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Vulnerability Assessment of Hawai'i's Cultural Assets Attributable to Erosion Using Shoreline Trend Analysis Techniques

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Haunani H. Kane, Charles H. Fletcher, Bradley M. Romine, Tiffany R. Anderson, Neil L. Frazer, and Matthew M. Barbee

Department of Geology and Geophysics
School of Ocean and Earth Science and Technology
University of Hawai'i
1680 East West Road
Honolulu, HI 96822, U.S.A.

www.JCRonline.org

ABSTRACT

KANE, H.H.; FLETCHER, C.H.; ROMINE, B.M.; ANDERSON, T.R.; FRAZER, N.L., and BARBEE, M.M., 2012. Vulnerability assessment of Hawai'i's cultural assets attributable to erosion using shoreline trend analysis techniques. *Journal of Coastal Research,* 28(3), 533–539. West Palm Beach (Florida), ISSN 0749-0208.

Hawai'i's beaches are a focal point of modern lifestyle as well as cultural tradition. Yet coastal erosion threatens areas that have served as burial grounds, home sites, and other forms of cultural significance. To improve understanding of the convergence of erosion patterns and cultural uses, we mapped shoreline changes from Kawela Bay to Kahuku Point on the capital island of O'ahu. Shoreline change rates are calculated from historical photographs using the single-transect (ST) and eigenbeaches (EX) method to define the 50- and 100-year erosion hazard zones. To ensure that shoreline change rates reflect long-term trends, we include uncertainties attributable to natural shoreline fluctuations and mapping errors. A hazard zone overlay was compared to cultural data provided by the Hawaii State Historic Preservation Division (SHPD) and the Office of Hawaiian Affairs (OHA) to identify threats to cultural features. Cultural features identified in the study include iwi kupuna (burials), Hawaiian artifacts, and Punaulua (a freshwater spring). Our analysis indicates that, except for Punaulua, all cultural features identified are vulnerable to coastal erosion at historical rates. The data produced in this study may be used as a proactive management tool to rank the vulnerability to threatened cultural features, as well as to develop protocols to appropriately manage cultural assets.

ADDITIONAL INDEX WORDS: *Hawai'i, coastal erosion, shoreline change, eigenbeaches, single-transect, burials, artifacts.*

INTRODUCTION

Hawai'i's beaches are valuable because they are a focal point of modern lifestyle as well as cultural tradition. On O'ahu, the capital island of Hawai'i, 60% of all beaches are experiencing long-term erosion with an average rate of -0.06 ± 0.01 m/y (Fletcher *et al.*, 2011). In addition approximately 8% or 8.7 km of O'ahu's beaches have been lost to erosion. Furthermore, sea-level rise will likely cause erosion to expand and accelerate. Hawai'i's shoreline management system awards coastal dunes to counties and awards beaches to the state (Fletcher *et al.*, 2010). Counties focus on planning and permitting, while the state Department of Land and Natural Resources (DLNR) has a mandate to conserve public lands. Within the DLNR, the Office of Conservation and Coastal Lands oversees submerged lands (beaches and seafloor), and the State Historic Preservation Division (SHPD) preserves historic burials and artifacts. Communication between the various agencies that manage the shoreline may be hindered because of conflicting mandates, which ultimately challenges management efficacy. Knowing beforehand the areas that might be threatened by coastal erosion can be an effective planning tool in this context.

In Hawai'i and other Pacific Islands, coastal lands vulnerable to erosion may contain cultural features such as iwi kupuna (burials), historical artifacts, ancient home sites, and magnificent physical features. In addition to the multiple agencies that manage the shoreline the process is further complicated because of the lack of consistent management protocol to deal with erosion threats to cultural assets. Thus it is not uncommon for the public to unknowingly mistreat cultural features exposed by erosion. Romine *et al.* (2009) and Hapke *et al.* (2010) defined a methodology for determining shoreline change rates and uncertainty at the littoral cell scale; however, identifying chronic erosion threats to cultural deposits requires higher resolution. This study demonstrates methodology for identifying chronic erosion threats to cultural assets by identifying erosion hazard zones based upon shoreline change rates and uncertainties at individual shoreline transects. Cultural features that fall within the erosion hazard zones may be potentially threatened by erosion, thus highlighting the need for specific management planning.

