PACIFIC ISLAND CLIMATE ADAPTATION SICENCE CENTER

FINAL REPORT

QUANTIFYING SHORELINE CHANGE AT THREE DIVERSE COASTAL GEOMORPHOLOGIES ON HAWAI‘I ISLAND

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II. ACKNOWLEDGEMENTS

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Lastly, we would like to acknowledge additional funding sources from the University of Hawaiʻi at Hilo Student Association and the Hauʻoli Mau Loa Foundation for conference travel.

Cover photographs by Rose Hart

III. SUMMARY OF PROJECT GOALS

Despite its vast coastline and unique coastal ecosystems and resources, Hawaiʻi Island has never had any systematic monitoring of long-term and short-term shoreline change rates to inform local coastal zone management policies. Consequently, Hawaiʻi Island is in a weak position for adapting to the expected impacts of sea level rise (SLR), building community resilience, and protecting nearshore resources and environments. To better understand and predict coastal vulnerabilities here, our project goals were to:

1. Determine past long-term (decadal) rates of shoreline change using available historic aerial imagery datasets, based on existing published techniques (e.g. Fletcher et al., 2003; Hapke and Reid, 2007; Romine and Fletcher, 2013).
2. Determine contemporary short-term (monthly- yearly) shoreline change from repeated sUAS flight operations and total station surveys (e.g. Goncalves and Henriques, 2015; Habel et al., 2016).
3. Estimate future shoreline changes with combined SLR and place-based coastal change rates (e.g. Marrack, 2015).
4. Share these results with the County of Hawaiʻi and community members, and incorporate these results into setback regulations (e.g. Abbott, 2013).

Three coastal locations are investigated in this study: Hāpuna Beach State Park (a calcareous, white sandy beach), Honoliʻi Beach Park (a sea cliff), and Kapoho Tide Pools (a subsiding lava field) (Figure 1). These sites were selected collaboratively with the Hawaiʻi County Planning Office to represent different types of priority coastline found on Hawaiʻi Island (Fletcher, 2002).

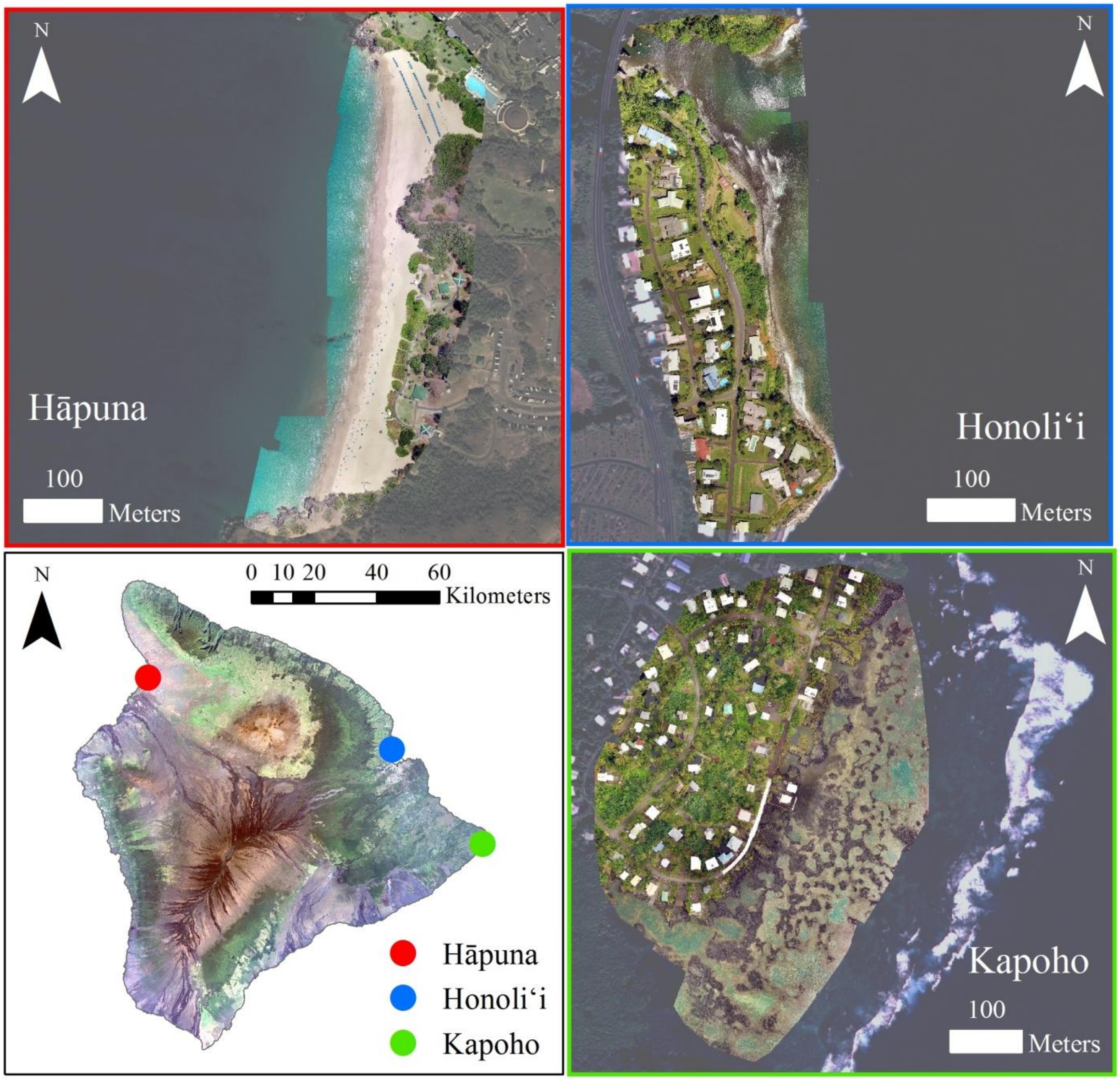

Figure 1. Map of study site locations and high resolution sUAS-derived orthophotomosaics. Hāpuna is a calcareous, white sandy beach located on the northwest coast of the Hawaiʻi Island. Honoliʻi is a coastal bluff located on the east coast of Hawaiʻi Island. Kapoho is a subsiding lava field on the southeast coast of Hawaiʻi Island.

IV. EMPIRICAL FINDINGS

IV.I. Hāpuna Beach

IV.I.I Long-term shoreline change

Our study found that the shoreline of Hāpuna Beach is variable throughout time, but does show evidence of long-term coastal erosion between 1964 and 2018 (Figure 2). Using a weighted least squares regression in the Digital Shoreline Analysis System software (Thieler et al., 2017), we estimate that Hāpuna Beach has undergone erosion at an average rate of -0.18 ± 0.17 m yr^{-1} since 1969. Additionally, we estimated shoreline change of winter specific (i.e. October- March) and summer specific (i.e. April- September) shorelines. We quantified an erosion rate of -0.13 ± 0.19 m yr^{-1} since 1964, and -0.17 ± 0.15 m yr^{-1} since 1969 for winter and summer shorelines, respectively.

