SHORT-TERM SHORELINE CHANGE ON OAHU'S NORTH SHORE DURING A STRONG EL NINO YEAR

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By

Robert A. Walker

Thesis Committee:

Neil Frazer, Chairperson

Charles H. Fletcher

Bradley Romine

Tiffany Anderson

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1 INTRODUCTION

Recent studies have shown that over 70% of beaches in Hawaii are experiencing chronic (long-term) erosion (Fletcher, et al., 2012). With future sea level rise, erosion rates may increase and the loss of beach and shoreline areas will be exacerbated (Anderson et al., 2015). Coastal erosion at Sunset Beach on Oahu's North Shore is a serious concern that threatens beach and nearshore environments, public infrastructure, and private residences (Figure 1). As public agencies and private property owners seek to protect coastal development, community stakeholders and resource agencies also recognize the significance of the public beach as a natural resource to be protected. Improved understanding of short-term shoreline changes can support efforts to increase long-term coastal resiliency of the region.

Long-term shoreline change rates were estimated for the region based on historical T-sheets and aerial photographs dating from 1928 to 2006 (Fletcher et al., 2010). Anecdotal evidence relates some understanding of seasonal changes: strong North Pacific swells dominate the winter, and shorter-period trade wind-generated swell drives shoreline change in summer. Less documented, and less understood, are the short-term seasonal and inter-seasonal changes that occur.

Figure 1. Beach erosion on at Sunset Beach in December 2013

This document provides an overview of a coastal observation program that was developed and implemented for a 2.5 km stretch of coastline surrounding Sunset Beach on the North Shore of Oahu. Monthly beach profiles were collected between January 2015 and February 2016 to quantify shoreline elevations and document geomorphic shoreline response when subjected to various seasonal wave conditions. Nearshore hydrodynamics and coastal forcing were investigated using wave and current instruments deployed offshore during the study period, however detailed analyses are not included in this report.

2 BACKGROUND

2.1 Geologic Framework

The study area is located on the north-west facing shore of Oahu (Figure 2). The coastal environment in the Sunset-Ehukai region generally consists of a gently sloping fringing fossil reef offshore, with limited modern reef growth (Fletcher et al., 2008). Channels carved through the reef during periods of lower sea level provide a mechanism for currents and sediment transport.

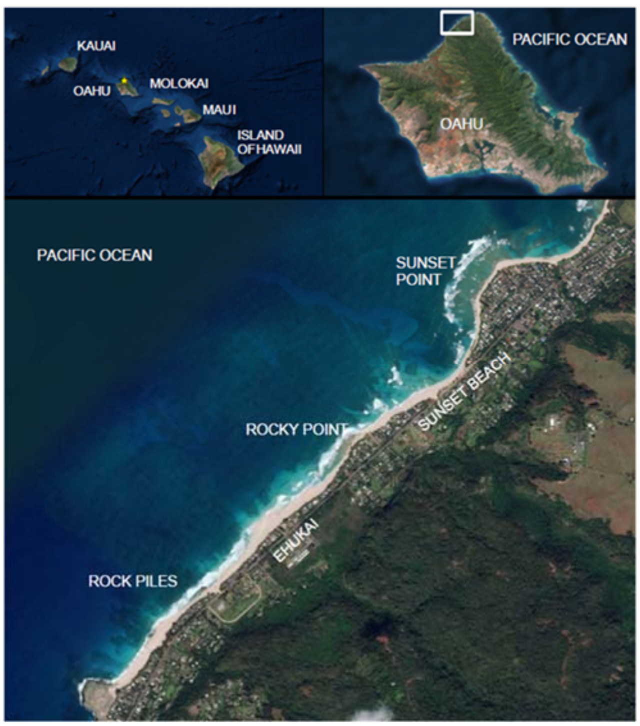

Figure 2. Study site between Sunset Beach and Rock Piles on the North Shore of Oahu, Hawaii.

Narrow beaches consist primarily of biogenic carbonate sands, backed by a coastal plain composed largely of fossiliferous limestone and unconsolidated sand (Fletcher et al., 2011) (Figure 3). Beach width and berm height fluctuate significantly with the season, with beaches generally wider and flatter in the summer and narrower and steeper in the winter, with some exceptions. A prominent feature of the beach is the existence of a natural storm berm, which was built up by wave overwash during high wave events. This high berm underlies shorefront properties and portions of the coastal highway, and serves as the primary natural coastal protection feature for the region. Degradation of this natural storm berm by coastal erosion, coastal development, foot traffic, or a combination of these factors decreases coastal resiliency within the region. Thus, management of coastal development within this natural coastal feature is of primary interest to resource agencies.

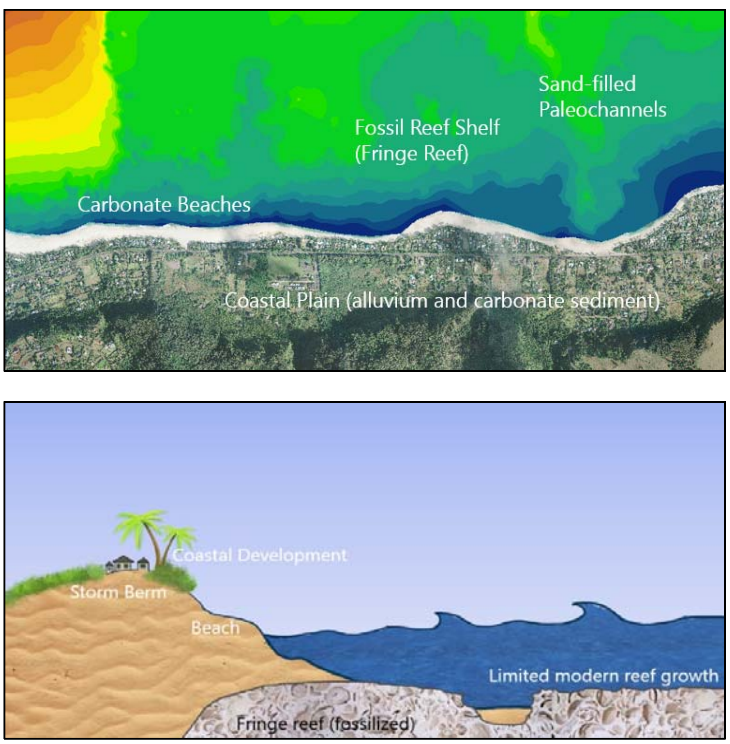

Figure 3. Plan view showing offshore bathymetry (top) and cross-section views showing typical site geology (bottom).