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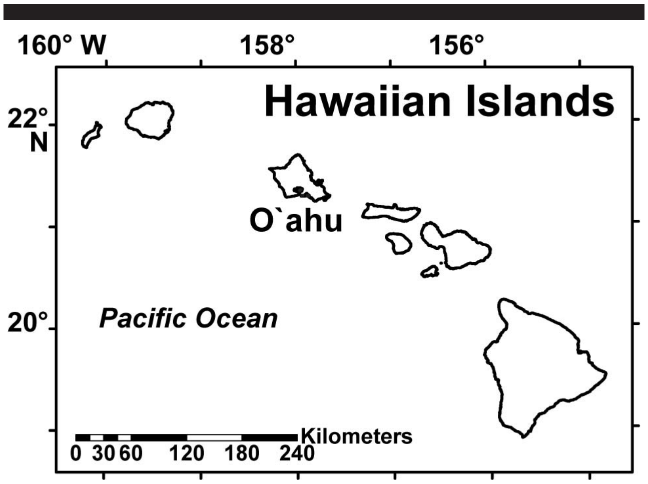

Figure 1. The vulnerability assessment of cultural assets attributable to erosion takes place on the northern coast of Oʻahu, Hawaiʻi.

STUDY AREA

The study area is located on the north coast of the capital island of Oʻahu (Figure 1). The study area extends from Kawela Bay to Kahuku Point, covering approximately 4.3 km of sandy shoreline. Three sections in particular, Kawela Bay, Turtle Bay, and Kahuku Point, are former settlements and contain an abundance of cultural features (Figure 2). Kawela Bay Beach is located in the western region of the study area and lies between two limestone headlands. To the west of Kawela Bay is Pahipahiālua Beach and to the east is Wakiu Beach. The shoreline at Kawela Bay is characterized by year-round small waves attributable to the protection provided by a shallow fringing reef. The beach at the Turtle Bay Resort is known as Kalokoiki Beach. Kaihalulu Beach extends from Kalaeokamanu Headland to Kahuku Point. The Kaihalulu shoreline is largely composed of exposed limestone shelf with a perched calcareous beach above the water line. Extending to the east of Kahuku Point and beyond the bounds of the area of study is Hanakaʻīlio Beach. This sandy pocket of beach is bordered on both sides by outcropping carbonate grainstone (eolianite). Throughout the area of study shoreline positions are highly variable. Seasonal shifts in sand expose calcareous reef rock, beach rock, and eolianite outcrops.

The beaches in this study predominately face toward the N and NW. Winter months are dominated by large north Pacific swell, typically 1.5–5.0 m with 12 to 20 s periods (Bodge and Sullivan, 1999). The annually recurring significant deep-water wave height of the north Pacific swell is 7.7 $\pm$ 0.28 m (Vitousek and Fletcher, 2008). Tradewind swell persists throughout the year, being most common during the summer; typical tradewind swell produce wave heights of 1–3 m with 6–8 s periods (Bodge and Sullivan, 1999).

Burials, Hawaiian artifacts, and former home sites have been identified in the Kawela Bay Subsurface Cultural Deposit and the Kahuku Point Subsurface Cultural Deposit (O'Hare and Hammat, 2006). Additional burials, as well as a culturally significant freshwater spring named Punaulua, have also been identified. Hawaiian burials are especially prevalent in coastal areas because dunes have historically served as important burial sites. Hawaiians place a high value on protocol with respect to the treatment of iwi kupuna because they believe that when a Hawaiian passes the mana, or one's divine power, the soul remains with the iwi kupuna (K. Markell, personal communication, 2009).

MATERIALS AND METHODS

Mapping Historical Shorelines

We followed the methods of Romine *et al.* (2009), Fletcher *et al.* (2003), and Rooney *et al.* (2003) for mapping historical shoreline positions and calculating positional uncertainties. To identify erosion and accretion trends, historical shorelines are digitized from 0.5 m orthorectified aerial photo mosaics and National Oceanic and Atmospheric Administration National Ocean Service (NOAA NOS) topographic survey maps (T-sheets) (Romine *et al.*, 2009). A low water mark (LWM) position or "beach toe" is used as a shoreline proxy. Nine to 11 historical shorelines are available for the study area dating from 1910–2007. Two beaches in the study area have been significantly altered by coastal engineering. For this reason we do not include historical shorelines prior to that event in our analysis. In the early 1970s construction of the Turtle Bay Resort resulted in the removal of natural vegetation, diversion of a stream, and sand mining at Kalokoiki Beach (transects 119–125). After reviewing imagery at Kawela Bay Beach, it was observed that a stream mouth (transects 28–32) was removed between the 1967 and 1971 images. At both Kalokoiki beach and the portion of Kawela Bay beach mentioned previously, shorelines prior to 1971 are removed from the time series, and rates are calculated to best represent the subsequent shoreline change.

