PICSC Final Report

Administrative

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Project Title: Reconstructing pre-historic climate variability in Hawaii and the tropical Pacific using tree rings

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Public Summary

This project was comprised of two inter-related studies that focused on the annual growth rates of dominant native tree species on Maunakea volcano on the island of Hawaii. The goal of the first study was to build a tree-ring chronology from māmane (*Sophora chrysophylla*) to examine past trends in climate on Hawaii to better inform predictive models for climate change in the Pacific region. The goal of the second study was build a long-term dataset on native Hawaiian tree growth and mortality (primarily ‘ōhi‘a, *Metrosideros polymorpha*, and koa, *Acacia koa*) that will be used to improve predictions about the future of old-growth forests on Hawaii and their role in both capturing and storing carbon. In the first study, over 80 māmane samples were collected from high elevation areas and examined for annual growth rings. This will build on the chronology we have established that dates back 92 years and demonstrates that these trees lay annual rings and that the ring-width is associated with amount of rain that fell during the previous summer. We are continuing to work on establishing a chronology that extends even further back in time. In the second study, we found that old growth Hawaiian forests that have been fenced to exclude ungulates are quickly regenerating and adding significant amounts of above ground biomass. Basal area for all tree species has increased, with the notable exception of koa, which has significantly decreased over the past 20 years. Our results demonstrate that introduced ungulates may have large effects on carbon cycling and forest dynamics in island ecosystems, and that management actions such as fencing and ungulate removal can reverse these effects.

Technical Summary

This project was comprised of two studies that focused on the annual growth rates of dominant native tree species on Maunakea volcano on the island of Hawaii. The goal of the first study was to build a tree-ring chronology from a long-lived native Hawaiian tree (māmane, *Sophora chrysophylla*) that extends back at least two centuries. This will allow an examination of past trends in climate on

Hawaii and will provide better data for predictive models for climate change in the Pacific region. This first study is ongoing and comprised of three phases: the field data collection phase, the sample preparation phase, and the ring analysis and dating phase. As outlined below in the *Organization and Approach* section, the first two phases have been completed, but we continue to await laboratory results on radiocarbon ages of rings, thus the third phase has not been finished.

The second study examines the long-term effects of ungulates on above-ground biomass (AGB), growth rates, mortality rates, and abundance of native Hawaiian trees in a high elevation wet forest. We established two hundred 30m diameter plots spaced at 100m intervals within two $1km^2$ study areas at Hakalau Forest NWR. Over 7000 live and dead trees >5cm diameter at breast height (DBH) were tagged, identified, measured, and mapped directly after ungulate exclusion and again 20 years later in 2014 and 2015. New individuals >5cm DBH that recruited into the plots over the 20 year period were identified, tagged, and measured. We used an allometric model developed for *Metrosideros polymorpha** ($AGB = 0.88DBH^{1.86}$) to estimate and compare changes in AGB within our plots over the 20 year period of forest regeneration. We were also able to use these data to determine which tree species are responsible for the increases in AGB, and also which species are declining in abundance over time. Overall, we found a significant increase in Above Ground Biomass at Hakalau since the mid-1990's ($T = 20.4$, $df = 148$, $P < 0.0001$). Interestingly, 36.4% of the increase in AGB was due to new recruitment of trees into the >5cm DBH category, and 47.4% of the increase in AGB was due to growth of trees initially tagged in the mid-1990's. The remaining 16.2% of AGB was held in trees that died between time periods. In addition, there were large increases in abundance and basal area over time of five native tree species across the study sites, including ʻōhiʻa, ʻōlapa, kōlea, kawaū, and pukiawe. Unfortunately, there have been large decreases in basal area for koa (*Acacia koa*) during the past 20 years. Of the 110 large (>50 cm DBH) koa present on the plots in the 1990's, 32% had died by 2015, compared to only 10.4% of the large ohia (Fig. 4). Much of this decrease in koa was due to large trees falling and not being replaced in the canopy. Overall, this study demonstrates that the ecosystem-level benefits of fencing and ungulate exclusion in montane wet forests on Hawaii, and provides a solid argument for managers who are interested in excluding ungulates from additional montane wet forests across the state.

