The Tropical HTIRC mission is to advance the science and application of tree improvement, management, and protection to improve tropical hardwood forests, with emphasis on the Hawaiian Islands.
Aloha Kākou!

I hope that you enjoy this 2020 Tropical HTIRC Annual Report, which is the third annual report produced by our center to help promote communications and highlight each year’s progress and developments.

The year 2020 started out in a spectacular way. We held our 2020 Tropical HTIRC annual advisory committee meeting a little early (mid-December) at the beautiful Lyon Arboretum in the back of Mānoa Valley outside of Honolulu. This was probably my favorite Tropical HTIRC meeting so far – well attended and genuine, creating many opportunities for new project ideas and collaborations. My highlight was the lunchtime talk by Bob Rose and Neil Hannahs (Paniolo Tonewoods) describing a proposed statewide initiative for koa reforestation, which is the kind of landscape-level approach we need to strive toward. The day at Lyon Arboretum was complemented as usual with a full field day at Pu’uwa’awa’a and Kealakekua Mountain Reserve on Hawai’i.

On March 5, 2020 our second son was born (Hjalmar Sten Jacobs), who is now very close to walking. We were only days away from hospital delivery rooms being closed to visitors, including dads, due to reports of a novel, rapidly spreading virus. Like for everyone, COVID-19 caused re-directions for our Tropical HTIRC program during 2020, but we pivoted and have great plans for when we can finally get back into the field regularly.

In 2020, we maintained the existing membership of our Tropical HTIRC Steering / Advisory Committee, which provides guidance on the strategic directions of the center, prioritization of research themes, and staffing. We expect to lean more on this group during 2021 as we develop our new 5-year Tropical HTIRC strategic plan, which will cover 2022-2026. Our priorities continue to evolve, and I envision greater emphasis during the next 5 years on Hawaiian native forest trees such as ‘iliahi (sandalwood) and ‘ōhi’a, while also maintaining a strong program in koa. We also need to better promote graduate training opportunities for locals that are likely to pursue careers.
working on natural resource issues in Hawai‘i. The academics and faculty of Purdue University and University of Hawai‘i at Mānoa, combined with the land resources and experience of our partners provides a unique opportunity to positively influence the next generation of Hawai‘i forest ecologists and managers.

We continue to recruit and maintain a productive, diverse staff of Tropical HTIRC graduate students and scientists – see their profiles below. In 2020, Lilian Ayala Jacobo (Purdue) and Achyut Adhikari (University of Hawai‘i at Mānoa) each successfully defended their MS theses. Lilian is now a research forester at the Paraguayan Institute of Agricultural Technology. Achyut continues to work on plant diseases in Hawai‘i and is planning to pursue a PhD.

We were thrilled in 2020 to recruit two new students, local Hawai‘i – born and raised, into graduate studies at Purdue. Tawn Speetjens is studying ‘iliahi nursery propagation and restoration planting for his MS degree, in collaboration with Hāloa ‘Āina. Kylle Roy is studying the chemical ecology of beetles, fungi, and ‘ōhi‘a trees in association with Rapid ʻŌhi‘a Death for her PhD degree. Kylle was awarded a Sloan Scholar to pursue her doctorate degree through the Sloan Foundation Indigenous Graduate Partnership. Aloha, E Komo Mai.

Emily Thyroff will hold her preliminary exam, during which she defends her dissertation proposal on ‘iliahi restoration, at University of Hawai‘i at Mānoa in March 2021. Her research is in close collaboration with Kealakekua Mountain Reserve. Rebekah Ohara is aiming to defend her dissertation on community managed forests at Purdue by the end of 2021, while also serving as CEO of Akaka Foundation for Tropical Forests. Aziz Ebrahimi has completed a draft of one his dissertation chapters, using physiology and genomics to study cold hardiness in koa. Bee Redfield has been navigating the Hawai‘i travel restrictions and is initiating her first PhD trial on Santa Cruz Island, CA, studying island scrub-jay impacts on Quercus spp. seed dispersal and
diversity, which may serve as a framework for pending Hawai‘i studies. Indira Paudel (post-doc) has drafted a manuscript from her study with eco-physiology of koa populations across elevation gradients. Kyle Rose (research scientist, part-time) is leading a publication to report results of treatments that he used to successfully graft koa.