Seven sources of uncertainty are included in the shoreline change models to account for the natural variability of shoreline positions (*e.g.,* waves, tides) as well as mapping errors (*e.g.,* image resolution). These sources of error include Digitizing Error (E_d), Pixel Error (E_p), Seasonal Error (E_s), Rectification Error (E_r), Tidal Fluctuation Error (E_{td}), T-sheet Plotting Error (E_{ts}), and T-sheet Conversion Error (E_{tc}). Total positional uncertainty (E_t) is the root sum of squares (RMS) of individual errors. The total positional uncertainty in this study ranged from 5.68–14.13 m and is applied as a weight for each shoreline position by the shoreline change models that use weighted least square regression.

The E_d results from the analysts' interpretation of the shoreline position that is digitized from aerial photographs. E_d is determined by taking the standard deviation (SD) of the differences in the shoreline positions digitized from a group of experienced operators working on a sample area of shoreline (1.44–5.14 m). E_p, or pixel size, refers to the resolution of our orthophoto mosaics (0.5 m) and T-sheets (3 m); E_s, or seasonal change, is accounted for through the use of summer and winter beach profiles for 8 years at Sunset Beach, located to the west of the study area (Gibbs *et al.*, 2001; C.H. Fletcher, B.M. Romine, and M. Dyer, unpublished data, 2008). The seasonal change is the difference between LWM positions along a shore-perpendicular transect between summer and winter (4.49 m). E_r is an RMS error that is calculated because of the misfit of the

