were generally aligned with topographic watersheds. The GIS flow distance toolset within ArcMap 10 allows the simulation of water flowing downstream within each watershed. This determines the distance from each site to a final drainage along the coast. The sample was created by first preparing the historical DEM (10m resolution) of Oahu to remove any sinks or depression artifacts in the data. The flow direction was then determined; this is a raster representation based upon elevation of the direction water would flow from each cell into its neighbors. The cells along the coastline of Oahu were set to flow outwards to represent drainage into the ocean. Finally, the flow length downstream was determined which resulted in a raster dataset where each cell contained the value of its stream flow distance in meters from the coast.

Figure 26. Oahu ahupua`a districts.

The flow distance raster was then spatially joined to the heiau sites dataset which resulted in a distance value for each heiau. This value was then divided into four zones using the Jenks method and the numbers of sites within each zone noted. An equivalent number of random locations were selected for each zone and the intervisibility for each of these random sites was compared to known heiau sites using a Kolmogorov-Smirnov two-sample analysis. The analysis rejected the null hypothesis (significance of .022, α = .05, N=128) and supported the observation that sites are located with respect to intervisibility.

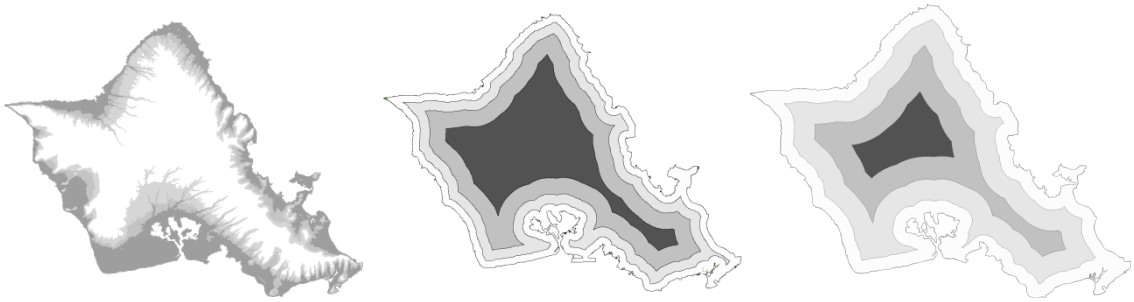

Figure 27. **Random sampling zones** determined by elevation (left) coast (center) and flow distances (right).

Further Sampling

Further sampling could incorporate measures of least-cost distance. Least-cost distance is a GIS tool to compute the effort required to travel within a landscape. Sakaguchi (2009) utilized a least-cost path analysis in his study of the defensibility of prehistoric sites within the Mid-Fraser region. He utilized least-cost distance algorithms to create a probable travel network between fortified villages. It is possible that a least-cost distance analysis could create an even more accurate representation of the distance between heiau and the coast or other features. An least-cost distance path would also

need to incorporate coastal and sea approaches, which would necessitate an inclusion of wind, wave, and current models.

Proximity random sampling can be utilized to introduce variations in site locations. In one example (Tilley 1994), observations in the field suggested that view characteristics would be changed dramatically if sites were relocated a small distance. Fisher (1996) tested this observation by selecting alternative random sites in rings of varying proximity around Bronze Age cairns. He then compared their sea and land viewshed areas against those of the cairns themselves. However, no statistically significant differences were found.

Mean sampling can be used iteratively. Lageras (2002) created two histograms of viewsheds; one of monumental sites and the other of random points. The differences between the two groups' means were calculated and it was found that the random group had a smaller mean viewshed. This process was then repeated 10,000 times using randomly created subsets of sites and random points. The analysis showed that the mean difference between the viewsheds of each subset was greater than the original.

Chapter V. Conclusion

Summary

Heiau are the monumental remnants of the Old Hawaiian religion still existent in the contemporary landscape. While it is evident that religious ritual was the major function of heiau, ethnographic and archaeological review suggest that heiau also played a role as symbols of elite control. As a spatial nexus of spiritual and political power, heiau were located in visually prominent locations. This study proposes that this conjunction was not unintentional and that visibility was an important characteristic of heiau.

In order to conduct a spatial analysis a geographic dataset was compiled. The dataset was assembled from existing archival, geographic, and digital sources. Only records that contained precise position data were included and this resulted in a selection of 127 sites out of more than 200 possible for the island of Oahu.

An exploratory data analysis of the dataset revealed interesting observations of site distribution and function. Unfortunately, the fragmentary extent of the dataset poses more questions than it can answer. It can serve, however, as a basis for further ethnographic and archaeological study.

The importance of visibility via the mechanisms of viewshed and intervisibility was analyzed within the GIS toolset. Visibility was found to be a descriptive characteristic of site location and topography. The use of intervisibility as a quantifiable variable was proposed to statistically test visibility. Attempts to utilize a random

sampling methodology supported the assumption that heiau were located with respect to intervisibility.

Discussion

The elevated location of many luakini results in an expansive view over the surrounding landscape. Viewshed analysis and distribution by function type confirms that this is the case. Luakini heiau contained larger viewsheds than the agricultural or other categories. This seems to correspond to ethnographic and historical accounts of their prominence and supports the argument that sacrificial heiau were as much visual symbols of political power as religious sites.

As actual bastions or as fortresses, visibility analysis does not allow any obvious conclusions to be drawn. Research undertaken by Lock and Harris (1996), Martindale and Supernant (2009), and Jones (2006) attempted to quantify the defense of prehistoric sites as a function of visibility. The same methodology could also be applied to luakini heiau.

Further Research

The exploratory data analysis established that intervisibility was a significant characteristic of heiau location. Random sampling resulted in the rejection of the null hypothesis in three out of four tests, but further analysis is required to clarify the relationship between intervisibility and viewshed. Intervisibility was selected as a test variable because it was within the computational limits of the analysis. A custom

algorithm similar to that utilized by Lageras (2002) to calculate viewshed differences between sites and randomly-sampled points would offer more definite conclusions but require more intensive computation.

If additional statistical analysis can establish the significance of visibility it would be possible to further classify heiau, such as with a cluster analysis. Cluster analysis is an exploratory statistical technique that allows the measure of similarities by distance between individual entities based on the presence or absence of specific traits. The process uses numerical procedures to divide a group of units into homogeneous sub-groups (Hodson 1970). This reduces the number of entities under study into new classes and enables further interpretation.

Historical applications of cluster analysis in archaeology focused on the variation of artifact features. Pugh (2002) utilized a cluster analysis to discern architectural types of Mayan temples. As Shimuzu (1980) and Bennet (1933) observed, heiau architectural features do not readily submit to classification. However, a cluster analysis of visual characteristics such as viewsheds and intervisibility- and topographical characteristics like elevation, slope, and aspect- could create a new typology.

This would be a typology reliant on spatial facts and not antiquarian or preconceived cultural notions. Additionally, a spatial typology could be used to describe the large number of heiau whose function is unknown. It is even possible that a spatial typology would allow predictions to be made about the locations of lost sites.

Of course, it is important to remember that visibility analysis is at best an approximate attempt to quantify the human experience of vision. As Wheatley (2002) observes, relying on the importance of vision to non-Western viewers is a potential

ethnographic fallacy. However, the visual prominence of heiau is well documented within the historic era, and though many are destroyed or forgotten, those that remain are an important archaeological link to understanding the traditions and culture of ka po`e kahiko or "the people of old."

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