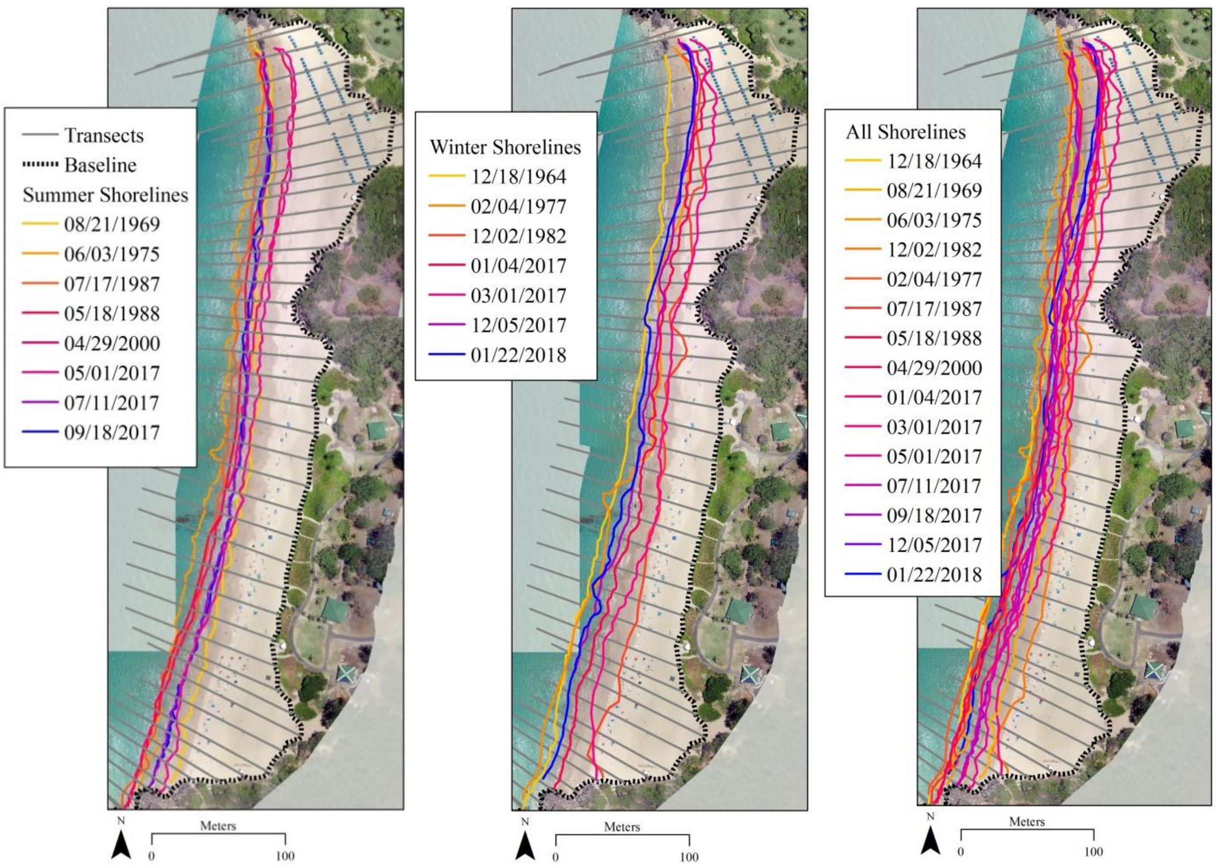

Figure 2. (Left) Summer shoreline Positions, (Middle) winter shoreline positions, and (Right) all shoreline positions.

IV.I.II Short-term shoreline change

Using sUAS, we successfully measured short-term, seasonal change at Hāpuna Beach. In general, we observe patterns of erosion during winter months and accretion during summer months. We produced a digital elevation model (DEM) from each sUAS survey and supplemental topographic surveys to map beach erosion and accretion throughout the year (Figure 3). As the beach transitioned into the summer months, we observed sand accretion along the backshore with gradual sand accumulation along the foreshore through July 2017. In September 2017, there was an episode of erosion concentrated along the north end of the beach, possibly due to a combination of heavy rainfall and wind. Erosion continued into December 2017 towards the southern end of the beach, with visible accretion at the interface of the foreshore and backshore by January 2018. We validated these findings with imagery that show the burial and exposure of a rock outcrop on the beach (Figure 4).

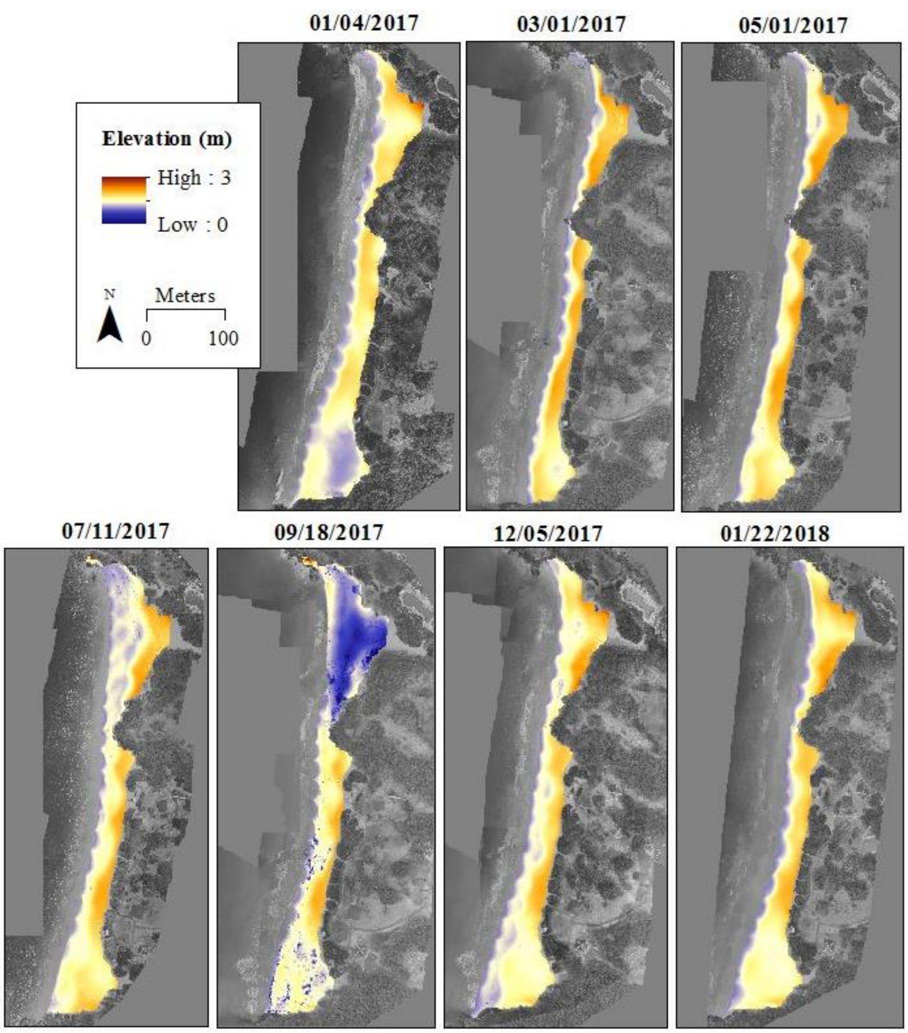

Figure 3. Bare-earth DEM maps for all sUAS dates surveyed.