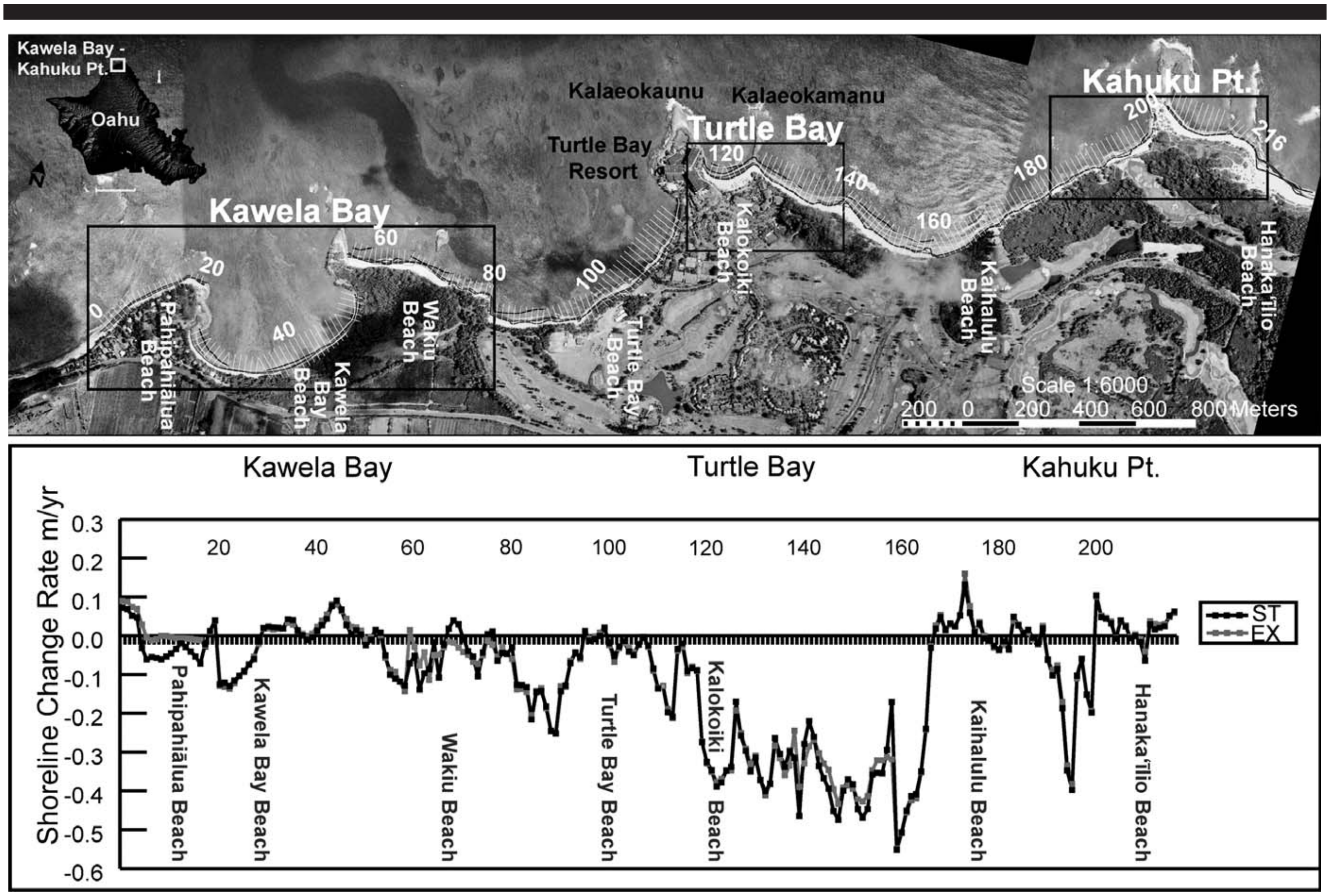

Figure 2. Kawela-Kahuku, O'ahu. The three study areas are indicated by black boxes. Historical shoreline positions are measured at shore-perpendicular transects spaced 20 m. The ST and EX shoreline change rates correspond to the numbered transects. Shoreline change rates >0.0 (+) indicate accretion, while shoreline change rates <0.0 (−) indicate erosion.

orthorectification model of the aerial images and the T-sheets to the master orthorectified image and digital elevation model (DEM) images. For the most part E_r values are larger for T-sheets (2.57–9.4 m) than for orthophoto mosaics (0.14–2.73 m). E_{td} arises from surveys of the horizontal movement of LWMs between spring low tides and spring high tides from three beaches on SE O'ahu (3.14 m). E_{ts} is based upon Shalowitz's (1964) analysis of topographic surveys that involve mapping the high water line (HWL) as a proxy for shoreline position (5.1 m). E_{tc} results from the conversion of the HWL shoreline to a LWM position so that historical shorelines from T-sheets can be compared to those derived from aerial photographs. E_{tc} was found by taking the SD of the offset between the HWL and LWM positions obtained from beach topographic profile surveys at Sunset Beach (4.38 m) (Romine *et al.*, 2009).

Calculating Shoreline Change Rates and Uncertainty

Individual Transect Rates

Distances between historical shorelines were measured at shore-perpendicular transects spaced 20 m alongshore (Figure 1). Annual shoreline change rates were calculated from the time series of historical shoreline positions at each transect using the single-transect (ST) method and the eigenbeaches (EX) method developed by Genz, Frazer, and Fletcher (2009) and Frazer, Genz, and Fletcher (2009). This project combines ST and EX, where the results produced by these two methods are used to cross-validate shoreline change rates.

The ST is the most commonly used method for calculating change rates and provides a good first approximation of shoreline change at a beach (Genz, Frazer, and Fletcher, 2009; Romine *et al.*, 2009). We apply weighted least squares regression with ST to calculate a shoreline change rate and uncertainty. During this process a trend line is fit to the time series of historical shoreline positions such that positions with lower uncertainty have greater influence (Fletcher *et al.*, 2003; Genz, Frazer, and Fletcher, 2009). The resulting slope of the trend line is the shoreline change rate.

Recent work by Frazer, Genz, and Fletcher (2009) and Genz, Frazer, and Fletcher (2009) has resulted in a second shoreline change rate model: the EX method. Similar to ST, EX uses linear regression with time and cross-shore shoreline change; however, EX also models shoreline data in the alongshore direction. By incorporating data from all transects along a beach into a single model, fewer mathematical parameters are needed to calculate change rates at transects, resulting in a more parsimonious model. The EX model also assumes that shoreline data from adjacent transects are dependent upon each other, therefore accounting for the sharing of sand between transects, which ST fails to do. The uncertainty associated with both ST and EX is often high as a result of the limited number of shorelines (often <10 shorelines) and their noisy (high positional uncertainty) behavior.