New to this 2020 Annual Report, we have included a section below on Tropical HTIRC partner updates – as a way to keep connected until we can get back together. We also highlight our 2020 accomplishments from a selection of projects designed to meet our research, extension, and education strategic objectives for tropical hardwoods, as presented in the 2017-2021 Tropical HTIRC strategic plan. Many of our projects continue to emphasize koa, a keystone Hawai‘i native forest canopy tree. We describe ongoing research for koa including cold tolerance, population ecophysiology, seed scarification, disease resistance, grafting, and seed collection. We also describe a large, multi-partnered effort to study implementation of community-based forests in Hawai‘i, as well as planned future research on bird-mediated seed dispersal. We continue our emphasis on other important native Hawai‘i forest trees, and below we feature descriptions of several ongoing projects with partners on ‘ilähi restoration and Rapid ʻŌhi‘a Death disease resistance. We will continue to communicate developments from these projects in future Tropical HTIRC annual reports.

During 2020, many of our extension and outreach programs were postponed due to the pandemic. These activities remain integral to our Tropical HTIRC mission and we are excited to resume our planning of field days, workshops, and symposia. While our "normal" two-day annual Tropical HTIRC advisory committee meeting and field tour appears unlikely for 2021, we aim to return to our winter meeting schedule in early-2022. In the meantime, we continue to promote communications on staffing, research progress, events, and publications through our newly revised Tropical HTIRC website.

Mahalo for your commitment and collaboration to benefit Hawai‘i forests.

Douglass F. Jacobs
Director, Tropical HTIRC
The role of the committee is to provide guidance on the strategic directions of the center, prioritization of research themes, and staffing. The committee is comprised of members representing diverse groups associated with ecology and management of Hawai‘i’s forests. Many of the committee members are active collaborators on Tropical HTIRC research and extension projects.

<table>
<thead>
<tr>
<th>Member</th>
<th>Title, Institution</th>
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<tbody>
<tr>
<td>Steve Bergfeld</td>
<td>Hawai‘i Island Branch Manager, DLNR Division of Forestry and Wildlife</td>
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<tr>
<td>Phil Cannon</td>
<td>Forest Pathologist, USDA Forest Service, Pacific Southwest Region</td>
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<tr>
<td>Nicholas Comerford</td>
<td>Dean, College of Tropical Agriculture and Human Resources, University of Hawai‘i at Mānoa</td>
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<tr>
<td>Michael Constantinides</td>
<td>State Forester, USDA Natural Resources Conservation Service, Pacific Islands Area</td>
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<tr>
<td>Susan Cordell</td>
<td>Director, Institute of Pacific Islands Forestry, USDA Forest Service, Pacific Southwest Research Station</td>
</tr>
<tr>
<td>Nicklos Dudley</td>
<td>Forester and Maunawili Experiment Station Manager, Hawai‘i Agriculture Research Center</td>
</tr>
<tr>
<td>J.B. Friday</td>
<td>Extension Forester, University of Hawai‘i at Mānoa</td>
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<tr>
<td>Christian Giardina</td>
<td>Research Ecologist, USDA Forest Service, Pacific Southwest Research Station</td>
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<tr>
<td>Matt Ginzel</td>
<td>Professor and HTIRC Director, Entomology and Forestry and Natural Resources, Purdue University</td>
</tr>
<tr>
<td>Diane Haase</td>
<td>Western Forest Nursery Specialist, USDA Forest Service, Pacific Northwest Region</td>
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<tr>
<td>Robert Hauff</td>
<td>Protection Manager, DLNR Division of Forestry and Wildlife</td>
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<tr>
<td>Travis Idol</td>
<td>Associate Professor of Tropical Forestry and Agroforestry, University of Hawai‘i</td>
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<tr>
<td>Nicholas Koch</td>
<td>Research and Specialty Consulting, Forest Solutions, Inc.</td>
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<tr>
<td>Creighton M. Litton</td>
<td>Professor of Ecosystem Ecology, University of Hawai‘i at Mānoa</td>
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<tr>
<td>Robert K. Masuda</td>
<td>First Deputy Director, DLNR</td>
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<tr>
<td>Irene Sprecher</td>
<td>Forest Program Manager, DLNR Division of Forestry and Wildlife</td>
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<tr>
<td>Robert Wagner</td>
<td>Department Head, Forestry and Natural Resources, Purdue University</td>
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Tropical HTIRC

Partner Updates

To help stay connected during the global pandemic, we have included a new section in this 2020 Annual Report with updates from Tropical HTIRC partners.