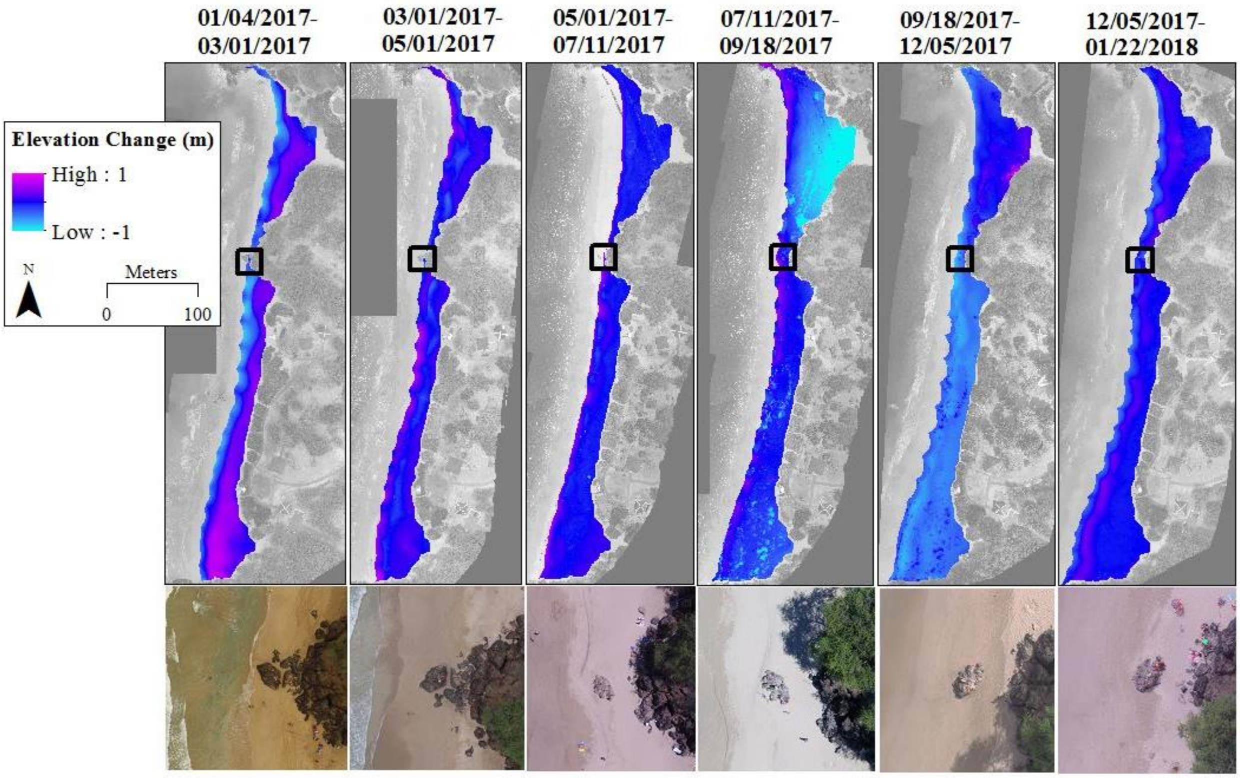

Figure 4. DEM maps highlighting beach sand erosion (bright blue) and accrual (bright pink). Below are images validating intra-annual changes via a rock outcrop by highlighting beach sand erosion and accretion.

With our sUAS-acquired data, we also calculated changes in beach area and elevation (Table 1). Our observations from these analyses suggest that beach area is generally larger in summer months, smaller in winter months, but that elevation gains via sand accretion does not necessarily produce larger beach area.

Table 1. Short-term shoreline change measurements at Hāpuna Beach, HI

Date	*Area (ha)*	*Maximum Elevation (m)*	*Minimum Elevation (m)*	*Mean Elevation (m)*	*Δ Mean Elevation (m)*	*Δ Area (ha)*
1/4/2017	2.39	2.78	0.62	1.52	~	~
3/1/2017	1.59	2.61	0.69	3.37	1.85	-0.80
5/1/2017	1.81	2.53	0.53	1.69	-1.68	0.22
7/11/2017	2.47	2.57	-0.06	1.58	-0.11	0.66
9/18/2017	2.53	3.29	-0.82	1.30	-0.28	0.06
12/5/2017	2.51	2.61	0.74	1.58	0.28	-0.02
1/22/2018	2.23	2.62	0.67	1.63	0.05	-0.28

Shoreline positions were also observed to fluctuate seasonally but do not migrate uniformly throughout the year (Figure 5); intra-annual shorelines overlap with each other and vary independently of the season. We see a mean shoreline positional variation of 7.33 ± 2.29 m, with the greatest shoreline variation occurring at the northern region of the beach.