Individual rate uncertainties are produced by both the ST and EX models at the 95% confidence interval (CI). We use a nonparametric bootstrap method to account for additional uncertainty with the EX method, which was not addressed in Frazer, Genz, and Fletcher (2009) or Genz, Frazer, and Fletcher (2009). Bootstrapping automatically incorporates all model complexity, including the inherent error in the data-derived eigenvectors, without requiring assumptions about the population distribution. The bootstrap method resamples the data 500 times with replacement and produces a probability distribution from which an uncertainty can be calculated (Efron, 1981; Efron and Tibshirani, 1993). The resulting individual uncertainties for EX are similar in magnitude to the individual uncertainties associated with ST. The ST or EX rate is considered statistically significant if the rate is greater than the uncertainty (95% CI).

Regional Average Rates

Regional average rates are the average ST or EX rates for all n transects in a littoral cell. Regional average rates are calculated for Waiale‘e Beach (n = 0–19), Kawela Bay Beach (n = 20–54), Wakiu Beach (n = 55–80), Turtle Bay Beach (n = 80–118), Kalokoiki Beach (n = 119–125), Kaihalulu Beach (n = 126–200), and Hanaka‘īlio Beach (n = 201–216) (Figure 1). Hapke *et al.* (2010) defined a method of calculating the uncertainty of regional average rates based upon the assumption that the rate uncertainty at each transect is partially independent of the other uncertainties. They use an effective number of independent uncertainty values (n*) calculated from a spatially lagged autocorrelation (ρ) of the individual rate uncertainties in the following equation from Bayley and Hammersley (1946),

$$\frac{1}{n*} = \frac{1}{n} + \frac{2}{n^2}\sum_{j=1}^{n-1}(n-j)\rho(j\tau). \qquad (1)$$

The uncertainty of a regional average rate U_{R*} takes into consideration n* and is estimated following Hapke *et al*. (2010) (Equation 2), where U_R is the average of individual uncertainties,

$$U_{R*} = \frac{1}{\sqrt{n*}}U_R. \qquad (2)$$

The results produced by ST and EX are used to cross validate the regional average shoreline change rates. If ST and EX methods agree on both the direction of the shoreline trend (sign) and both rates are statistically significant (95% CI), then the shoreline is “very likely” experiencing erosion or accretion. If ST and EX methods agree with the direction of the shoreline trend but one or both rates are not statistically significant, then the shoreline is “likely” experiencing erosion or accretion. Regional average rates that may not be significant can nonetheless be used to indicate the general shoreline change trend and thereby benefit planners who have made past decisions without any data available. If ST and EX methods disagree on the direction of the shoreline trend, or if there is insufficient data, then the trend may not be determined.

Regional average rates and uncertainties are reported in units of cm/y, otherwise some of the beaches in this study area would indicate no change and zero uncertainty. Data produced in this report may differ from data in use by shoreline management authorities, because we use additional shoreline transects to project erosion hazard zones. For those areas where our transects overlap with management data, shoreline change rates and uncertainties at individual transects will be the same.

Erosion Hazard Zones

Cultural information is provided by the Office of Hawaiian Affairs (OHA) and the SHPD of the Hawai‘i DLNR. Shapefiles (.shp) provided by OHA are used to identify and locate burials, Punaulua, and cultural deposits found within the study area. All mapping is georeferenced using the same Universal Transverse Mercator (UTM) projection.

We used the most recent vegetation line (2006 or 2007) as a proxy for the landward extent of the modern beach. Erosion hazard zones are defined by extending the vegetation line 50 and 100 years at individual transect rates produced by ST and EX. The model assumes that the vegetation line and the LWM migrate at the same rate over time. Hardened surfaces may create areas where this assumption is violated and are dealt with on a case by case basis. The width of the erosion hazard zone is based upon the uncertainty of each ST and EX shoreline position. Those cultural features that fall within both the ST and EX erosion hazard zones are at significant risk of coastal erosion. Those areas that are threatened by both ST and EX within 50 years are depicted in a 50-year erosion hazard zone. A 100-year erosion hazard zone is used only for cultural features that are threatened beyond 50 years. Cultural deposits may cover large areas along the shoreline, which results in some portions of the asset being threatened by erosion, while other portions are not. ESRI ArcGIS was used to determine the area of the cultural deposit as well as the percent of the cultural deposit threatened by ST, EX, and combined ST and EX hazard zones.