2.2 Coastal Development and Infrastructure

Oceanfront development along the Sunset-Ehukai beach region is limited to single family homes, public parks and facilities, and a two-lane coastal highway that, in some places, experiences wave overtopping and sediment deposition during high wave events. The sandy beach is a highly dynamic system that is prone to dramatic seasonal changes in beach width and berm formation. Coastal development that has encroached on top of the storm berm is threatened by episodic and seasonal erosion. For example, the public bike path at Sunset Beach is threatened by coastal erosion during the winter caused by strong North Pacific swells, while the beach is wide and flat during the summer. In contrast, the beach just several hundred meters down the coast fronting Kammies surf spot (between Sunset Beach and Rocky Point) is threatened by erosion during summer conditions when trade wind generated waves scour sand away and towards Rocky Point, undermining structures in the process. This recurring erosion hotspot at Kammies may recover during the winter when North Pacific swell brings sand back into the region.

2.3 Wave Exposure

The Hawaiian Islands are subject to high waves on a routine basis (Figure 4a). On the North Shore of Oahu, strong, long-period (14-18 seconds) North Pacific swells dominate in the winter, with an annually recurring maximum significant wave height of 7.7 meters (Vitousek and Fletcher, 2008). During summer months, the islands of Oahu, Kauai, and Niihau provide wave sheltering to the Sunset-Ehukai region from Southern Hemisphere swells and Kona storm events (Figure 4b). Persistent trade winds which blow from the northeast approximately 75% of the year are the primary driver of wave activity during summer months, generating average wave heights of 2 meters and peak periods of 9 seconds (Fletcher et al., 2011). Wave exposure for the Sunset-Ehukai region is presented in Figure 5.

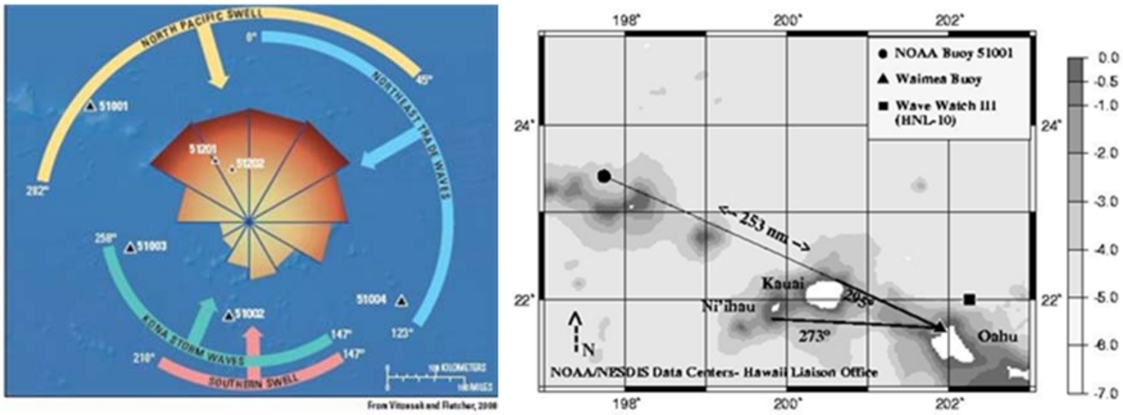

Figure 4. a) Predominant swell directions impacting Hawaii islands (from Vitousek and Fletcher, 2007). b) Wave sheltering from the islands of Kauai and Niihau impact the wave climate at Sunset Beach (source: NOAA).

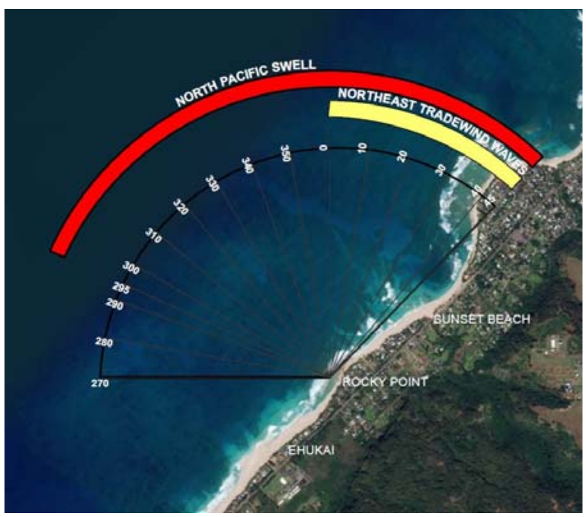

Figure 5. Swell exposure at Sunset Beach, Oahu, Hawaii.

3 PREVIOUS STUDIES

Hwang (1981) investigated beach changes on Oahu based on a review of historical aerial photographs from 1949 to 1979. For the Sunset Beach area, he noted that observations of the vegetation line showed a slight tendency for vegetation to grow seaward, indicating a trend of accretion instead of erosion. However, coastal development and planted landscaping may have influenced these results as well. This trend was interrupted by a December 1969 storm that caused severe damage including up to 21 feet of shoreline erosion in some areas around Sunset Beach (Hwang, 1981).