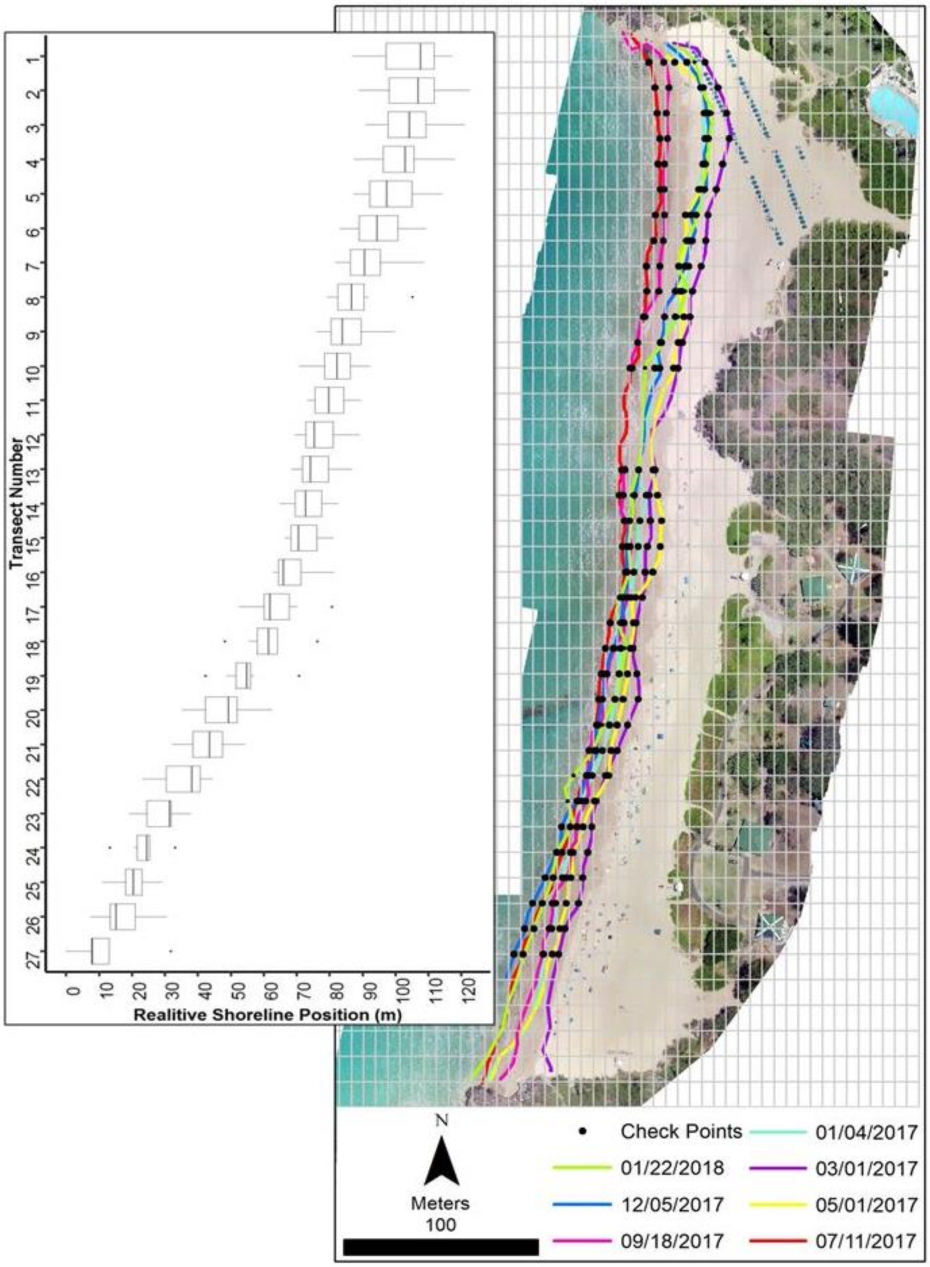

Figure 5. Intra-annual shoreline position variation

IV.I.III. Future Vulnerabilities

Using a simple hydrostatic model (i.e. bathtub model), we found that 1 ft (0.3 m) of SLR would result in ~46% beach area remaining under smallest and largest beach morphology conditions. In contrast, 3ft of SLR would completely inundate the present-day beach regardless of seasonal beach morphology, leaving as little as 6% of the beach remaining (Figure 6).

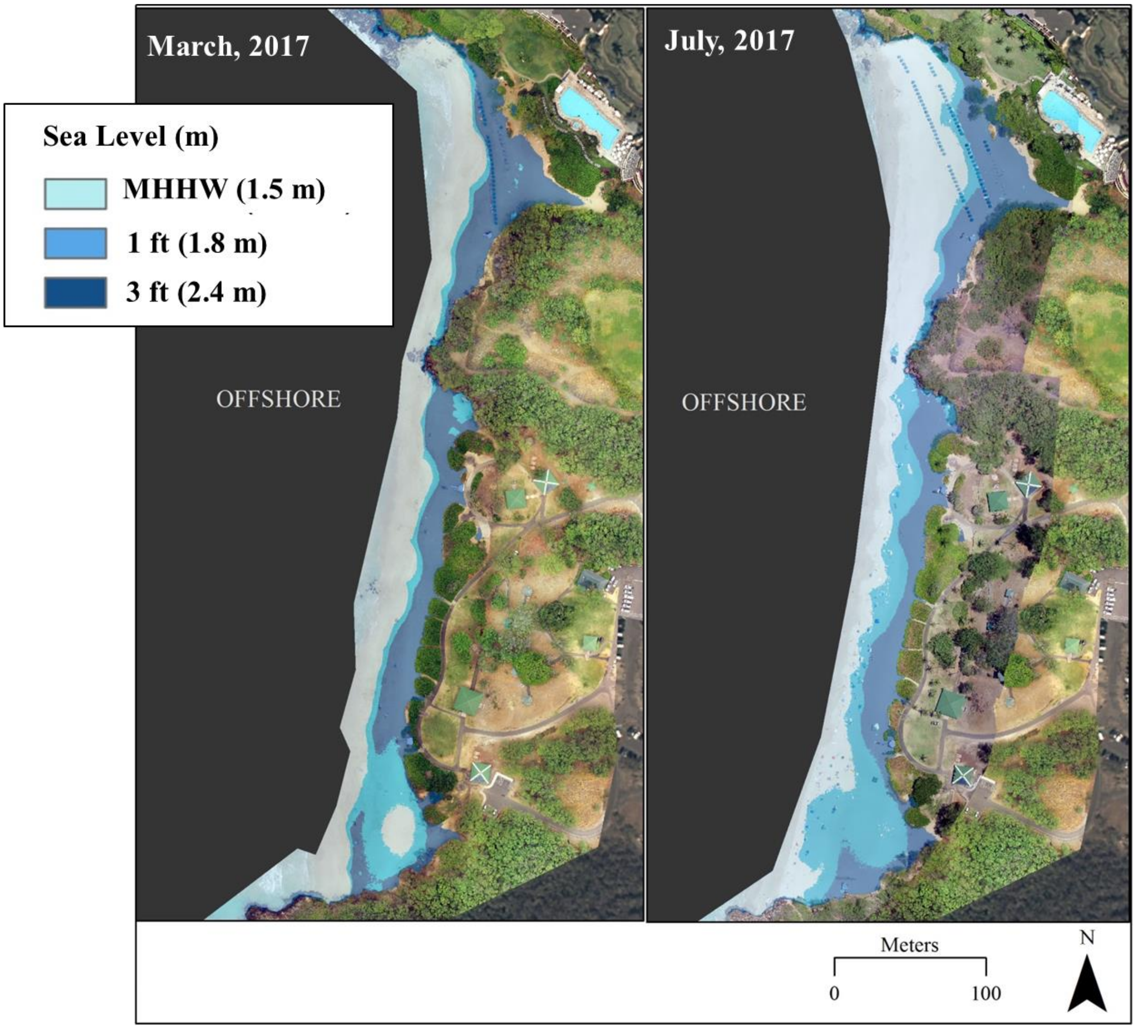

Figure 6. Potential SLR impacts at Hāpuna Beach under 2017 winter and summer beach morphology conditions.

IV.II. Honoli‘i Sea Cliff

IV.II.I. Long-term shoreline change

Our analyses of long-term cliff retreat at Honoli‘i finds that the top edge of the sea cliff has receded a maximum of 9.5 m in 54 years with an end point rate of -0.12 ± 0.01 m yr^{-1} (Figure 7). We also conducted a weighted least squares regression that similarly indicates the cliff has receded at a rate of -0.13 ± 0.26 m yr^{-1}. These statistical analyses were completed using the Digital Shoreline Analysis System software (Thieler et al., 2017).