In 2020, the Akaka Foundation ‘ohana grew to five full-time staff, five part-time employees and three part-time interns who support Teaching Change, the Pu’uwa’a’wa’a Community-Based Subsistence Forest Area, ‘Ōhi’a Disease Resistance Program and the Hawai’i Insect Herbivory Project.

The Teaching Change program began offering virtual huaka’i, and adapted our field courses to support the learning objectives of our various STEM-based education programs. In 2020, we reached 68 students and seven teachers through our online programs. This includes a two-week hybrid online/in-person summer course for Kohala Middle School. This program focused on improving environmental literacy and career-connected learning in students through a series of presentations on various environmental science topics, and introducing students virtually to local conservation professionals. We also had the opportunity to provide two socially-distanced field courses with students to learn about native flora and fauna and connect with nature. In 2020, Teaching Change also launched the first half of two, one-year long programs: the NEON program run in collaboration with Hilo High School, and a Professional Development Pathways Program developed for Kea’au High School. These programs also focus on biocultural learning and career connected learning, but dive deeper into topics through a year-long format.

The Pu’uwa’a’wa’a Community-Based Subsistence Forest Area (P-CBSFA) Hui Nui, or working group, made significant progress...
in the development of a community-based Stewardship Plan. Hawai’i Game Management completed fencing of the 84-acre project area in June, 2020 and installed four gates to ensure ease of access for the community. The Hui Nui contracted Geometrician Associates to create a web application which features a searchable interactive map that details resources and history of the Pu‘uwa‘awa‘a. Maps were divided into “story maps” with narrative and the working maps. Application users can easily switch back and forth between them.

Finally, the Akaka Foundation welcomed Dr. Katie Kamelamela as a part-time Community Forest Administrator and Ashley-Anne Nehu Shaw as a full-time Reforestation Technician to support the vision of the P-CBSFA.

We continued to support the ‘Ōhi’a Disease Resistance Program (ODRP), hiring Blaine Luiz full-time in April 2020 to serve as the Program Coordinator. With financial support from USDA Forest Service and the Hawai’i Community Foundation, our staff and interns helped to lead this research effort through coordination, collection of ‘ōhi’a cuttings, seed collection, phenology checks and greenhouse support that included preparing fresh cuttings from ‘ōhi’a trees to be rooted.

In partnership with Lund University and the USDA Forest Service, the Hawai’i Insect Herbivory Project staff continued to conduct monthly field collections from various sites throughout the island (Kohala, Laupāhoehoe, Hakalau, Volcano, and Stainback). The crew continued analysis of various leaf litter, decomposition, and soil samples in the lab at the Institute of Pacific Islands Forestry (IPIF). 2020 was a year of new challenges and adaptations, and together with our partners, we are fortunate to have thrived through the pandemic. We are looking forward to 2021 as another year of growth.
BUDGET OUTLOOK
The state is currently operating under a 10% budget restriction and working with the legislature on the biennium budget, which will likely include additional cuts to general funds and limited capital improvement projects over the next two years. We are still under a hiring freeze and anticipate it continuing over the next year or two.

HAWAII WOOD UTILIZATION TEAM (HWUT)
Project team has been looking for a location to display an accessory dwelling unit (ADU) built from acquired and manufactory materials but have not been able to find a suitable/available location (mostly due to COVID limitations and restrictions on gather). We may delay construction of the ADU until COVID restrictions are lifted/lessened. We submitted a new grant proposal for the Wood Innovation Grant, including plans for Hawaii’s first CLT (cross-laminated timber) building and development of a wood drying technical guide for Hawaii hardwood species.