Purpose and Objectives

High elevation habitats in Hawaii are considered highly vulnerable to the effects of climate change (Giambelluca and Luke 2007), and understanding climate trends at high elevations is important for validating regional climate models for the Hawaiian Islands. Furthermore, this information will help protect at-risk native species and ecosystems. Long-term monitoring of the high elevation forests (1800-2400m) on Mauna Kea documents that drought, possibly due to climate change, is affecting the critically endangered Palila bird and some other bird species (Banko et al. 2013). In addition, high elevation wet forests on windward

Maunakea represent the last remaining habitat for a number of endangered Hawaiian bird species, and these forests and forest birds may be vulnerable to climate change as well as to past and present ungulate disturbance. Information about the climate history and forest dynamics on Mauna Kea is needed to improve climate models, to understand the effect of ungulates on the carbon cycle in Hawaii, and to develop more effective conservation strategies for threatened species and ecosystems.

This project builds on thesis work conducted by TCBES graduate student Kainana Francisco. Kainana demonstrated for the first time that some Hawaiian trees exhibit annual rings and was able to produce a tree-ring “chronology” going back to the 1920’s. One objective of this study was to expand our previous sampling to include long-dead māmane trees as well as other long-lived species to build the first ring-based annually resolved hydroclimate reconstruction for Hawai`i that spans multiple centuries*.* This will not only provide a critical record for assessing climate variability and its extended impact on the Hawaiian Islands over the past several centuries but would also represent much-needed empirical data that would be invaluable to regional and global climate modelers and ecosystem managers.

A second objective was to better understand how Above Ground Biomass (AGB) and other aspects of forest dynamics such as tree mortality rates have changed as a result of management actions such as fencing and ungulate removal in a high elevation wet forest at Hakalau National Wildlife Refuge. Tropical wet forests around the world have been recognized as important carbon sinks and sources. Non-native ungulates are known to have large effects on the ecology of these forests, particularly in island ecosystems, however the effects of ungulates on the ability of these forests to store carbon is poorly understood.

Organization and Approach

Building a tree ring chronology that spans multiple centuries in Hawaii requires a field effort that samples live trees, recently fallen trees, and long dead trees. Our lab has also demonstrated that some native Hawaiian trees are extremely old, ranging up to 600-700 years for ‘ōhi‘a (*Metrosideros polymorpha*) and about 200-300 years for mamane, based on radiocarbon dates.

Unfortunately, the ring structure in these native trees can be quite assymetrical (Figure 1) due to lobate growth, so commonly used tree-coring procedures on live trees will not necessarily yield representative ring width patterns for crossdating and analysis. This necessitates the collection of cut slabs or “cookies” so

Figure 1. Example of Mamane tree slab from the upper slopes of Mauna Kea, showing clearly visible annual rings.

that the entire ring structure can be clearly seen and the ring widths precisely dated and accurately measured. In addition, the ring structure of older native trees is more difficult to detect than in younger ones, meaning that sometimes only the younger portion of the rings in a given tree is "readable". For this study, we focused on obtaining cut disks from dead fallen māmane, as well as other long-lived species such as Naio (*Myoporum sandwicensis*) growing above approximately 1800m on Mauna Kea (including Kaohe Game Management area and Pohakuloa Training Area). We obtained over 80 disks from dead-fallen trees at Kaohe and over 40 disks at Pohakuloa. A 2cm thick disk was cut from each dead fallen tree in the field, planed, and sanded with progressively finer sandpaper (up to 600 grit). Using a stereoscope and J2X measuring software, ring widths were measured across 3 radii for each sample. In addition, we are using radiocarbon data to identify the location of the "bombspike" in each of our samples. This information is critical to properly dating the rings. Unfortunately, laboratory analyses of the bombspike data have been delayed due to problems at the radiocarbon lab where we sent the samples, and this portion of the project is still on hold.

When the radiocarbon data is received, the data from all the processed disks will then be inputted into the program COFECHA (Holmes, 1983) to verify within-tree crossdating and establish between-tree crossdating. Once crossdating has been firmly established, the ring width data will be inputted into the program ARSTAN (Cook, 1985; Cook and Holmes, 1986) to detrend and standardize the chronologies in order to maximize the common signal and minimize the effect of "noise". Correlation and response function analysis (Fritts, 1976) will then be used to examine the relationship between measured monthly rainfall (over the past several decades from nearby rain guages) and ring width patterns. These relationships will then be applied to ring patterns from much further back in time to reconstruct pre-historic rainfall patterns for each sampling location. From the māmane dendrochronology results from Mauna Kea, we will compile a continuous history of growth ring patterns with which to compare and possibly extend and relate to other sub-alpine areas on Hawaii and Maui.