A report by Sea Engineering in 1997 further characterized the storm berm at Sunset Beach and provided an evaluation of wave runup. The report noted that continued degradation of the high berm after the severe erosion in 1969 was likely due to a combination of seasonal erosion from high waves, and degradation due to foot traffic and heavy use (Sea Engineering, 1997). A 2009 study by the University of Hawaii Sea Grant Program summarized sediment transport characteristics based on empirical knowledge and observations (Eversole, 2009). The report states that sediment transport in the Sunset Beach region is dominated in the winter by bi-modal longshore seasonal transport driven by predominant wave direction: swells from the North-Northwest tend to transport sand to the west, while swells from the West-Northwest are responsible for easterly transport of sand observed during the winter season. During summer conditions, typical trade wind swell out of the east to northeast dominates and tends to transport sand to the west along the shoreline (Figure 6). The study notes that further research is needed.

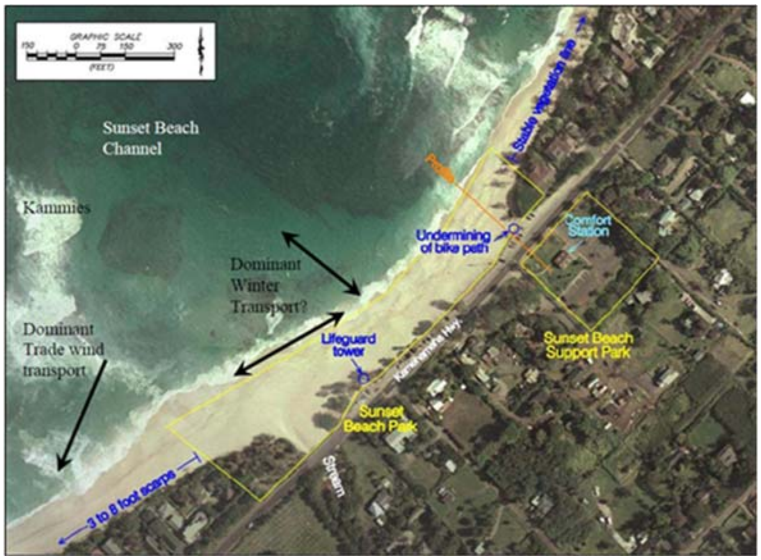

Figure 6. Nearshore sediment processes are characterized qualitatively (Eversole, 2009).

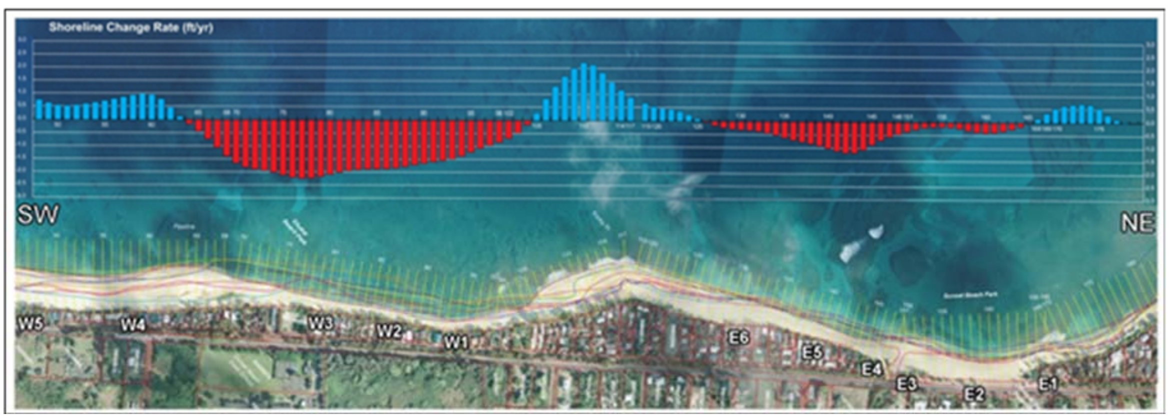

Figure 7. Long-term shoreline change rates estimated from historical aerial photographs from 1928 to 2006 (Fletcher et al. 2010). The current beach survey transects are indicated on the figure as E1 to E6 and W1 to W5.

Long-term shoreline change rates were estimated for the Sunset Beach region based on historical T-sheets and aerial photographs dating from 1928 to 2006 (Fletcher et al., 2010). Figure 7 shows the long-term shoreline change rates, with blue indicating chronic accretion and red indicating chronic erosion. This study also included a series of beach profiles at

Sunset Beach (re-occupied by this study as Site E3). The report notes that large seasonal changes in shoreline position result in high uncertainty in the long-term rates.

The US Army Corps of Engineers investigated Regional Sediment Management (RSM) for the Sunset Beach region in 2015. Numerical models were implemented to simulate wave transformation and current patterns in the region. Modeling results indicated that large and episodic wave events in the winter direct sediment transport to the east, while in the summer the consistent trade winds generate waves and currents that transport sediment back to the west (Podoski, 2017). The RSM investigations also provide evidence of nearshore eddy formation and current flows through channels in the reef, which are expected to add to the complexity of sediment transport in the region.

4 STUDY OBJECTIVES

Observational data of coastal processes are critical to improving understanding of shoreline response to ocean forcing, and may support planning efforts aimed at improving coastal resiliency.