KOA FORESTRY ECONOMIC MODEL
DOFAW, in partnership with the US Forest Service, UH, private and non-profit entities, is working on the development of a koa economic/financial model. The contractor for the project will:
1. Develop a forest economic/financial model for koa.
2. Support the identification and guide the collection of information needed from partners to inform, improve, and/or revise the model.
3. Develop a “how to use” manual for land managers, decision makers, and investors to be able to understand and use the model to support their land management decisions.

FOREST CARBON PROJECTS
DOFAW is continuing to work through the carbon certification process for Kahikinui Forest Reserve and Nakula Natural Area Reserve. Current timeline for completing the project documents is January 2021, inventory in spring 2021, and validation and verification of the project in late spring/early summer 2021. Major hurdles for the project, at this time, are finding agreement on the listing documents with Verra and development of a cooperative agreement for other projects to enroll under the grouped carbon project (i.e.: Kahikinui/Nakula is being certified as
grouped reforestation project meaning we can bring on other project areas under the certification). We are working closely with The Nature Conservancy as they develop their improved forest management carbon certification; they have also developed a grouped/aggregated project and are developing a similar cooperative agreement for lands that might be interested in joining.

DOFAW is also working with the US Forest Service to develop a DLNR Forest Carbon Plan; the plan will include an estimate of existing carbon stocks on DLNR managed lands and identification of areas that could sequester additional carbon. The project involves development of a model and analysis of various spatial information; the Forest Service is completing the project as “a wall to wall” analysis – meaning the information developed for the DLNR lands will be available for lands statewide.

KAPAPALA KOA CANOE MANAGEMENT AREA

Forest Solutions is finalizing the inventory for the Kapapala Koa Canoe Management Area for DOFAW and the community/stakeholder working group; once the inventory is complete, we will be looking to finalize the draft management plan and undertaking the necessary environmental compliance.

HAWAIIAN SANDALWOOD SEED ORCHARDS

DOFAW is working with HARC on the second year of this project. HARC has identified several sites for the establishment of the seed orchards, and is collecting seeds and heartwood samples of potential mother trees across the state.

FOREST ACQUISITION PROJECTS

With the help of Trust for Public Lands, DLNR successfully acquired the Kamehamenui property on Maui and received a large private donation from a community member to begin some of the needed management work and to start developing recreational infrastructure and planning. DOFAW is working on several other potential land acquisition including the approximately 13,000-acre Hawaii Koa Forest on Hawaii Island and two conservation easements in South Kona area; three fee acquisition projects on Maui; and two fee acquisition projects on Oahu.

INITIATIVES

DOFAW is currently working on putting together its pledge for the 1 trillion trees initiative, which looks to bring together public and private land managers with corporate partners.
Needless to say, 2020 was a turbulent year for Forest Solutions. We shut down our field operations for 8 weeks in February and March, keeping everyone on payroll and foresters working from home. After that and thanks to our helpful clients and the PPP program, we started back up again with full crews and have been working steady ever since.

There are a few things that we are particularly proud of for 2020:

1. Successful startup of the Kealakekua Forest Nursery - 130,000 native seedlings in the first year. While the nursery really started in 2019, it was only in 2020 that we delivered all the ordered seedlings, about 90,000 koa, 32,000 ʻilialihi and about 10,000 mixed native species including aʻaliʻi, ʻōhiʻa, pilo and naio. We have another bumper year in store for 2021, with an order book of 180,000 native seedlings. We owe a debt of gratitude to Katrina Isch who actually grew all these seedlings, DOFAW for seed collection permit agreement and also to Kealakekua Mountain Reserve for the 400 acres of planting that created the business in the first place.

2. Completed a full inventory of the Kapāpala Koa Canoe Forest. This forest is planned to become an important source of wood for racing, fishing and voyaging canoes. There is more to be done, but the forest is still in good health and can support this important traditional practice for decades to come.
3. Devised log grades based on current market conditions for koa logs. In a project where we collaborated with Kealakekua Mountain Reserve, we devised a simple system of log classification to provide more market standardization. The table below is in inches and feet. Logs are priced according to quality, with Salvage being the lowest and Veneer being the highest. We expect continued improvements in scaling methods and standards in the coming years. Unsurprisingly, the small sawlog class, which is for logs in the 14-17" class as well as larger logs with more rot, was a high proportion of total supply. Still, there is a substantial amount of wood in the large saw (18-24") and veneer (24"+) classes. These are the more highly sought after sizes and command a higher price point.