To address the second objective of this study, we undertook a large effort to resurvey long-term vegetation plots at Hakalau Forest NWR. From 1994-1997, we established two-hundred 30m diameter plots spaced at 100m intervals within two 1km^2 study areas at Hakalau. Over 7000 live and dead trees >5cm diameter at breast height (DBH) were tagged, identified, measured, and mapped. In 2014 we began re-measuring all trees within these plots to determine growth and mortality rates. New individuals >5cm DBH were identified, tagged, and measured. We used an allometric model developed for *Metrosideros polymorpha** (AGB = 0.88DBH$^{1.86}$) to estimate and compare AGB across the landscape at Hakalau both soon after ungulate removal and approximately 20 years later. We were also able to use these data to determine which tree species are responsible for the increases in AGB, and also which species are declining in abundance over time.

Project Results
The field work as well as lab prep of samples for Study 1 has been completed but we continue to wait for radiocarbon results before statistical analysis of results can be completed. Shea Uehana, who was supported as a technician to conduct this study, was recently accepted as a graduate student in the TCBES Master's program at UH Hilo. His Master's Thesis will focus on using the samples he has collected to extend the māmane tree ring chronology further back in time (and thus completing the original objectives of Study 1). He will be supported with additional funds that have been acquired by PI Hart.

Study 2 has been completed, all data has been analysed, and results were presented at three conferences in 2015 (please see Outreach section). Overall, we found a significant increase in Above Ground Biomass at Hakalau since the mid-1990's ($T = 20.4$, $df = 148$, $P < 0.0001$; Fig. 2). Interestingly, 36.4% of the increase in AGB was due to new recruitment of trees into the >5cm DBH category, and 47.4% of the increase in AGB was due to growth of trees initially

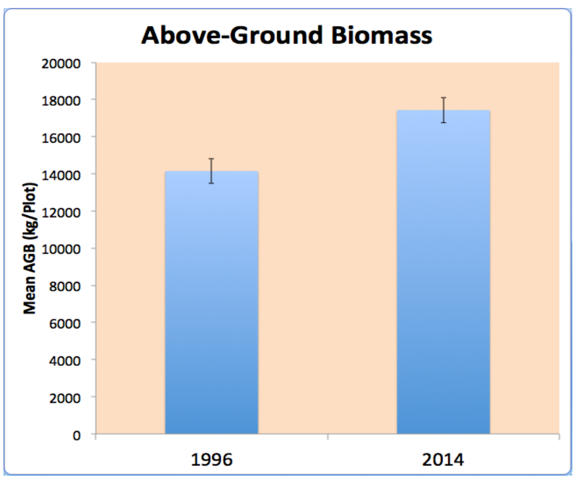

Figure 2. Changes in above ground biomass (kg/plot) at Hakalau over an approximately 20 year period

tagged in the mid-1990's. The remaining 16.2% of AGB was held in trees that died between time periods. In addition, there were large increases in abundance and basal area over time of five native tree species across the study sites, including ʻōhiʻa, ʻōlapa, kōlea, kawaū, and pukiawe (Fig. 3). Unfortunately, there have been large decreases in basal area for koa (*Acacia koa*) during the past 20 years (Fig. 2). Of the 110 large (>50 cm DBH) koa present on the plots in the 1990's, 32% had died by 2015, compared to only 10.4% of the large ohia (Fig. 4). Much of this decrease in koa was due to large trees falling and not being replaced in the canopy.