RESULTS

Kawela

Kawela Bay is fronted on the west by Pahipahiālua Beach and on the east by Wakiu Beach. Three cultural features were identified in the Kawela study area: the Pahipahiālua Beach Park Burial, Punaulua, and the Kawela Bay Subsurface Cultural Deposit. The Pahipahiālua Beach Park Burial is a single burial that was discovered along the Pahipahiālua shoreline. Located along the western point of Kawela Bay,

Table 1. *Regional average rate and uncertainty of all beaches and corresponding shoreline trends.*

Beach	Transect	*n*	ST Avg Rate (m/y)	EX Avg Rate (m/y)	Shoreline Trend
Waialeʻe	0–19	20	−0.02 ± 0.04	0.01 + 0.04	undetermined
Kawela	20–54	34	0.04 ± 0.03	0.03 + 0.03	likely accretional
Wakiu Beach	55–80	25	−0.03 ± 0.03	−0.02 ± 0.03	likely erosional
Turtle Bay Beach	81–118	37	−0.08 ± 0.02	−0.08 ± 0.02	very likely erosional
Kalokoiki Beach	119–125	6	−0.07 ± 0.11	−0.07 ± 0.06	likely erosional
Kaihalulu Beach	126–199	73	−0.18 ± 0.12	−0.16 ± 0.12	very likely erosional
Hanakaʻīlio Beach	200–235	35	0.01 + 0.12	−0.01 ± 0.03	undertermined

n = number of transects

Punaulua is a brackish pond fed by a freshwater spring. Punaulua pond is still intact and is believed to have once been fished by Hawaiians for ulua (crevalle fish, *Caranx hippos*). The Kawela Bay Subsurface Cultural Deposit extends along most of Kawela Bay, as well as Wakiu, covering a total of 30,399.6 m^2. O'Hare and Hammat (2006) identified midden, Hawaiian artifacts, and a total of five burials within the Cultural Deposit. Wakiu once served as an important fishing area that contained large schools of moi (sixfeeler threadfin, *Polydactylus sexfilis*) and a fishpond and was used as a manufacturing site for fishing gear (O'Hare and Hammat, 2006).

The regional average shoreline change rates were calculated separately at the 95% CI for the three beaches within Kawela using ST and EX (Table 1). At Waialeʻe the average ST and EX rates are −0.02 ± 0.04 m/y and 0.01 ± 0.04 m/y, respectively. The Waialeʻe shoreline is highly variable and contains a limited number of transects (n = 30) making it difficult to determine the direction of the shoreline change trend. At Kawela Bay the average ST and EX rates are 0.04 ± 0.03 m/y and 0.03 ± 0.03 m/y, respectively. Although both ends of Kawela Bay indicate a shoreline trend that is eroding, a majority of Kawela Bay is likely accreting. The average shoreline change rate for Wakiu Beach is −0.03 ± 0.03 m/y and −0.02 ± 0.03 m/y; Wakiu Beach is likely eroding.

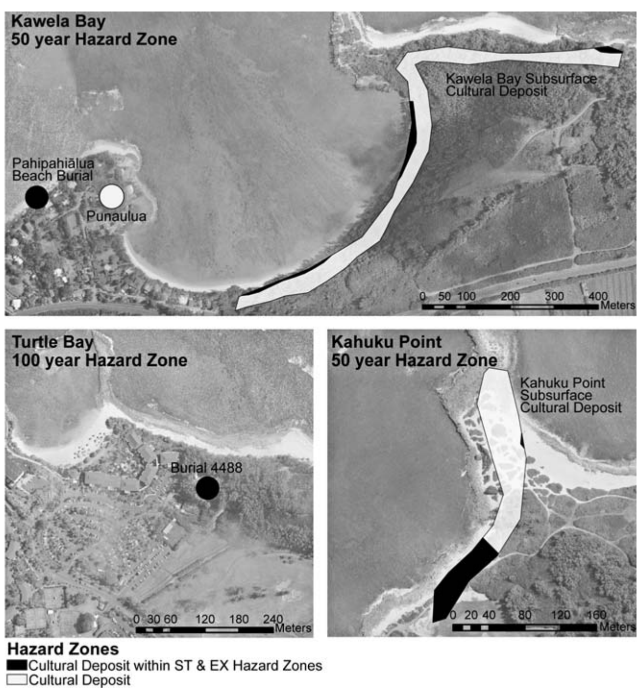

Figure 3. The intersection of cultural features and erosion hazard zones are highlighted in black. At Kawela and Kahuku Point cultural features are threatened by the 50-year ST and EX erosion hazard zones, while a single cultural feature at Turtle Bay is threatened by the 100-year ST and EX erosion hazard zone.