Key objectives of this study include:

- Characterize and quantify short-term changes (seasonal, and inter-seasonal) within the Sunset-Ehukai study area
- Establish a database of coastal observational data for future research

5 METHODS

A beach monitoring program was developed for the Sunset Beach region consisting of 11 cross-shore transects distributed across the study area. Six transects were located on the east side of Rocky Point, and five transects were located on the west side of Rocky Point. Compass headings for each profile location were chosen based on an evaluation of shoreline orientation and site features by use of geo-referenced aerial photographs. For each profile location, front and back reference points were established to facilitate consistent staking of survey lines during consecutive surveys (Appendix A). Additional side reference points were then added as needed to allow for horizontal datum transformations. Transformations consisted of rotating and translating raw data into a common reference frame based on fixed reference points. The Global Positioning System was used to determine the locations of three profile reference points in relation to real-world coordinates so that beach profile data could be tied in to established horizontal and vertical datums. As-Built drawings of site infrastructure and a digital elevation model created from the 2013 US Army Corps of Engineers National Coastal Mapping Program topobathy LiDAR were also utilized to confirm elevations of reference points.

The beach profile data were collected using a total station theodolite in combination with a telescoping survey rod, which enabled collection of both horizontal (position) as well as vertical (elevation) data. Data were collected along each profile transect, documenting key geomorphological features and any grade changes along the profile line. When resources and site conditions allowed, hydrographic survey data were also collected by having a swimmer in the water with the survey rod. Figure 8 presents an example of two beach profile surveys collected at profile W1 during January and May 2015. Representative beach profiles for select beach areas and time intervals have been provided in Appendix B. Photographs of beach conditions at the time of each survey are provided in Appendix C.

The beach profile data were then used to evaluate short-term shoreline change throughout the study area. Since not all profiles extended into the water, profiles were truncated at the local mean sea level elevation before determining volumes. The cross-sectional area (area under the curve) of the subaerial beach was estimated for each beach profile, extending from the shore-water interface to the landward edge of the beach, typically located at the Front Reference Point for each transect. This cross-sectional area of beach is then multiplied by a unit width to estimate a volume per unit width of the beach (m^3/m). Volume per unit width is then multiplied by the distance between beach profile transects to estimate the total volume change for each section of the beach. Beach profile data were not available for February 2015 at profile W4, and October 2015 and February 2016 at profile W5. In these cases, beach volume was estimated based on adjacent beach volumes and site photographs for comparison purposes.

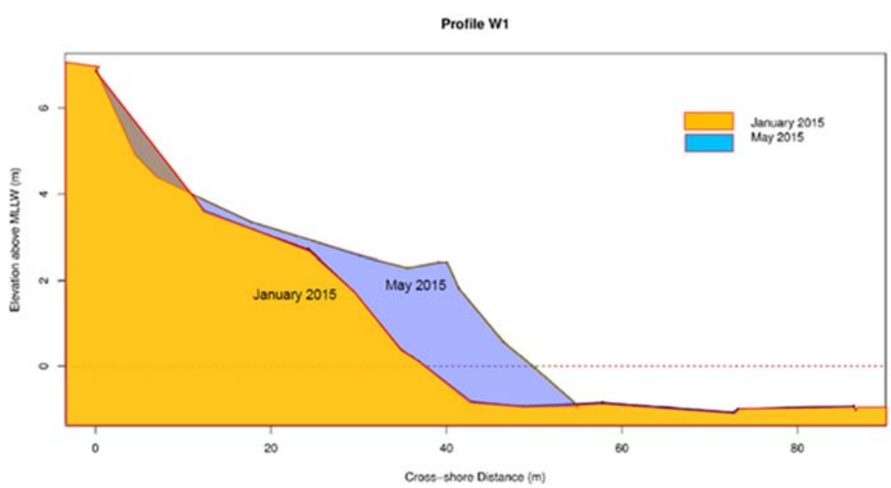

Figure 8. Example of beach profile data collected at profile W1 in January and May 2015. The comparison shows an increase in beach width during this time.

6 RESULTS

In general, the study area can be considered in terms of two main groups divided by the natural headland feature of Rocky Point (Figure 9). The East Profiles (E1 through E6) consist of Sunset Beach and the shoreline fronting Kammies, while West Profiles (W1 through W5) cover the region of shoreline from Ehukai down to Rock Piles.

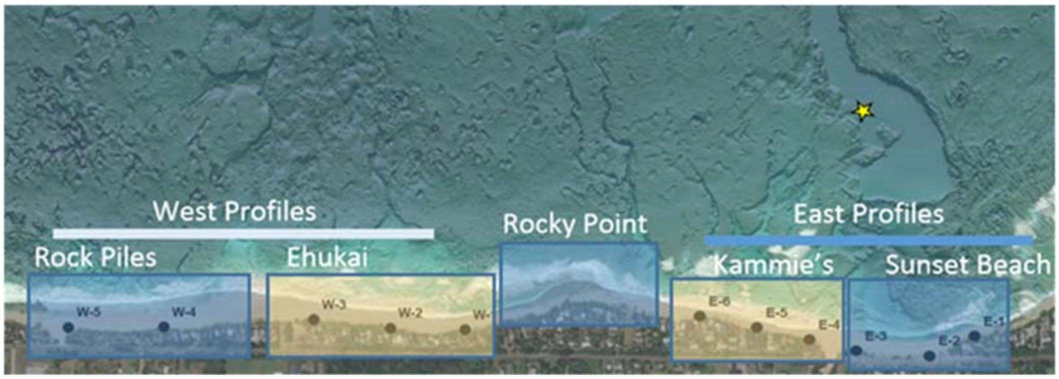

Figure 9. Map of the study area with beach profile locations. Observations of shoreline change present some trends based on location, shoreline orientation, and influence of offshore geomorphology.

