

Long-Term Aspects of High-Elevation Rainfall and Climate Change, O'ahu

Problem and Research Objectives

Climate and precipitation of the Hawaiian Islands is notoriously dynamic across geographic space (Giambelluca et al. 2011; Figure 1) and has long been recognized to vary over time with broad-scale atmospheric circulation (Chu 1995). Variation over time includes dynamics ranging from annual to decadal and longer, including ENSO- and PDO scale dynamics (Chu & Chen 2005). Mountain rain is the crucial component of groundwater recharge in Hawai'i (Giambelluca et al. 1993) and the ultimate source of water for the City and County of Honolulu. Water resource planning over the long term (several decades) requires a long-term understanding of the patterns and drivers of climate variation and change.

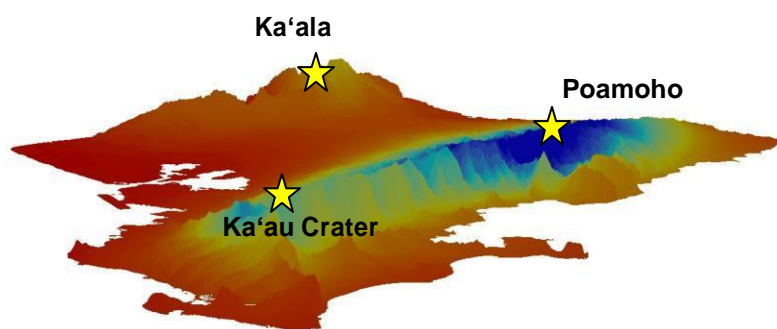


Figure 1. Three-dimensional rendering (base heights exaggerated) of O'ahu, Hawai'i viewed from the southeast showing our study sites. Coloring shows mean annual rainfall from 1978 to 2007 (Giambelluca et al. 2011).

In this study, we seek to better understand long-term patterns of rainfall by reconstructing from peat swamp sediments the long-term ecohydrological changes that have occurred at mountain sites on O'ahu. We have been focusing on three study sites laid out in our original proposal; Ka'au Crater, Poamoho Pond, and Mt. Ka'ala (Figure 1).

Methodology

We are employing two main lines of enquiry: 1) fossil pollen abundances reflecting changes in local vegetation over time and 2) stable isotope geochemistry of hydrogen, carbon, and nitrogen of bulk sediment and specific biomolecules (leaf waxes; *n*-alkanes). Owing to the considerable time investment needed to complete pollen analysis, fossil pollen work has concentrated on the last 8,000 years of sediments at Ka'au Crater. Stable isotope geochemistry work has also focused on Ka'au Crater sediments as the first priority (see principle findings). Sediments have been collected from Poamoho Pond (1m) and from Ka'ala (1.5m) and will also be included in geochemistry measurements.

The position of the water table is one of the critical links between rainfall/hydrology, plant growth and soil organic matter dynamics, and thus the accumulation of organic sediments and their geochemical character. In recognition of this importance, we added a

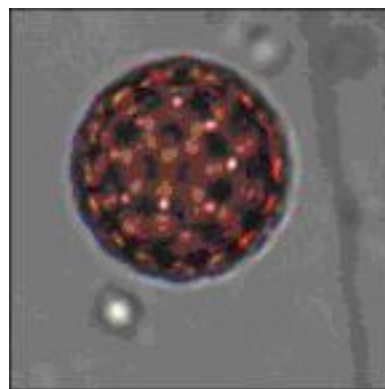


Figure 2. Light micrograph of a pollen grain of *Chenopodium* spp. (Hawaiian goosefoot) from Ka'au Crater sediments; an endemic dry-tolerant shrub which is found on all of the main Hawaiian Islands.

secondary component to this study to monitor the water table fluctuations with rainfall at Ka'au Crater and Poamoho Swamp. Water table loggers were installed at Ka'au Crater in July 2011 and at Poamoho in September 2011 (see principle findings).

Principal Findings and Significance

Fossil Pollen

Twelve samples from the Ka'au Crater sediment profile have been processed for fossil pollen analysis. This includes sieving together with acetolysis and hydrofluoric acid chemistry to remove material from the sediment, leaving the pollen unaffected, in order to identify pollen morphometrically using light microscopy. The pollen in six of the 12 levels has been drawn, photographed, described and counted, totaling over 1,000 grains and spores (Fig. 2). Pollen of approximately 34 different families of plants has been found thus far (Fig. 3). In total, more than 30 assemblages will be counted to show vegetation response over time to rainfall changes. Master's student Ms. Olivia Schubert is working on the pollen assemblages (see Student Support).