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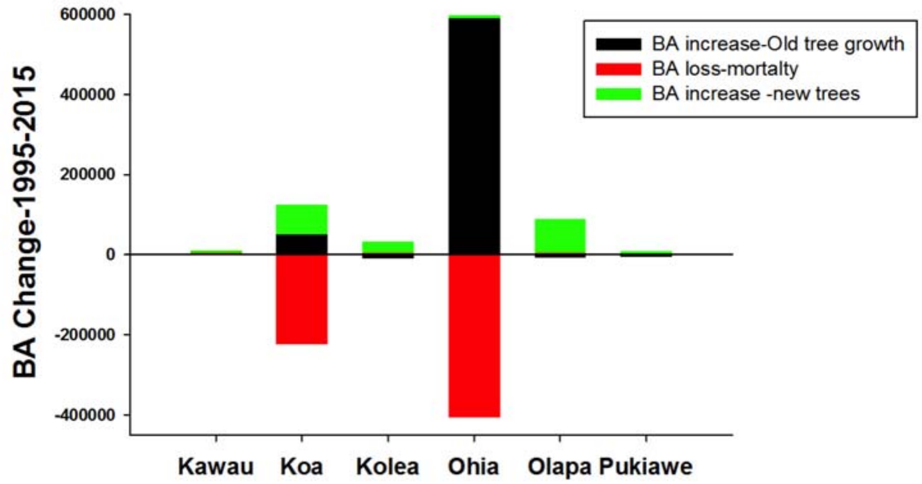

Figure 3. Total basal area (cm^2) change in all plots at Hakalau Forest NWR

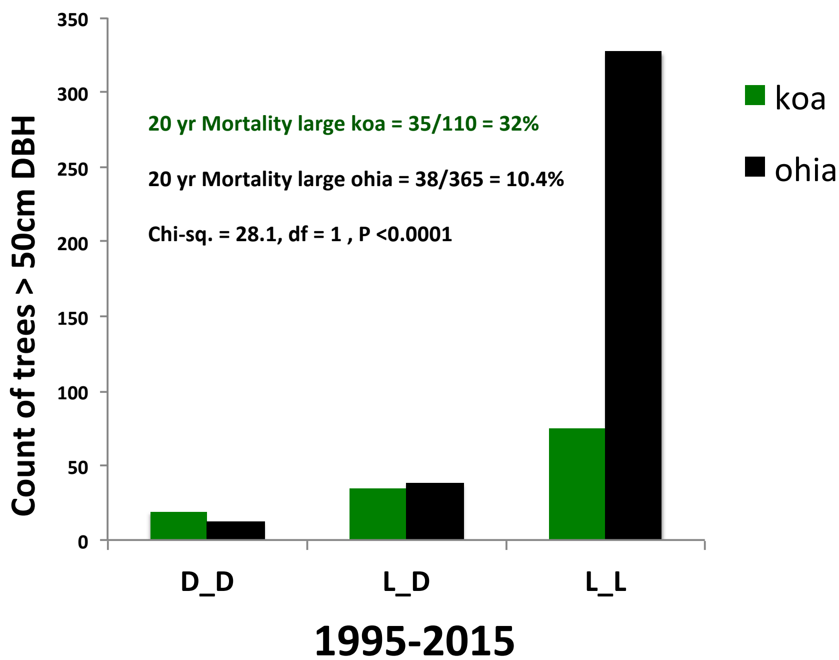

Figure 4. Twenty year mortality rates for large (>50cm dbh) ohia and koa at Hakalau Forest NWR. Koa died at significantly faster rates than ohia (Chi-sq. = 28.1, P <0.001).

Analysis and Findings

This study has shown that fencing and ungulate management in Hawaiian wet forests can result in long-term increases above-ground biomass, basal area, and abundance for all native tree species. Increases from recruitment and growth generally offset losses from mortality. One outlier in our findings is that large koa trees have experienced high mortality rates and appear to have significantly decreased in abundance over time at Hakalau, and presumably most other high elevation wet forests. This could negatively impact endangered forest birds that specialize to a certain degree on koa, such as the ‘Akia`polaau (*Hemignathus wilsoni*).

Conclusions and Recommendations

The goals of Study 1, which are to provide a tree ring chronology that spans multiple centuries, have still not been met, primarily because we continue to wait on results of radiocarbon analyses. First, the cooperating PI on this portion of the study, Dr. Gerd Helle from the Helmholz Center in Germany, took 8 months leave from work due to family obligations. When he returned, he found that the radiocarbon results were questionable and needed to be re-run. When we receive these results, we will be able to better anchor our māmane ring chronology to an accurate calendar date, which should allow us to extend the chronology further back in time. This work is being carried out by Shea Uehana, a UH Hilo Master’s student.