Figure 10 presents the volume per month, relative to the mean volume, for the East (green) and West (red) areas. The volume of the subaerial beach in the East area fluctuates between approximately +/- 10,000 m^3, with a maximum volume 100,000 m^3 in February 2015 and a minimum volume 84,000 m^3 in October 2015. The volume of the subaerial beach in the West area fluctuates between a much higher range of +/- 40,000 m^3, and experiences the maximum volume 178,000 m^3 in May 2015 and a minimum volume of 98,000 m^3 in January 2016. The increase (decrease) in volumes of West (East) profiles during times of predominantly trade wind conditions may suggest that sand moves around Rocky Point from Sunset Beach during the summer, eventually extending much like a sand spit into the area west of Rocky Point. This sand is then transported back to the east towards Sunset Beach by westerly swells occurring during the winter.

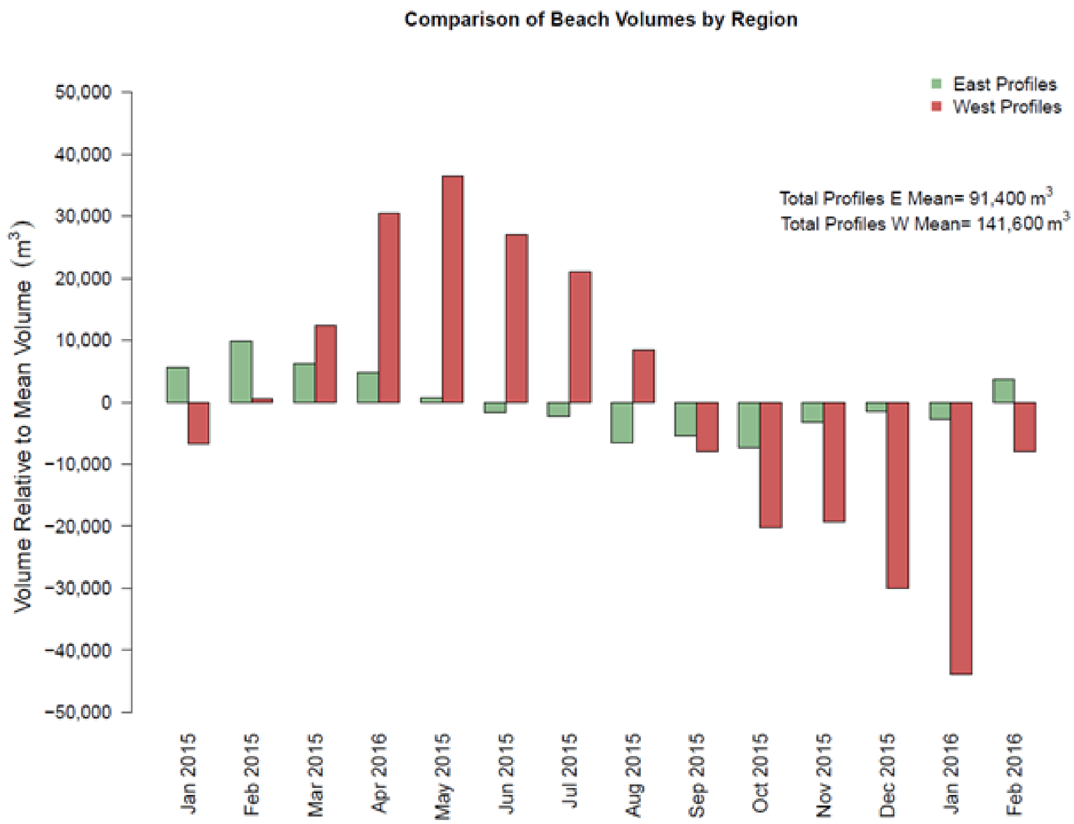

Figure 10. Comparison of monthly subaerial beach volume by region, comparing East profiles (E1 to E6) to West profiles (W1 to W5).

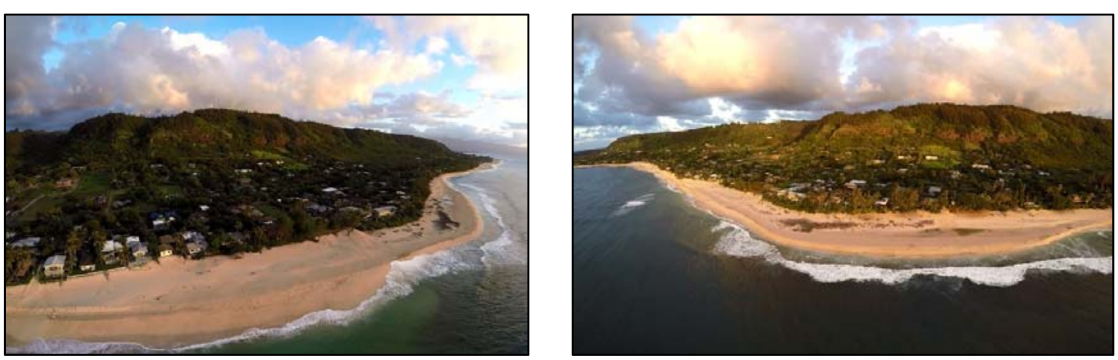

Figure 11. Oblique aerial photographs during September 2016 reveal significant accumulation of beach sand on both the east side (left photo) and west side of Rocky Point (right photo). Rocky Point accretes sand each year during summer trade-wind conditions, until the first strong winter swells begin to redistribute sand as waves refract around Rocky Point.

Evaluating beach volume changes throughout the study area, the East and West profile groups can each be further classified into two smaller sub-regions based on seasonal changes (Figure 9). In general, profiles E1, E2, and E3 respond similarly when subjected to changes in wave climate, while E4, E5, and E6 also exhibit similar characteristics. During summer months, Profiles E1, E2, and E3 at Sunset Beach see an increase in size of the subaerial beach, while profiles E4, E5, and E6 in front of Kammies surf break generally experience erosion. For the West profiles, during the summer months, W1, W2, and W3 extending from Rocky Point to Ehukai Beach Park experience erosion, while profiles W4 and W5 show accretion. These results are presented in Figure 12 based on observations between April and September 2015.