Stable isotope geochemistry

Nitrogen stable isotope values ($\delta^{15}\text{N}$) of bulk sediment from Ka'au Crater show surprisingly variable pattern over time, including enriched values in the oldest organic sediments (that have been subject to microbial decay for thousands of years) and those disturbed sediments at the surface. Additionally, a highly enriched departure is evident around 5000 years ago. Such an enrichment in ^{15}N is consistent with a greater degree of microbial processing of organic matter (trophic level enrichment of microbial biomass) and shows something other than just time or recent disturbance, and is consistent with a drop in water table around

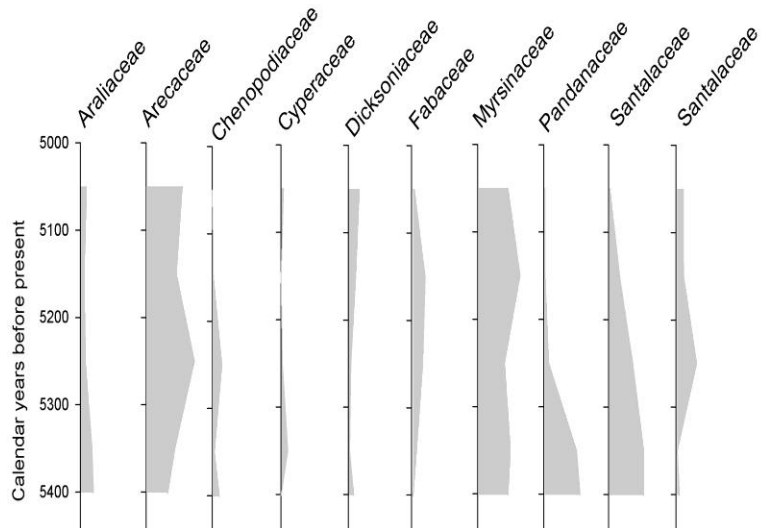


Figure 3. Selected fossil pollen abundance changes over time. Five levels dated between 5000 and 5500 years ago are shown for 10 of 34 different plant families, and indicate vegetation variability in the mountain environments of the southern Ko'olau, O'ahu.

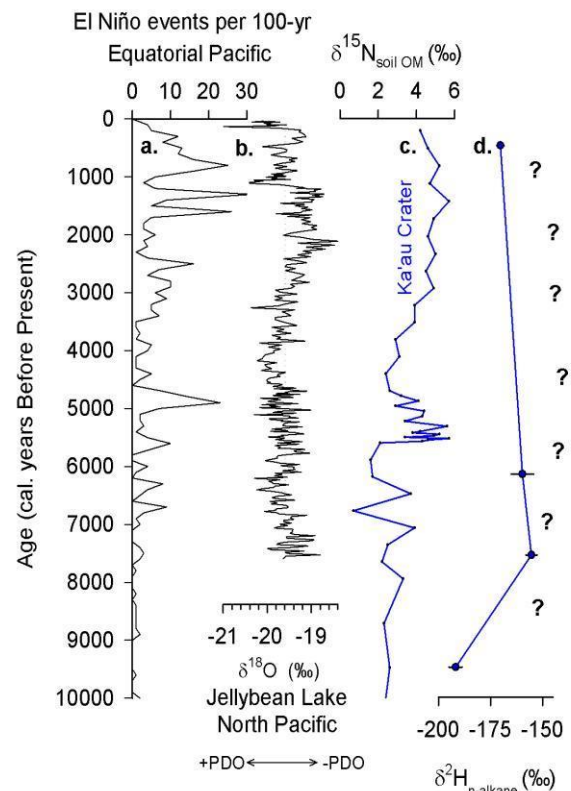


Figure 4. Long-term reconstructions of ENSO and PDO and isotope data from Ka'au Crater. **a.** El Niño events (Moy et al. 2002). **b.** PDO reconstruction (Anderson et al. 2005). **c.** $\delta^{15}\text{N}$ values of Ka'au Crater peatswamp sediment organic matter (OM). **d.** $\delta^2\text{H}$ values of leaf waxes from Ka'au Crater, which we are currently filling in at higher resolution. Note the dry anomaly (greater $\delta^{15}\text{N}_{\text{OM}}$) around 5,000 yrs ago.

5000 years ago, a period suggested by Uchikawa et al. (2010) to have had dominantly dry vegetation on O‘ahu’s leeward Ewa Plain, and during a period of prolonged negative-phase PDO and dominated by El Niño conditions (Fig. 4).