<table>
<thead>
<tr>
<th>Type</th>
<th>Min SED</th>
<th>Max SED</th>
<th>Min ln ft</th>
<th>Defect</th>
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<tbody>
<tr>
<td>Salvage</td>
<td>10</td>
<td>any</td>
<td>10</td>
<td>50%&gt;</td>
</tr>
<tr>
<td>Craft</td>
<td>7</td>
<td>13</td>
<td>6</td>
<td>&lt;30%</td>
</tr>
<tr>
<td>Sm Saw</td>
<td>14</td>
<td>17</td>
<td>4</td>
<td>&lt;50%</td>
</tr>
<tr>
<td>Lg Saw</td>
<td>18</td>
<td>23</td>
<td>6</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>Veneer</td>
<td>24</td>
<td>any</td>
<td>4</td>
<td>&lt;5%</td>
</tr>
</tbody>
</table>

Note: Defect (rot) that is more than the allowable percentage for each class causes a downgrade of the log into the next lower class.
Hāloa ‘Āina has been working with the state of Hawai‘i Department of Forestry and Wildlife (DOFAW) to place a conservation easement on the 2,780-acre project property. Funding for the easement was secured in 2020 and has been provided through the Hawai‘i County Public Access, Open Space, and Natural Resources Preservation Commission (PONC) and the US Forest Service (USFS) Forest legacy program. The easement will require the property owner to abide by a forest management plan (currently being drafted by Forest solutions, Inc.) and restrict subdivision, sale, and development of the property. The management plan will be reassessed every ten years and outline terms for restoration planting, forest monitoring, fence construction, firebreak maintenance, invasive species control (plant and animal), and sustainable rates of harvest of koa and ‘iliahi.

Hāloa ‘Āina is currently applying for the Environmental Quality Incentives Program (EQIP) with the NRCS to help fund the planting of 38,100 plants in 152.4 ac over a four-year period. The area targeted for planting was burned in 2010 and is one of the only locations on the project site that does not experience natural seedling recruitment. Hāloa ‘Āina also continues to lease and manage a 1,078-acre neighboring property owned by Kamehameha Schools. Some of the management milestones achieved to date include enclosing the unit with 3.95 miles of ungulate exclusion fencing, installation of 7.11 miles of 25’ wide fire breaks, removal of all feral sheep, establishment of regeneration monitoring plots, and planting 5,482 trees in areas that are experiencing limited natural regeneration. Future management activities will include the planting 40,000 more native seedlings.
Hāloa ‘Āina currently is the site of two propagation trials carried out by Tawn Speetjens, a MS student at Purdue University in the Forestry and Natural Resources program. His research examines nursery propagation and field planting strategies for *Santalum paniculatum*. Starting in in the summer of 2021, Hāloa ‘Āina is looking forward to hosting UH Mānoa MS student Kaleiheana-A-Pohaku Stormcrow as she conducts her research on ‘io, pueo, and barn owl populations present on the property. She will be looking at how vegetation affects detectability through using audio or visual surveys.
The Kealakekua Mountain Reserve (KMR), is a doTERRA Co-Impact Sourcing project aimed at native Hawaiian forest restoration, conservation, community engagement and wise use. KMR is currently focused on reforesting several thousand acres in South Kona, Hawai‘i Island. TropHTIRC has been a vital partner in advancing this goal. Key to our work in 2020, was establishing an on-site nursery, which grew more than 150,000 seedlings for out planting last year. Many of these trees were planted on 415 acres of KMR property. Emily Thyroff, in coordination with Katrina Isch, KMR’s nursery manager, have been working on advancing approaches to improve propagation and plant health.