During winter months, Profiles E1, E2, and E3 see an overall trend of erosion of the subaerial beach, while profiles E4, E5, and E6 generally experience erosion. For the West profiles, during the winter profiles W1 and W2 experience erosion while profiles W4 and W5 show

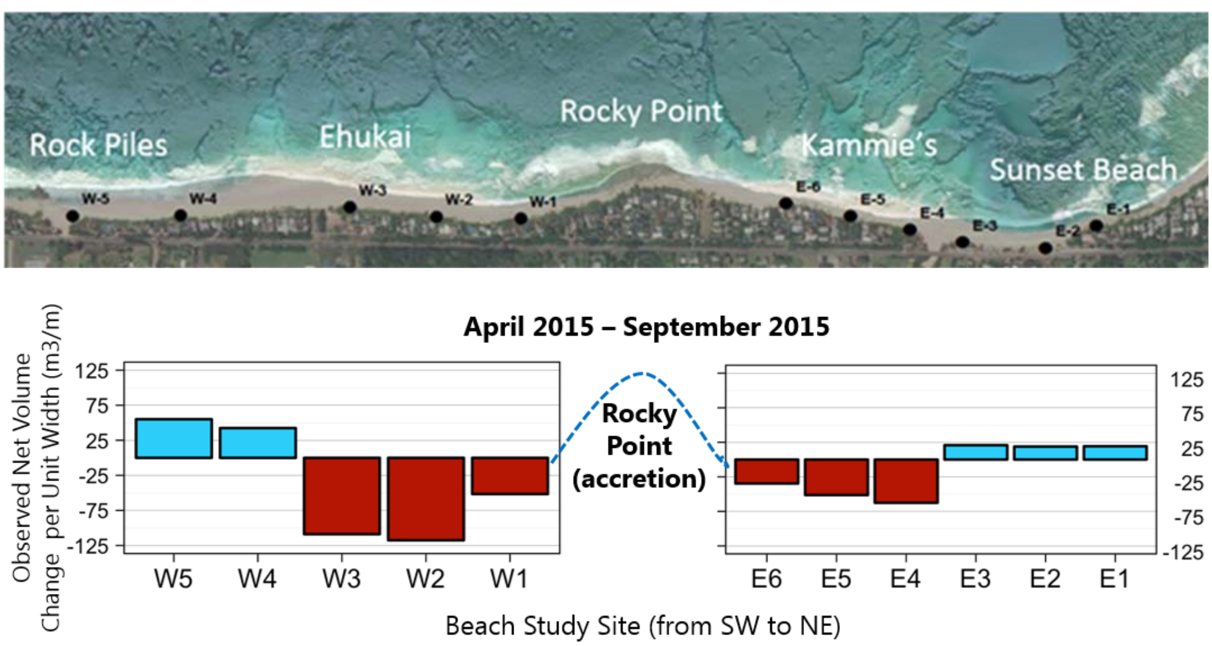

Figure 12. Observed net changes in volume per unit width of the subaerial beach during the summer months of April to September 2015.

accretion. These results are presented in Figure 13 and are based on observations between October 2015 and February 2016.

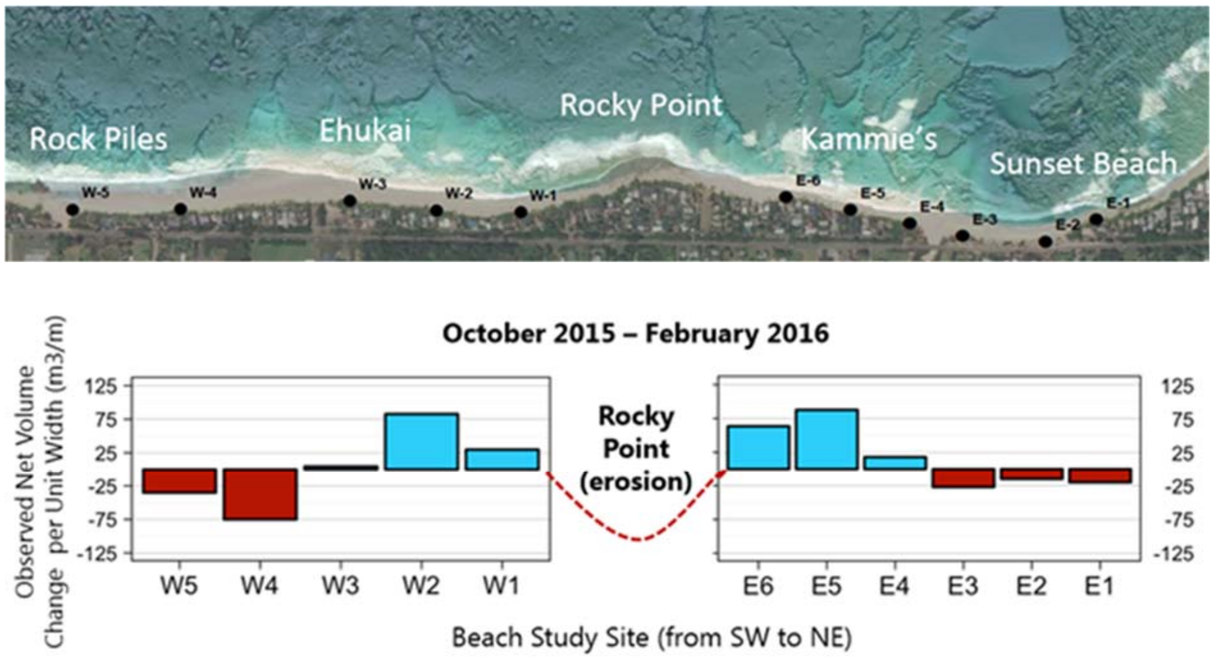

Figure 13. Observed net changes in volume per unit width of the subaerial beach during the winter months of October 2015 to February 2016.