Study 2, which was a survey and analysis of long-term tree growth data, was very successful, and has demonstrated that introduced ungulates may have large effects on tree dynamics and carbon cycling in island ecosystems, and that management actions such as fencing and ungulate removal can reverse these effects. In addition, these actions may lead to increased vegetation diversity.

Management Applications and Products

This study integrated research and management by providing much needed information on the growth response of dominant forest tree species to climate variability and invasive species. This is of great importance to ongoing restoration projects such as the State of Hawaii’s Department of Forestry and Wildlife’s (DOFAW) Mauna Kea Forest Restoration Project, as well as management efforts at Hakalau Forest NWR for a variety of rare and endangered Hawaiian bird species. Managers at Hakalau, for example, can move forward with expensive fencing efforts knowing that solid data exists demonstrating the beneficial long-term effects of fencing on forest dynamics.

The extended chronologies that will be produced in this study will have value to a wide variety of scientists interested in climate change in the Pacific, including climate and ecosystem modelers who need better information on past rainfall patterns for model validation purposes. Our data will also be important for land managers who need to better understand and prepare for how the unique high-

elevation forests will respond to projected changes in climate, given the "backdrop" of past climate changes. In addition, our dendrochronology research will provide a database on the longevity of many tree species, and information on how tree age varies with habitat. This demographic information is critical to understanding the long-term dynamics of Hawaiian forests, yet there is currently little data regarding the lifespan of trees in these forests.
Public presentations and articles produced so-far from this project are listed below:

Hart, P.J., Pang-Ching, J., Uehana, S. and Bishop, M. 2015. Twenty years of vegetation recovery following ungulate removal at Hakalau Forest NWR. Hawaii Conservation Conference, Hilo Hawaii. Oral presentation, approximately 200 people.

Hart, P.J., Pang-Ching, J., Uehana, S. and Bishop, M. 2015. Twenty years of vegetation recovery following ungulate removal at Hakalau Forest NWR. Association for Tropical Biology and Conservation annual meeting in Honolulu Hawaii. Invited oral presentation, approximately 100 people.

Uehana, S., and Hart, P.J. 2015. "Management actions promote regeneration and increase carbon storage in a montane Hawaiian wet forest" PICSC Conference, Honolulu. Poster presentation.

Hart, P.J. 2014. "Tree growth and age in ancient Hawaiian forests- evidence from tree rings". Hawaii Dry Forest Conference, Kailua-Kona. Invited oral presentation, approximately 400 people.

Francisco, K., P.J. Hart, J. Li, E. Cook, and P. Baker. 2015. "Annual rings in a native Hawaiian tree, *Sophora chrysophylla*, on Maunakea Hawaii". *Journal of Tropical Ecology* 31: 567-571.

Patrick Hart wrote an article for the Friends of Hakalau Forest August newsletter. The article was titled "Twenty years of vegetation recovery following ungulate removal at Hakalau Forest NWR".

Morford, Stacy. Aug 21, 2015. Tree rings on Hawaii could hold new knowledge about El Nino. Published on the State of the Planet Blog, Earth Institute, Columbia University. (http://blogs.ei.columbia.edu/2015/08/21/tree-rings-on-hawaii-could-hold-secrets-about-el-nino/)

Outreach

This study has benefitted the local community by supporting students from under-represented groups in the STEM fields in all aspects of research. Kainana Francisco, Tishanna Ben, Joshua Pang-Ching, and Shea Uehana are native Hawaiian/Pacific Islander graduate students in the TCBES program at UH Hilo that were supported by this study and who have been absolutely central to our accomplishments so far. They have added a much-needed perspective to our work in this highly sensitive area. Other students who have been supported by and contributed to this project include William Ray, Mackey Bishop, Andrew Yoshimoto, Robyn Rector, and McKayla Meyer. They will continue to share the knowledge they have gained through this study with local K-12 school groups and college students.

Information from this project has been transferred in a number of ways:

- *Field trips*- Graduate students associated with this project have been accompanied into the field by numerous student volunteers from UH Hilo. This has given these students first hand experience with data collection and management issues in different high elevation forests on Maunakea.
- *Public talks and Published manuscripts*- (please see above)

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