In-field studies at KMR are being conducted by Emily Thyroff to better understand the hemi-parasitic relationship between Santalum paniculatum and its host species. KMR has worked to connect Emily with local K-12 classrooms where she can share the research with students and answer their questions. KMR has active programs with both Ke Kula ‘O ‘Ehunuikaimalino (the local K-12 Hawaiian immersion school) and Konawaena High School (through its environmental studies and chemistry courses) that involve students in understanding propagation, reforestation, forest health and the critical role of native forests in the Hawaiian culture.

On-site trials are also being conducted regarding the viability of landscape-scale regeneration through aerial seeding in connection with DroneSeed. KMR has had the privilege of working with Matthew Aghai, DroneSeed’s Director of Research and Development, to frame the trial and determine if this technology can be viable here in Hawai‘i. Early results appear promising. KMR is hoping to extend these research efforts in 2021 with DroneSeed’s assistance. Other key partners for KMR include Forest Solutions (particularly, Nick Koch and Willie Rice) and the State of Hawai‘i Division of Forestry and Wildlife (particularly, Irene Sprecher, Tanya Rubenstein and Marissa Chee), which have provided critical technical assistance, encouragement and support. Each of these invaluable partners has assisted KMR in realizing its lofty goals in 2020 and in setting KMR on the path to native forest restoration success.
Hawai‘i Agricultural Research Center (HARC)

Paniolo Tonewoods signed an agreement with HARC in the Fall of 2020 to host a Hamakua Seed Orchard on the Siglo-owned “Kapoaula” property, a 565-acre rolling pasture located midway between Waimea and Honokaa. The Hamakua Seed Orchard will eventually provide a secure supply of Wilt Resistant Koa for both the Kapoaula reforestation plan and for HARC distribution for use in restoration and reforestation efforts within the defined Hamakua Eco Region. The progeny trial and orchard are being jointly designed by PT consultant geneticist Dan Cress (Regenetics Forest Genetics Consulting) and Nicklos Dudley (HARC). Cleared of native koa forest in the late 19th century, the Kapoaula site is under a state-approved Forest Stewardship Plan adopted in 2019. The plan calls for roughly 80% of the land to be planted in wilt-resistant koa for sustainable management focused on instrument wood production. The remaining steeper ground is designated for koa and native understory plantings. The ridge crest location and surrounding open pastureland create a high potential for wind damage and deformation. To provide adequate shelter, windbreaks are currently being planted.

Kanile‘a ‘Ukulele

Paniolo Tonewoods has worked closely with the Souza family, owners of Kanile‘a ‘Ukulele company. For the past few years, PT has assisted the company in producing instrument-grade materials from logs purchases from other private landowners for the company’s ukulele production in Hawai‘i as well as in China. Recently, the PT team harvested selected koa trees from their Big Island “Nani ‘Ekolu” property, adjacent to Kealakekua ranch. Those logs will be shipped to the Pacific Rim Tonewoods’ mill in Concrete, Washington. There the Souza’s sons will again work alongside PT staff to break the logs into boards, mark to exacting specifications, kiln-dry and ship the processed blanks for crafting acclaimed ‘ukuleles at their Oahu factory.

Haleakala Ranch & Maui Native Nursery

The partnership between Haleakala Ranch, Maui Native Nursery and Paniolo Tonewoods continues its collaborative research to propagate elite koa from 30+-year old trees
identified during the 2015 harvest. Using the nursery developed air layering techniques, these selections are replanted at the ranch in selected units. Some of these selections will also be planted at Kapoaula.

**Kamehameha Schools**

Under a 5-year license, harvesting of koa on a portion of the Kamehameha Schools Hōnaunau Forest on the Big Island continues to provide quality materials to Taylor Guitars. The project is designed to demonstrate forest regeneration using scarification and plantings, combined with intensive animal exclusion and perimeter fencing.

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In November, 2019 Michael Constantinides was promoted to a new position with NRCS Pacific Islands Area (PIA) as Assistant Director for Technology, and in June, 2020 we were fortunate to backfill and hire a new PIA Forester named Matt Cocking who came to us with solid NRCS experience out of California. He has a number of priorities for tree regeneration and forest restoration, including working with the Plant Materials Center on Molokai.