Change in beach volume per unit width for the East and West profile groups can be further evaluated individually to identify trends in shoreline response to varying wave conditions. Figure 14 presents the monthly changes in volume per unit width for two sub-regions: 1) profiles E1, E2, E3, and 2) profiles E4, E5, E6. These observed regional monthly changes in volume can be correlated with observed changes in the wave climate. For example, Figure 14 shows significant changes in beach volume per unit width between the months of February, March, and April 2015. A cursory review of the PACIOOS wave buoy data show the month of February 2015 included more westerly swells compared to March 2015.

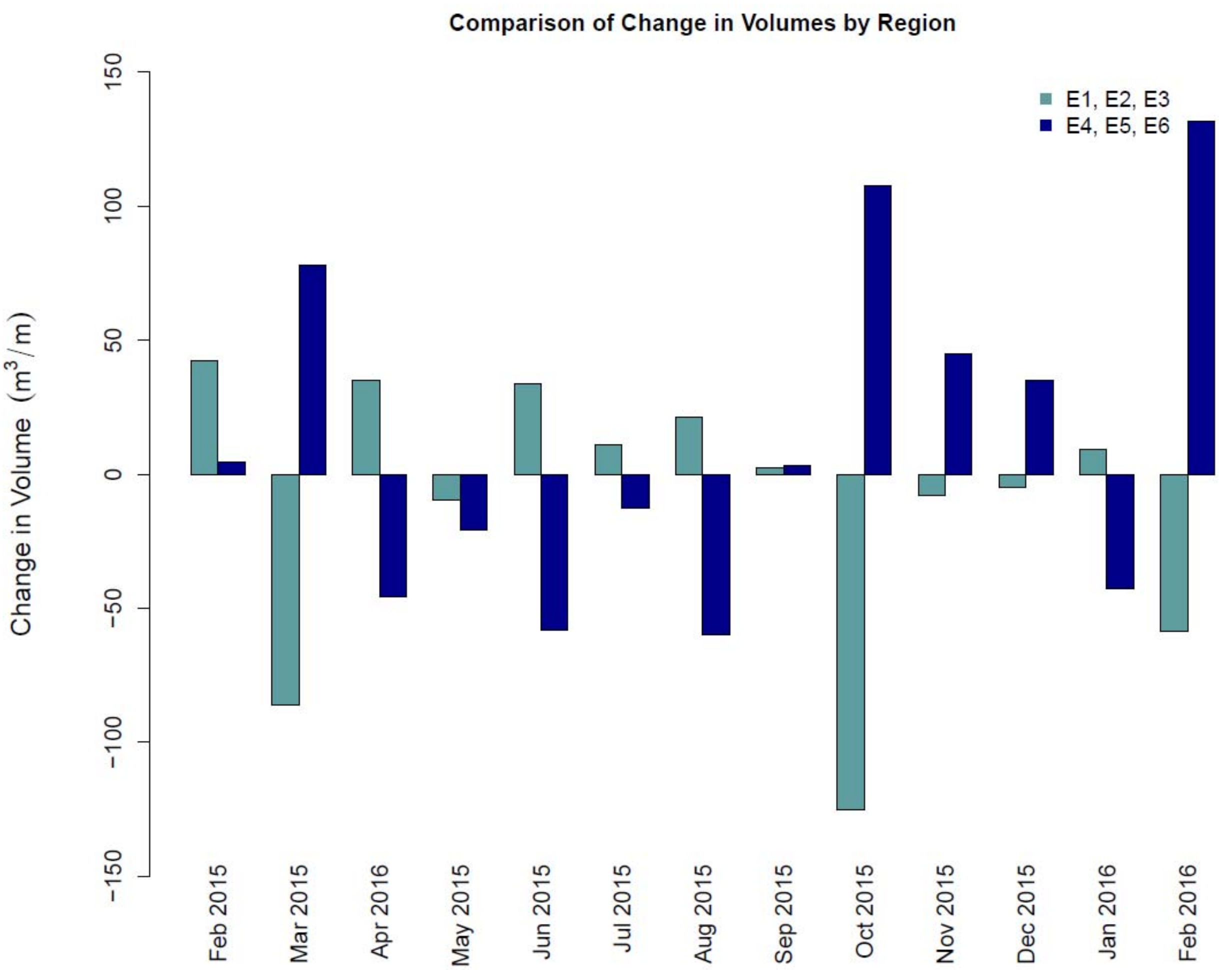

Figure 14. Estimates of monthly subaerial beach volume change for East sub-regions E1-3 and E4-6 during the time interval of February 2015 to February 2016.

7 DISCUSSION

With seasonal and episodic shoreline erosion already threatening different locations of the study area on an annual basis, the risk of increased coastal hazards in the future necessitates pro-active planning and implementation of adaptive shoreline management strategies. This study provides the first quantitative reporting of short-term shoreline changes along the Sunset-Ehukai beach shorelines. Observational data and documentation of site conditions presented in this study can support future efforts to improve coastal resiliency of the region.

As the State of Hawaii has adopted a general policy in opposition to shoreline armoring along sandy shorelines, public agencies and private landowners that seek to mitigate seasonal and episodic beach erosion along developed shorelines are left with limited options. The natural storm berm, as discussed in Section 3, serves as the primary natural coastal protection feature separating the beach system from the backland. Continued degradation of the storm berm by natural and anthropogenic impacts within the Sunset-Ehukai beach region will bring increased coastal vulnerability to the region. In addition to longer-term coastal planning initiatives, efforts to preserve and enhance the storm berm in the region should be further investigated.