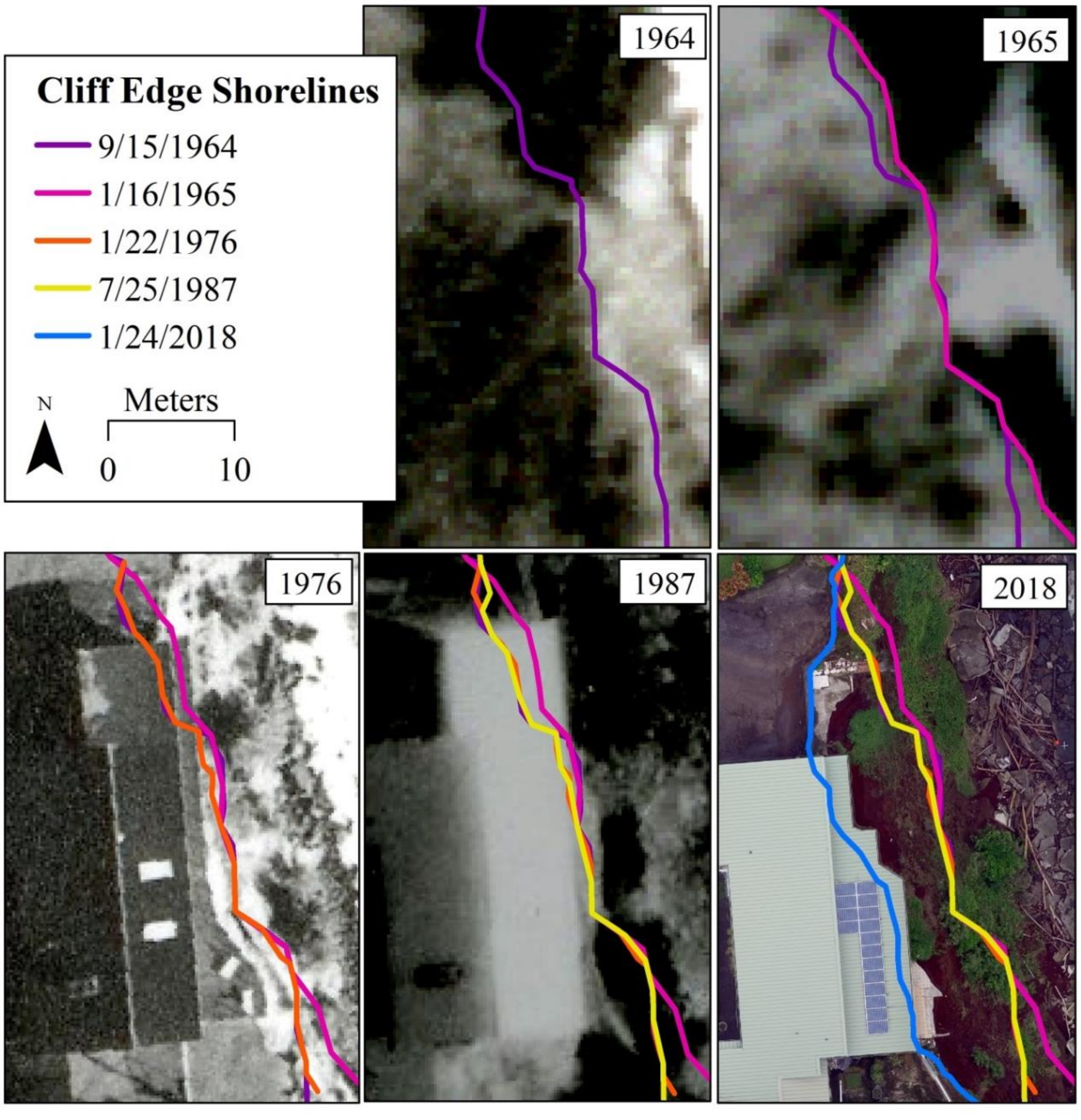

Figure 7. Visible cliff retreat between 1964 and 2018.

IV.II.II Short-term shoreline change

Between January 2017 and January 2018, the Honoliʻi sea cliff receded a maximum of 2.44 ± 0.02 m in one location (Figure 8). A total area of 34.5 m^2 was eroded during this period. Cliff edge retreat is not consistent over time, evident in episodic, short-term events that were recorded using the sUAS data. Oblique and ground-based photos highlight where the cliff is actively undercut, and consequently causing further deposition of cement foundation, patio tiling, and sediment to the base of the sea cliff (Figure 9).

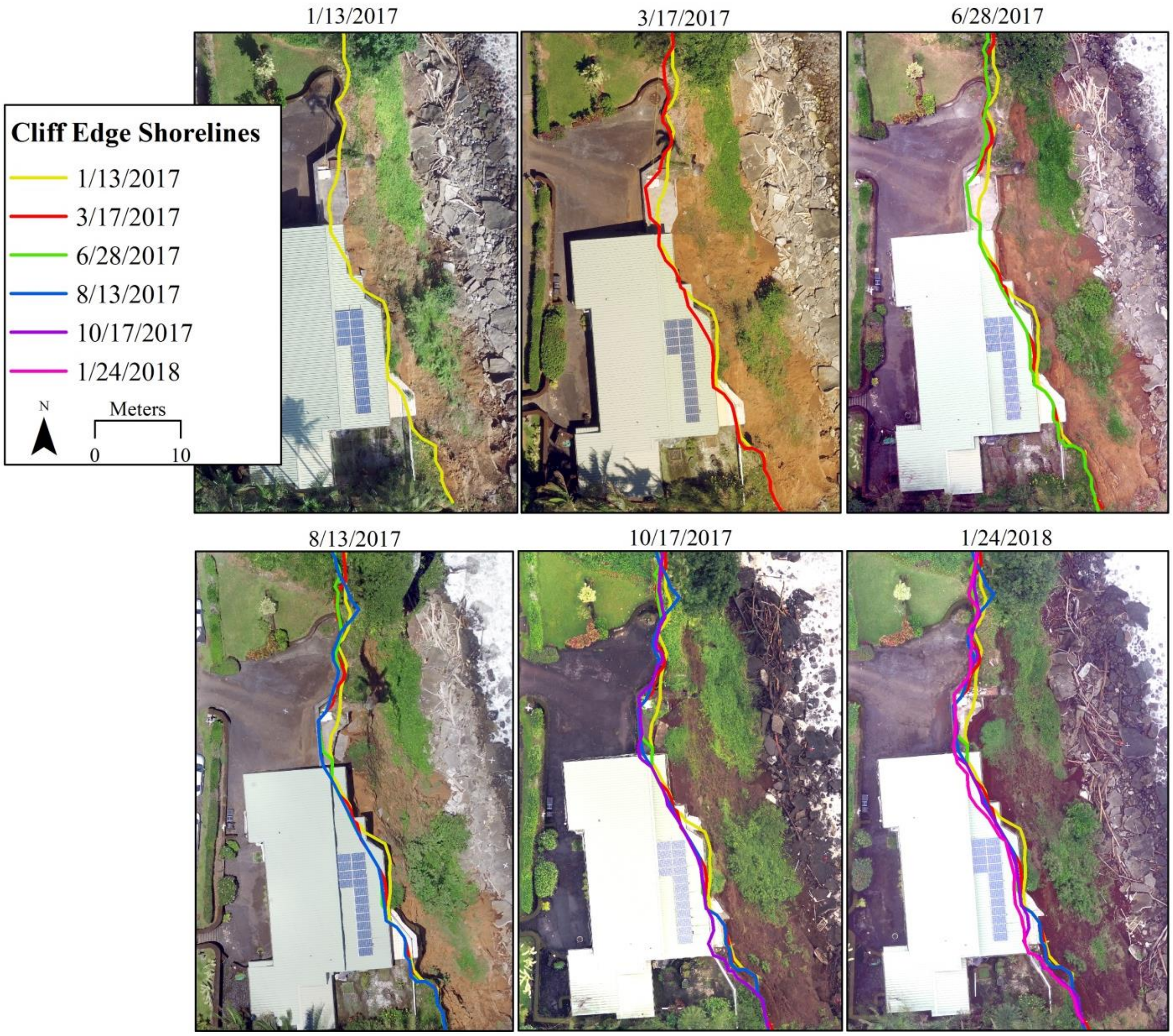

Figure 8. Subset of shoreline positions and associated orthophotomosaics at Honoliʻi between January 2017 and January 2018.

Figure 9. Undercutting of the property and sea cliff, and subsequent debris deposition at the base of the cliff.

IV.III. Kapoho (Vacation Estates)

IV.III.I. Present Day Coastal Vulnerabilities

We determined present-day coastal vulnerabilities to Kapoho by conducting one sUAS survey on October 8, 2017, during a low tide and on June 23, 2017, during an extreme high tide (i.e. king tide). Using those data, we identified existing anchialine ponds and delineated extreme flooding and pond overflow. Additionally, we used those data to show that present-day extreme flooding surpasses the 20 ft setback, and in some areas even surpasses the 40 ft setback line (Figure 10). We estimate that 68% of total parcels/properties were impacted by the present day extreme flooding event (Figure 10), and 39 on-site waste disposal systems (OSWDS; i.e. cesspools and septic tanks) were flooded due to present-day tidal flooding and subsequent anchialine pond over flow (Figure 11).