One area where we may have potential overlap with Tropical HTIRC is with our Conservation Innovation Grant (CIG) program. PIA will be releasing a Notice of Funding Opportunity for our upcoming annual grant funding cycle in CIG in February. You can monitor our website to track that, and consider whether Tropical HTIRC or partners may have interest in applying. I believe that while the theme of this years’ offer is going to be soil health, that you could still apply while trying to link in to the stated CIG priorities that are offered as best as possible.
Purdue University Department of Forestry and Natural Resources (FNR) is very proud to be a strong cooperating partner in Tropical HTIRC. We are thrilled to continue contributing faculty, staff, and graduate student support to advance the science that supports the protection and restoration of native tropical hardwood forests in the Hawaiian Islands.

Of particular note during the past year for TropHTIRC was FNR's admission of the first native Hawaiian graduate student, Kylle Roy, as a Purdue Sloan Scholar in fall 2020. Kylle is a PhD student advised by Dr. Matt Ginzel whose dissertation research will seek to better understand the chemical ecology and development of management strategies for the fungus and ambrosia beetles that are associated with Rapid ʻŌhiʻa Death. Tawn Speetjens began as MS program in fall 2020 at Purdue to study ʻiliahi (sandalwood) nursery propagation and restoration planting. Bee Redfield’s PhD research began in spring 2020 studying the interface between forest restoration and habitat for native bird communities. We continue to celebrate the current and past contributions of Purdue faculty, staff, and graduate students in advancing TropHTIRC’s efforts, including Dr. Doug Jacobs (TropHTIRC Director), Aziz Ebrahimi, Lilian Ayala Jacobo, Rebekah Ohara, Indira Paudel, Kyle Rose, Anna Sugiyama, and Emily Thyroff (now with University of Hawaiʻi at Mānoa).

As with nearly all organizations, Purdue and FNR have been greatly challenged this year in maintaining our education, research, and public engagement missions in the face of COVID-19. Despite the difficulties, we were able to quickly adjust and successfully deliver most of our programs during 2020. As COVID subsides over the coming year or so, we look forward to resuming travel and continuing our more normal efforts in support of TropHTIRC.
Professor Travis Idol is co-advising (with Doug Jacobs, Purdue) UH Mānoa PhD student Emily Thyroff on her work with ʻilíahi (sandalwood) regeneration and restoration in partnership with private producers on Hawaiʻi Island. Emily has several projects ongoing to evaluate hemiparasitic resource transfer from koa to ʻilíahi seedlings, survival and growth of outplanted ʻilíahi in existing koa plantations related to gap size and overstory cover, and the effects of native host species and distance on survival and growth of outplanted seedlings of ʻilíahi and the host. Emily presented her project plans at a UH Ecology, Evolution, and Conservation Biology Evo-luncheon seminar and at the 2020 Hawaiʻi Conservation Conference. She was awarded a Graduate Student grant of $25,000 for two years from the Western Sustainable Agriculture, Research, and Education program to help support her dissertation projects. Emily will be taking her PhD comprehensive exams this spring semester. All of her dissertation research projects have been initiated, and data is being collected for field plantings.