Both the ST and EX models agree that within 50 years the Pahipahiālua burial and a portion of the Kawela Bay Subsurface Cultural Deposit may be threatened by erosion (Figure 3). Differences in the area of erosion hazard zones for the Kawela Cultural Deposit result from differences in the uncertainty of the ST and EX hazard zones. Both models agree that within 50 years approximately 187.2 m^2 (0.6%) of the Kawela Bay Subsurface Cultural Deposit may become threatened (Table 2). Within 100 years the area of the Kawela Bay Subsurface Cultural Deposit threatened by both the ST and EX erosion hazard zones slightly increases to 699.0 m^2 (2.3%) of the total area.

Turtle Bay

The Turtle Bay area includes both Kalokoiki Beach and the western portion of Kaihalulu beach. The iwi kupuna of five individuals included in Burial 4488 were found in sand that had been removed from the sand dunes inland of west Kaihalulu Beach during a sand-mining project. The average ST and EX shoreline change rates at Kalokoiki Beach are −0.07 ± 0.11 m/y and −0.07 ± 0.06 m/y, respectively (Table 1). Both ST and EX agree upon the rate of shoreline change, however, ST produced a larger rate uncertainty. The high uncertainty at Kalokoiki Beach is likely attributable to the limited number of transects (n = 6) as well as the reduced number of historical shorelines. The trend at Kalokoiki Beach is likely erosional. The ST and EX shoreline change rates at Kaihalulu Beach are −0.18 ± 0.12 m/y and −0.16 ± 0.12 m/y, respecitively. Kaihalulu Beach is very likely experiencing an erosional shoreline trend. Burial 4488 may become threatened by both the ST and EX hazard zones within 100 years (Figure 3).

Kahuku Point

The Kahuku Point Subsurface Cultural Deposit extends from the eastern region of Kaihalulu Beach to the Kahuku Point sand dunes. The Kahuku Point Subsurface Cultural Deposit covers a total of 8949.5 m^2 and contains burials, Hawaiian artifacts, and midden and is the site of a former

Table 2. *Area of cultural deposits threatened by erosion.*

Study Area	Feature	Area (m^2)	% Area
Kawela	Kawela Cultural Deposit	30,399.6	-
	50-y ST hazard	2372.7	7.8
	50-y EX hazard	187.2	0.6
	50-y ST and EX hazard	187.2	0.6
	100-y ST hazard	2659.5	8.7
	100-y EX hazard	699	2.3
	100-y ST and EX hazard	699	2.3
Kahuku Point	Kahuku Pt. Cultural Deposit	8949.5	-
	50-y ST hazard	2512.7	28.1
	50-y EX hazard	2434.3	27.2
	50-year ST and EX hazard	2434.3	27.2
	100-year ST hazard	2488.5	27.8
	100-year EX hazard	2425.4	27.1
	100-year ST and EX hazard	2425.4	27.1

Hawaiian settlement. Two of the six iwi kupuna identified at the Kahuku Point Subsurface Cultural Deposit were left in place at Kahuku Point, while the remaining iwi kupuna were reinterred at other locations determined appropriate by SHPD. Inland of Kahuku Point is Kūkiʻo Pond, which has been used to cultivate fish and taro. The exact location of the pond was not identified in this study because much of the land inland of Kahuku Point has been converted into a golf course.

To the west of the Kahuku Point is Kaihalulu Beach and to the east is Hanakaʻīlio Beach. Separate shoreline change rates were calculated for both beaches. As mentioned previously Kaihalulu Beach is very likely experiencing an erosional shoreline trend. Single-transect and EX shoreline change rates at Hanakaʻīlio Beach are 0.01 ± 0.12 m/y and -0.01 ± 0.03 m/y, respectively (Table 1). As with Waialeʻe, the high variability of the shoreline as well as a limited number of transects (n = 35) make it difficult to determine the shoreline trend at Hanakaʻīlio Beach.