7.1 Role of Vegetation in Stabilizing Storm Berm

This study demonstrates that the sandy beach in the region is extremely dynamic and heavily influenced by changes in storm patterns. However, even under extreme conditions, native dune vegetation helps stabilize the system. The Sunset Beach Bike Path provides an excellent case study to examine the critical role that native vegetation can provide in stabilizing the upper beach berm in the Sunset-Ehukai region (Figure 15).

Figure 15. Native vegetation along the Sunset Beach bike path played a critical role in reducing scour and erosion, and maintaining beach sands in place along the upper berm (May 2017).

The stability promoting effects of vegetation could be utilized in the study area by creation of a shoreline conservation zone, perhaps extending 10-15 feet seaward of the certified shoreline, where native vegetation is encouraged. Foot traffic erosion (Figure 16) through this zone could be managed by providing public access points that serve to protect the integrity of the storm berm and vegetation.

Figure 16. Foot traffic erosion plays a significant role in anthropogenic degradation of the storm berm at Sunset Beach (Left: April 2017; Right: November 2016).

7.2 Application of Observational Data in Local Beach Management

Sand within the littoral zone is a finite resource at any given time, and a lack of quantitative data regarding the sediment budget in the region complicates resource management decisions.

This study provides a rough order of magnitude of beach volume changes within the observation area. Observational data resulting from this study could inform future sediment management efforts that may be undertaken by stakeholders or public agencies.

7.3 Applications for Long-Term Shoreline Change Rates

The short-term changes to the volume per unit width of beach observed between April to September 2015 (Figure 15) present the same pattern of shoreline erosion and accretion as presented in the long-term shoreline change rate estimates discussed in Section 3

(Fletcher et al., 2010), as demonstrated in Figure 17. This may support that these published long-term shoreline change rates for this region are overly valuing the summer shoreline position in the long-term shoreline change rate estimates. Reviewing the historic aerial photographs used in the study, 5 of the 7 aerial photographs since 1949 were taken during the winter or spring months of January, February, April, or May, while the final two aerial photographs of the series were taken in July. Short-term shoreline change observations within the study area may help to inform estimates of long-term shoreline change by further differentiating seasonal extremities from long-term trends.

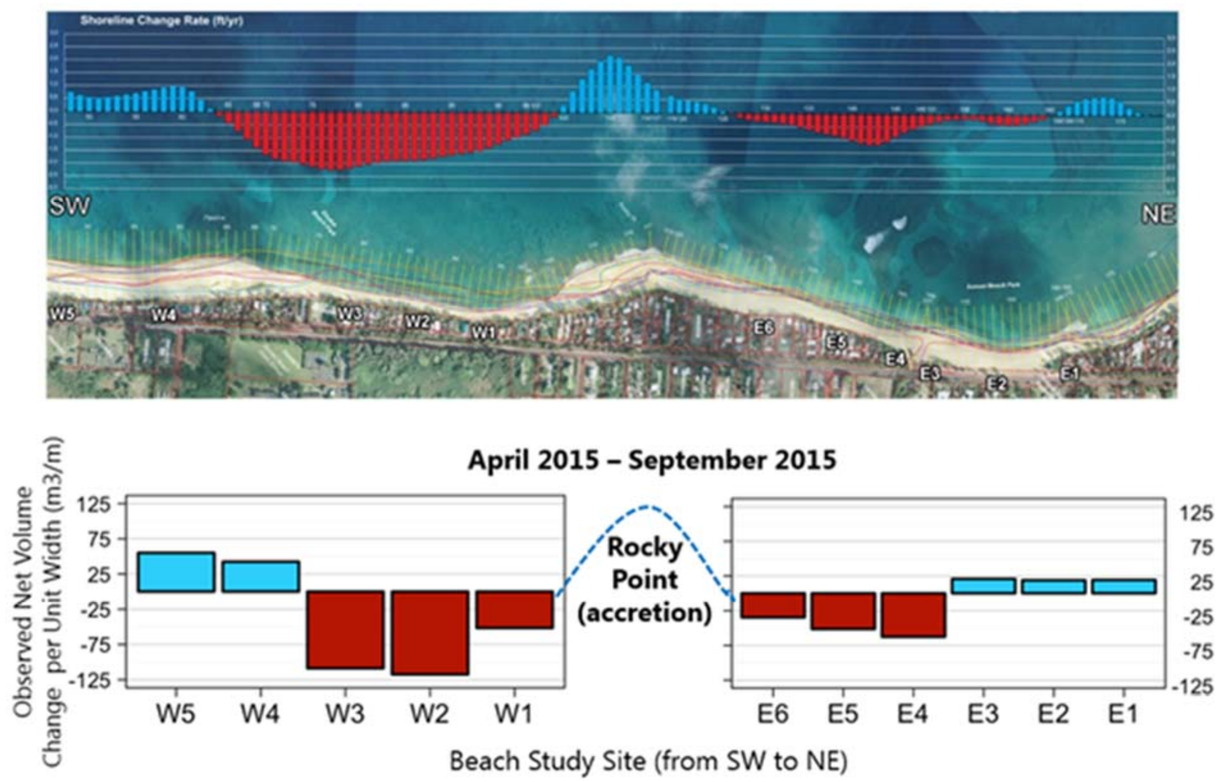

Figure 17. Top – Long-term shoreline change rate estimates based on a review of historical aerial photographs from 1928 to 2006. Bottom – Short-term observations of beach volume change per unit width over the summer season of 2015 (April – September) reveal similar trends with the long-term rates above.

8 CONCLUSION

Coastal observational data are critical to understanding complex nearshore processes. This study presents a 13-month data set of monthly beach profile data within a dynamic beach system on the North Shore of Oahu at Sunset Beach. Patterns of erosion and accretion are quantified on both seasonal and monthly time scales, and shoreline reaches are characterized based on response to coastal forcing.

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