Our isotopic measurements of plant leaf waxes (*n*-alkanes) extracted from Ka‘au Crater sediments have yielded promising early results. *n*-alkane abundance has ranged from 234 $\mu\text{g g}^{-1}$ to below detectable limits for samples between 14 cm and 390 cm in the collected profile, with leaf wax composition (abundance of different chain lengths) and hydrogen isotope values surprisingly variable; ranging from -132 to -192 ‰ (Table 1). An overall depletion in mean $\delta^2\text{H}_{n\text{-alkane}}$ over the last 8000 years is consistent with an overall drying pattern over thousands of years, which is also suggested by Uchikawa et al. (2010) for leeward O‘ahu. Presently, we plan to extract and analyze leaf waxes at higher resolution to test the hypothesis that the overall drying of O‘ahu climate has been punctuated by multi-decadal or longer periods of drought (Fig. 4). Presently, we plan to extract total lipids in May 2012 and will run samples this summer in collaboration with the compound-specific stable isotope lab at the NASA Goddard Institute for Space Studies.

Table 1. Leaf wax abundance, chain length distribution, and mean $\delta^2\text{H}_{n\text{-alkane}}$ value of Ka‘au Crater sediments

Depth (cm)	Description	Total <i>n</i> -alkane ($\mu\text{g g}^{-1}$)	ACL (average chain length)	CPI (25-35)	Average $\delta^2\text{H}$ (\pm S D: ‰)
14-16	near-surface	100.8	27.8	12.6	-170.3 \pm 3.6
270-272	Approx. 6200 yr old	122.4	28.4	6.2	-159.7 \pm 10.7
308-310	Approx. 7500 yr old	233.9	29.3	5.5	-155.4 \pm 5.4
334-336	Approx 9200 yr old	86.8	23.4	1.6	-191.9 \pm 5.5
366-368	Approx. 12,000 yr old	22.10	24.8	1.5	
388-390	>12,000 yr old	11.51	27.7	4.3	-131.9 \pm 9.1

Rainfall and water table dynamics

At Ka‘au Crater and Poamoho Pond, basin water balance consists of inputs (rainfall, surface water, and groundwater) and outputs (evapotranspiration and runoff) that affect water table dynamics and processes that affect sedimentation as well as plant growth and soil decomposition. We observe that water table depth changes at Ka‘au Crater vary with rainfall changes (Figure 5), but also observe that prolonged rainfall does

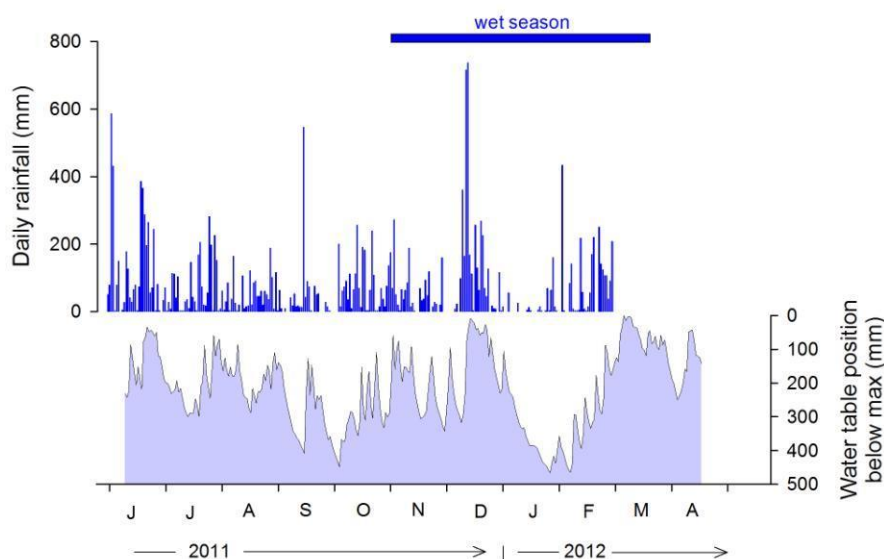


Figure 5. Rainfall in Palolo Valley (station GHCND:USC00517664) and changes in the position of the local water table in the center of the Ka‘au Crater peatswamp. The blue bar shows the duration of the wet season for the southern Ko‘olau Mountains showing the period of above-average daily precipitation, as defined and calculated by Grand and Gaidos (2010)

not result in storage (excess is lost to runoff) and that prolonged periods with little rainfall show a rapid response of water table drop (see Fig. 5; January and February 2012) rather than buffering from groundwater inputs or the water-holding capacity of the peatswamp. Water table dynamics (and the impact on ecohydrology and ecosystem processes) may be more sensitive to dry periods than wet periods. Continued monitoring over dry and wet seasons will help address the drivers of water table changes and impacts.

Future funding

Data, analysis, and hypotheses generated from this project were the seed for a subsequent proposal, which was submitted to the Pacific Islands Climate Change Cooperative and the Pacific Islands Climate Change Center on 2 April 2012 (\$267,107; status: pending).

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