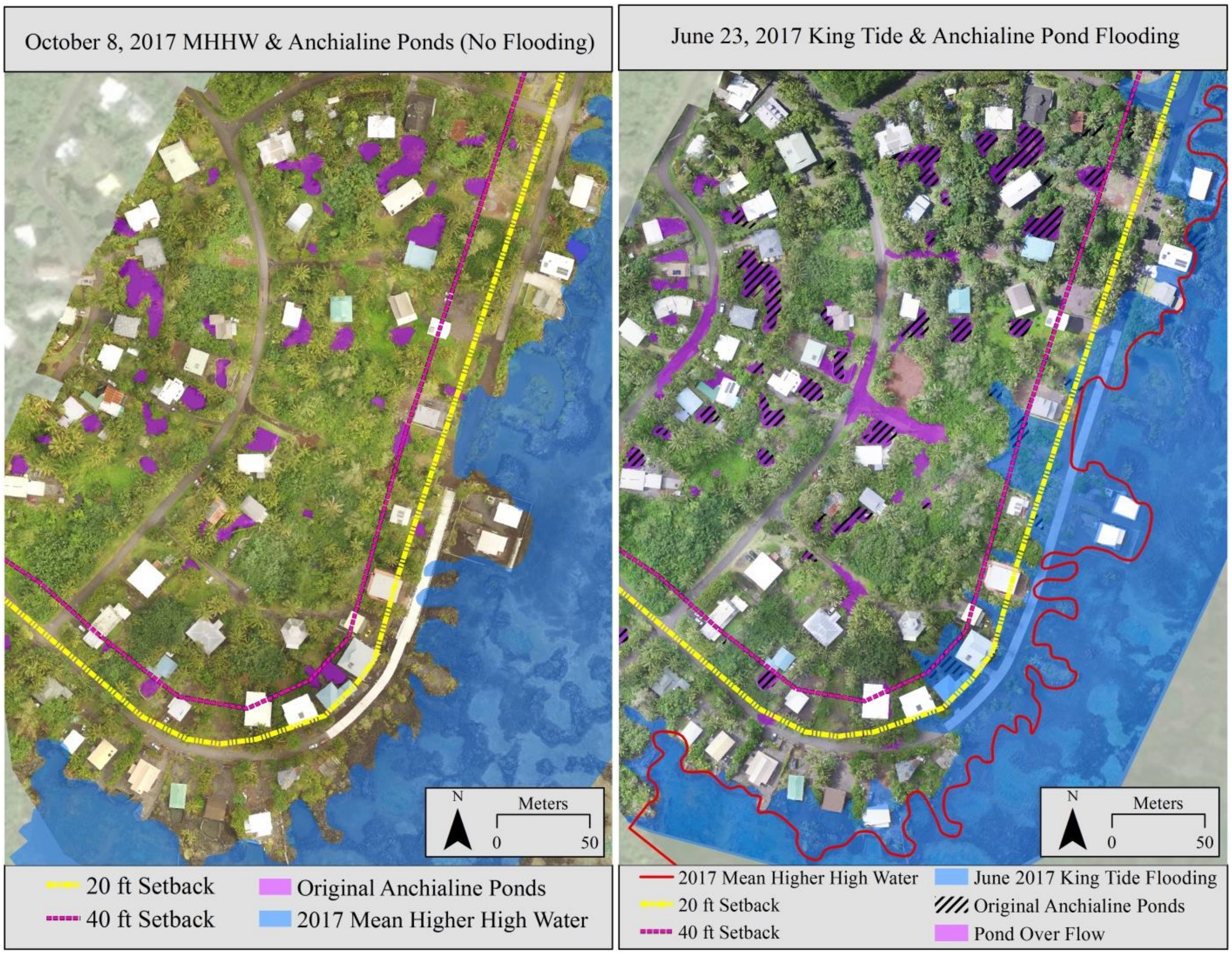

Figure 10. (Left) October 3, 2017 orthophotomosaic with anchialine ponds in dark purple and MHHW in dark blue; (Right) June 23, 2017 orthophotomosaic with anchialine pond over flow in dark purple, original anchialine pond boundaries in black dashes, extreme tide in dark blue, and present-day mean higher high water delineated in red. The 20 ft and 40 ft setback are represented as the yellow and fuchsia dashed lines, respectively.

Figure 11. TMKs and possible on-site waste disposal systems impacted by the June 2017 king tide event.

IV.III.II. Future Vulnerabilities

We created a simple hydrostatic sea level rise model (e.g. bathtub model) to estimate future sea level rise in 10, 25, 50, and 75 years, using a SLR rate of 3 ft by 2100 (Parris et al., 2012; Sweet et al., 2017). Based on these scenarios, we estimate that there could be nearly 2 m of SLR in 75 years. We also estimate that in 10, 25, 50, and 75 years, the local mean higher high water level will increase from 1.93 m to 2.21 m, 2.63 m, 3.32 m, and 4.03 m, respectively. Within 10 - 25 years, we further predict the entire study area will experience flooding much greater than the June 2017 king tide event. At any given future flooding scenario, we see the water level completely surpasses the 20 ft and 40 ft setback boundaries (Figure 12). Additionally, we see that almost all parcels/properties experience flooding in as early as 25 years, and within 75 years, all parcels and cesspools are affected by flooding (Figure 13).