Both the ST and EX model agree that within 50 years the Kaihalulu Beach portion of the Kahuku Point Subsurface Cultural Deposit, as well as lands inland of the deposit, will be threatened by erosion (Figure 3). Both models predict that approximately 2434.3 m^2 (27.2%) of the Kahuku Point Subsurface Cultural Deposit will be eventually threatened (Table 2). Within 100 years the hazard zone continues to migrate landward along Kaihalulu Beach, while the Hanakaʻīlio region of the Kahuku Point Subsurface Cultural Deposit continues to remain largely unaffected.

DISCUSSION

The rates at various beaches throughout the study area cannot be significantly distinguished from zero. This may be attributable to the high variability of shorelines as well as the limited number of transects at these beaches. Two beach behaviors may account for the high variability of shorelines: high seasonality and low change rate. Because shoreline data are typically only available with a decadal frequency, seasonal processes, which may be amplified or suppressed from one year to the next, serve as a source of noise. For instance historical aerial photographs as well as site visits indicate that Wakiu Beach experiences large seasonal changes as beach rock is seasonally exposed by shifting wave directions and seasonal energies. High shoreline variability may also characterize beaches where the long-term rate of change and the seasonal signal are both small. For instance Kawela Bay Beach is a typically stable beach that is largely protected from high seasonal change by headlands and a shallow fringing reef at the mouth of the bay.

This study applied a unique combination of ST and EX shoreline change rates and uncertainties to project future erosion hazard zones on a segment of shoreline that had not previously been analyzed. Cultural sites at greatest risk are identified as those that fall within both ST and EX erosion hazard zones. This methodology allows potentially threatened cultural sites to be identified before erosion events occur. Pahipahiālua Beach Park Burial, Kawela Bay Subsurface Cultural Deposit, and Kahuku Point Subsurface Cultural Deposit are all found to be vulnerable to coastal erosion within 50 years; Burial 4488 is vulnerable to coastal erosion within 100 years. Punaulua is located further inland on a raised carbonate headland and is the only cultural feature that all models agree will not be threatened by historical rates of erosion within the next 100 years.

Currently SHPD is given jurisdiction over all iwi kupuna and burial goods 50 years and older on public and private property. After consulting lineal descendents, SHPD dictates whether the inadvertently discovered iwi kupuna and burial goods will be reinterred in its current place or relocated. In addition the development of a preservation plan is a minimum requirement for permitted land disturbance. A preservation plan articulates the proper management and protection of all burial sites, including, but not limited to, buffers, landscaping, and access by known lineal or cultural descendents. Hawaiian artifacts with no burial association found on public land also fall under the jurisdiction of DLNR, usually SHPD. However, Hawaiian artifacts (other than burials) found on private land are considered to be property of the landowner and may or may not be preserved based upon the landowner's discretion. Based upon the responsibilities of the public as well as state and county agencies, it is important that each is aware of coastal erosion and its implications so that informed decisions can be made.

This study is the first to incorporate both shoreline change data and cultural data to a segment of shoreline known to be rich in cultural assets. Currently there is no protocol to deal with coastal erosion threats to cultural sites. The use of erosion hazard zones to identify vulnerable culture features can serve as a proactive management tool contributing to decision making in regard to cultural preservation. Using the data provided in this study, managers can rank the vulnerability of the threatened cultural features based upon significance and the timing of erosion threats. Protocols may then be developed to appropriately manage the assets, such as possible relocation and preservation of cultural features, as well as contacting the lineal descendents of the iwi kupuna.

We recognize that the historical rates of shoreline change applied in this study are likely to change in a future characterized by accelerating sea-level rise (Vermeer and Rahmstorf, 2009). Expanding our methodology using estimates of shoreline change driven by changes in sea level represents a logical future direction of research. Threats of coastal erosion to cultural assets is not unique to Hawai‘i. Globally many of the oldest settlements are located along the coast, giving coastal areas a rich cultural history. It is important to recognize the value of these areas and begin developing management options to preserve the cultural significance of these areas.

CONCLUSION

This study documents shoreline change rates and patterns and applies this information to the problem of managing cultural assets threatened by coastal erosion. Our analysis indicates that all cultural features identified, except for Punaulua (a coastal freshwater spring), are vulnerable to coastal erosion at historical rates. Managers can use the data provided in this study to rank the vulnerability of threatened cultural features and begin developing protocol to best manage and preserve the assets. The methodology provided here is not limited to Hawai‘i and may be used to identify threatened cultural features in other areas or to identify additional threatened features such as coastal infrastructure.

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