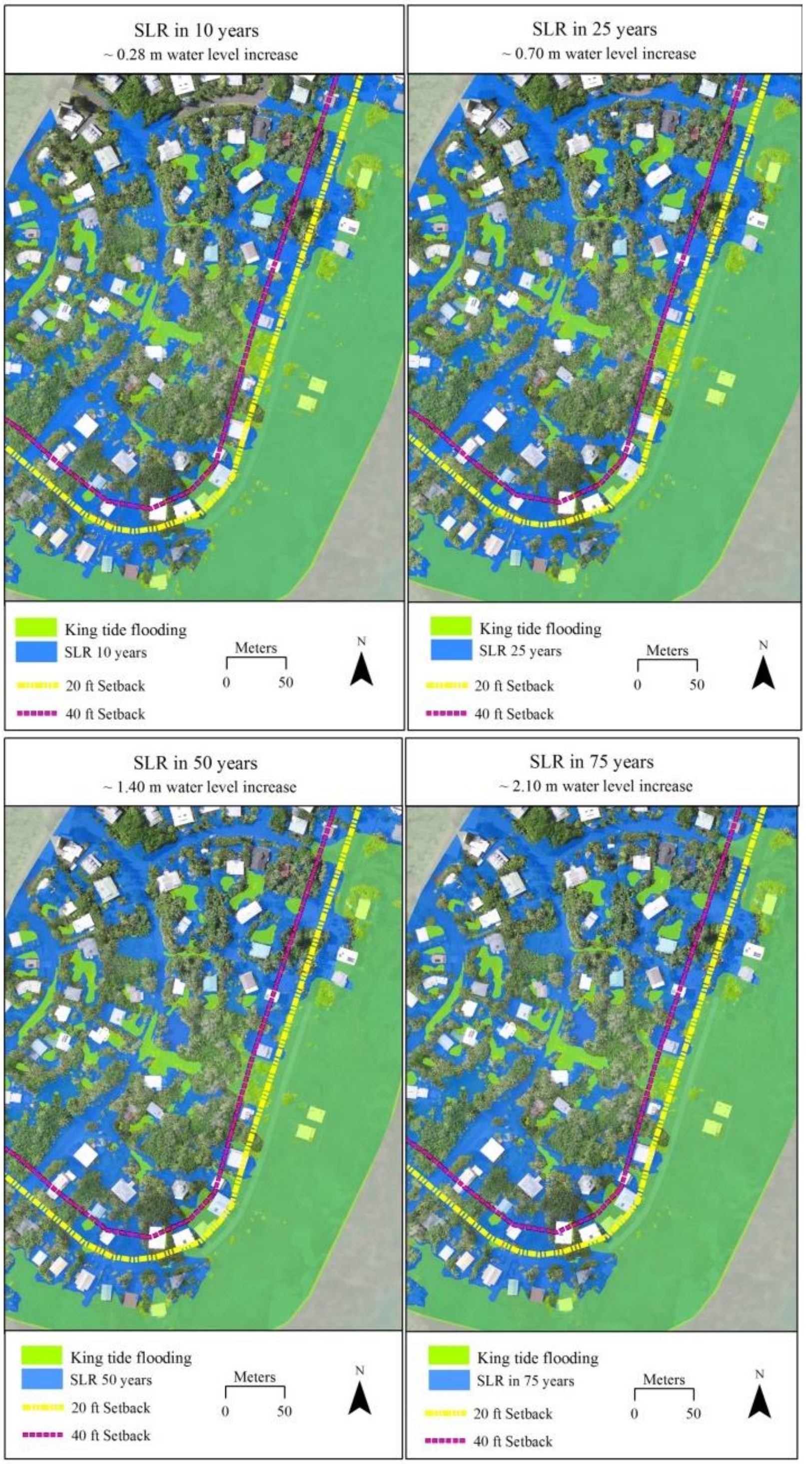

Figure 12. Potential flooding in 10, 25, 50, and 75 years. The June 2017 orthophotomosaic is used as a base map. The 20 ft and 40 ft setbacks are identified as the yellow and fuchsia dashed lines, respectively. The bright green regions indicate flooding from the June 2017 king tide event.

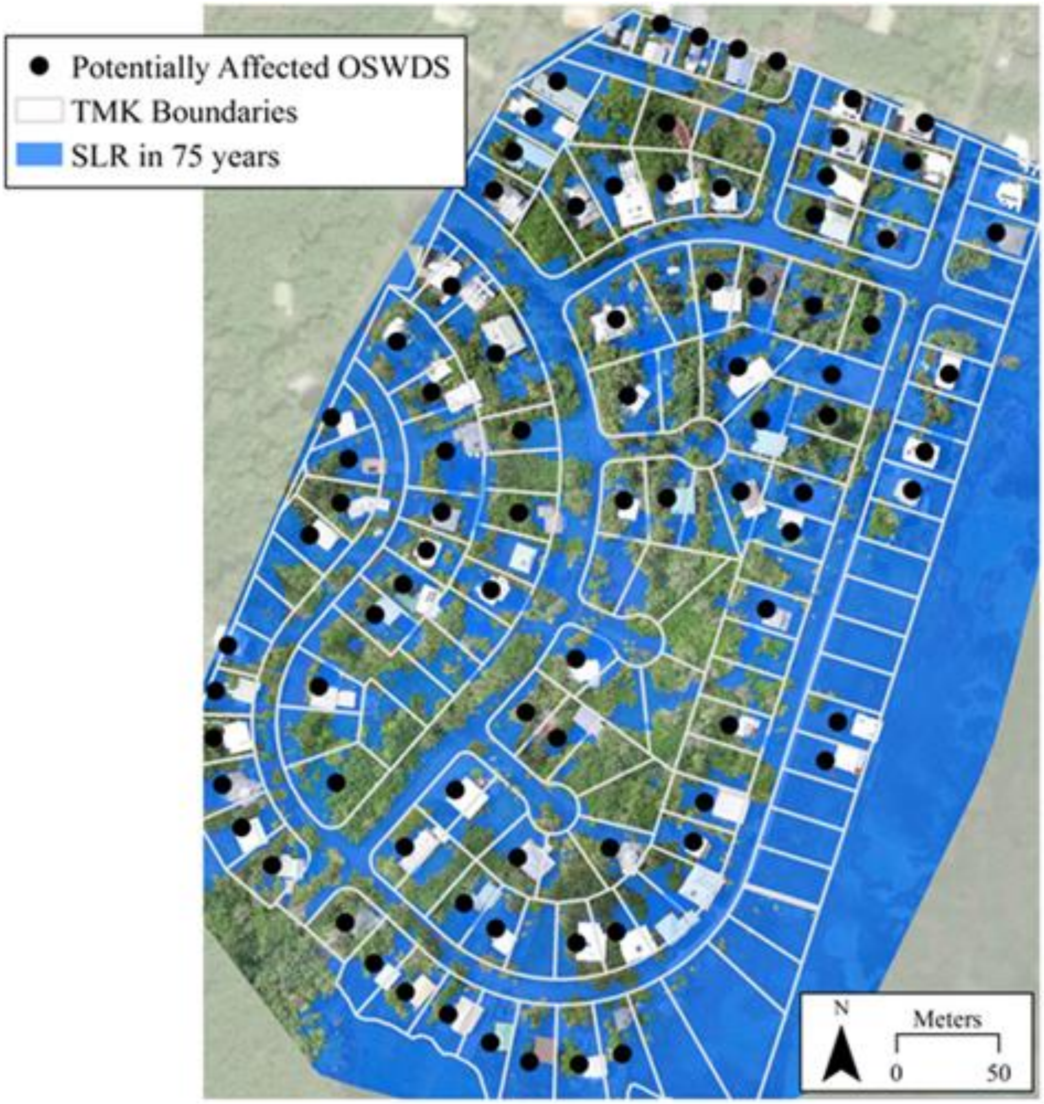

Figure 13. TMKs and onsite waste disposal systems impacted by SLR by 75 years.

V. STAKEHOLDER BENEFITS

Results from this project fill a critical knowledge gap by determining shoreline change rates at three diverse settings representative of Hawai‘i Island’s coastline. This is a significant benefit to Hawai‘i County planners because the present shoreline setback (i.e. the closest developable distance to the coast) is a minimum of forty feet from the designated shoreline for all lots, with some exceptions that allow for a twenty foot setback (Rule 11, Shoreline Setback of the Hawai‘i County Planning Department Rules of Practice and Procedure). This policy was established without any research supporting that twenty or forty feet is a reasonable and safe setback. This is particularly problematic for Hawai‘i Island, which has nearly 430 km of varied coast including sea cliffs, sandy beaches, and low-lying lava fields. Further, shoreline adjacent lots are subject to various levels of zoning and development.

As such, this project’s results greatly inform and necessitate scientifically supported shoreline setbacks and other special management areas rules (e.g. Abbott, 2013). Hawai‘i County planners are proactively using this project’s methodologies and results to make necessary adjustments to the shoreline setback policy, and determining other rules that can benefit from this project’s findings. Continued collaborations between researchers and county planners will greatly increase the adaptive capacity of Hawai‘i Island’s vulnerable coastal communities in the face of a changing climate.

VI. OUTCOMES ACCOMPLISHMENTS & DELIVERABLES

VI.I. Summary of personal accomplishments & additional project outcomes

In addition to the academic and stakeholder benefits, our project’s graduate student, Rose Hart, secured travel funds to present her research at local, national, and international conferences (Table 2). Further, she won an award for a poster presentation (Figure 14) given in October, 2017, and was invited to present her research at a Mathematics for Industry meeting in Kyushu, Japan in February, 2018. This research has also extended to collaborations with the Nature Conservancy (TNC), who involved Hart in the expansion of a web tool focused on visualizing the effects of SLR to anchialine ponds (tool can be found here). Hart's involvement with this TNC collaboration included deploying tide gauges in anchialine ponds, conducting total station surveys on Hawaiʻi Island's west and east coasts, and facilitating small group discussions to improve web tool accessibility.

Table 2. Conferences attended where this PI-CASC funded project was presented.

Conference Title	*Location*	*Month/Year*
Office of Maunakea Management Speaker Series	Hilo, HI	May, 2018
UH Hilo TCBES Symposium	Hilo, HI	April, 2018
American Association of Geographers Annual Meeting	New Orleans, LA	April, 2018
Mathematics for Industry Meeting	Kyushu, Japan	February, 2018
Mathematics for Industry Conference	Oahu, HI	October, 2017
Hawaiʻi Conservation Conference	Oahu, HI	July, 2017
Hawaiʻi Ecosystem Meeting (Vitousek Talks)	Hilo, HI	June, 2017
Island Sustainability Conference	Mangilau, Guam	April, 2017
American Association of Geographers Annual Meeting	Boston, MA	April, 2017

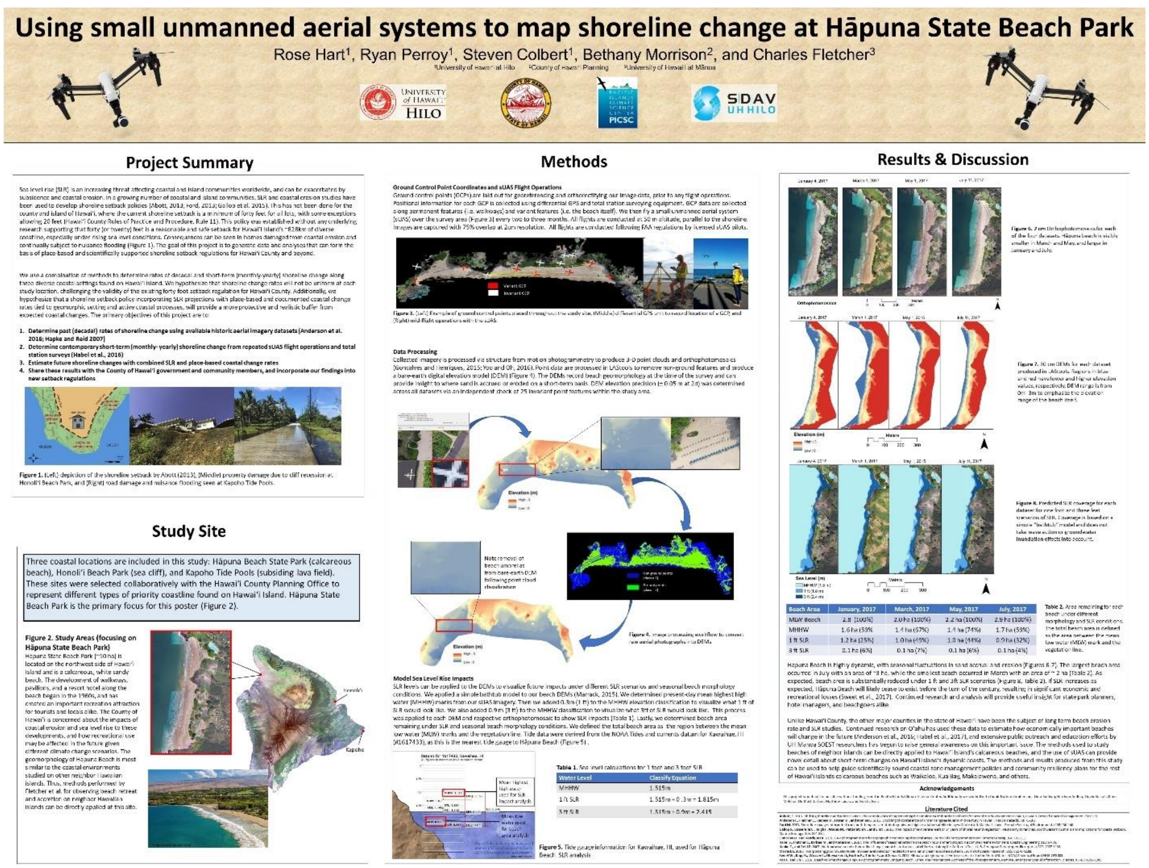

Figure 14. Poster that gained special recognition at a Mathematics for Industry meeting in Oahu, and which also led to an invitation to present the PI-CASC funded research in Kyushu, Japan.

Hart has acquired invaluable skills through this PI-CASC funded project, which has distinguished her as an asset to variety of other projects and fellowship programs. In April, 2018, Hart was accepted to interview at the NOAA Coastal Management and Digital Coast Fellowship matching workshop in South Carolina. There, she was accepted to be a fellow at the Alaska Division of Geological and Geophysical Surveys, which she respectfully declined to continue working on shoreline setback amendments for the County of Hawaiʻi. Hart defended her master's thesis in April, 2018, and graduated with her Master of Science in Tropical Conservation Biology and Environmental Science in May, 2018. Hart will continue to collaborate with the County of Hawaiʻi and pursue a career in coastal resource management.

VI.II. Summary of mentorship and outreach accomplishments

Hart mentored two undergraduate students via internship programs with the University of Hawaiʻi at Hilo and the Pacific Internship Programs for Exploring Sciences (PIPES) (Figure 15). In the spring semester of 2017, Hart mentored Harrison Andina, who helped produce shoreline position records for Hāpuna beach. Afterwards, Hart mentored David Russell during the summer of 2017, who helped produce shoreline records for the Honoliʻi sea cliff, and compute cliff erosion rates. Both interns contributed significantly towards the collection of other topographic and sUAS-acquired data. Andina and Russell presented their internship work at the 9th Annual Tropical Conservation Biology and Environmental Science Research Symposium (April 2017), and the PIPES symposium (August 2017), respectively. These internship and mentorship opportunities helped collect important data for this project while also building the next generation of leaders in natural resource management.

Figure 15. (Left) Former student intern, Harrison Andina, with former SDAV employee, Nathan Stevenson, flying a sUAS; (Right) former PIPES intern, David Russel, assisting Rose Hart with sUAS operations.

In addition to mentoring two interns, Hart also created and participated in education outreach activities. Hart supported GIS workshops for high school students and offered sUAS flight simulator experiences for various age groups at the 2016 Hawai‘i Aerospace Summit, which took place in Honolulu, HI; here Hart was also able to discuss her PI-CASC funded graduate research.

VI.III. Summary of project accomplishments & deliverables

Through this study we accomplished our goals by quantifying, for the first time, shoreline changes exhibited across Hawai‘i Island’s diverse and dynamic coast using historic and sUAS-acquired imagery. We also demonstrated the efficacy of sUAS for high resolution coastal monitoring. Our results give insight to chronic, seasonal, and episodic coastal processes impacting coastal communities and resources on Hawai‘i Island, and can help Hawai‘i County planners develop necessary adaptations to coastal management strategies.

VII. LITERATURE CITED

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