Extension Forester J.B. Friday focused his extension activities during 2020 mainly on Rapid ʻŌhiʻa Death. He also worked with Diane Haase (TropHTIRC advisory committee member) to develop webinars on nursery production for Puerto Rico in collaboration with the USDA Forest Service International Institute of Tropical Forestry (IITF). His most significant activity in koa forestry was to work with a forest economist to help develop a financial model. Landowners are often reluctant to invest in koa reforestation because of a lack of examples and a lack of financial models. In 2020 we began work on developing a financial model as a decision support tool for landowners who want to analyze risks and potential returns from investing in forestry. Forest economist Suzanne Kim of Motivate Capital is leading the development of the model with assistance from TropHTIRC partners Irene Sprecher (Hawaiʻi DLNR DOFAW), J.B. Friday (UH Mānoa Cooperative Extension Service), Nick Koch (Forest Solutions), and others. Our goal is to develop an easy-to-use model that will include potential income from both timber and other sources such as carbon sequestration.
Professor Creighton Litton continued an ongoing research project designed to explore how tropical wet forests respond to rising mean annual temperature (MAT) by quantifying ecosystem C input, C allocation (biomass, flux and partitioning), and C storage along a highly constrained 5.2°C MAT gradient on the Island of Hawaii. In 2020, work along the MAT gradient concentrated on (1) finalizing and publishing three studies examining nutrient availability, fine root productivity, and belowground C cycling in response to MAT, and (2) initiating a new study to examine the transfer and storage of C from litter to soils (being led by Malissa Tayo, a new MS student co-supervised by C. Litton, C. Giardina, and S. Crow).
Like for everyone else - FY20 was a strange year for the USDA IPIF. Thankfully with staff diligence and the aloha spirit in Hawai‘i we were able to move safely forward on numerous research fronts. Our forest health program continues to focus on Rapid ‘Ōhi‘a Death. In particular, the relationship between feral ungulates and the presence of ROD; the resistance and resilience of ‘ōhi‘a; and the development of methods to protect and prevent the spread of ROD. We have hired 2 permanent support staff to maintain these forest health efforts (Jonathan Marshall and Grace Tredennick). Our biocontrol program has been focused on developing biocontrol agents for many of the highly invasive melastome species (Miconia, Clidemia, etc.) as well as the development of pilot programs to operationalize the dissemination of Tectococcus ovatus (approved biocontrol agent for strawberry guava) across designated conservation landscapes of the Hawaiian Islands. Partnerships and collaborative efforts (such as with TropHTIRC) continue to expand.

In FY20 IPIF and Arizona State University Center for Global Discovery and Conservation Science have joined forces to reengage the Mauka-to-Makai concept to actively bring science together with managers of both land and sea resources. Currently this expansion is focused on jointly supporting post docs focused on the development of decision support tools and modelling efforts to support land stewardship decision making and priority setting regarding water and carbon, invasive species, wildfire, and restoration of native ecosystems statewide. We continue our investments in long term forest monitoring including: the Hawai‘i Permanent Plot Network (https://forestgeo.si.edu/sites/hawaii), which just completed a 3rd full census; and the USDA Forest Service Forest Inventory and Analysis program, which is completing its 1st re-census. This work continues to inform global syntheses on forest dynamics and will provide critical information for mitigating the impacts of climate change and supporting Hawaii's goal of becoming a net zero emitter of carbon. We also continue making important investments in the US Affiliated Pacific Islands, addressing restoration, fire management, sea level rise and agroforestry, a summary of which can be found at: www.fs.fed.us/psw/publications/spotlight/2020/research-spotlight-03-august.shtml.

www.trophtirc.org
**Achyut Raj Adhikari** successfully completed his MS degree in the Department of Plant and Environment Protection Sciences at the University of Hawai‘i at Mānoa in December 2020. Achyut received his BS from the Tribhuvan University, Nepal, in 2014. He has worked for crop biodiversity conservation and livelihood improvement of farming communities of Western Himalayas and mid-hills of Nepal. Achyut is interested in the management of biotic and abiotic stress in plants of agriculture and ecological importance through sustainable solutions. Achyut’s MS thesis focused on the breeding of *Acacia koa* for *Fusarium* wilt resistance. He made crosses among selected parents of koa at Hāmākua research station on the island of Hawai‘i and screened offspring under *Fusarium oxysporum* inoculated growing media. He studied the expression of chitinase genes among individual families screened for resistance. Achyut is currently working on the identification and characterization of *Phytophthora* root rot pathogen in avocado, and plants to continue studying plant and pathogen interactions for his PhD dissertation project.

**Aziz Emrahimi** is a PhD student at Purdue University, studying genes related to cold tolerance in koa and walnut. Aziz’s interest is in landscape genomics, phylogeny and evolution of tree species. Aziz is using genetics, genomics, and bioinformatics tools to address two critical steps for increasing the success of koa restoration at high elevation: characterization of koa genetic diversity across an elevational gradient, and the identification and characterization of genes influencing seedling cold tolerance.
Rebekah Ohara is a PhD student in the Forestry and Natural Resources Department at Purdue University focusing on the pathways and opportunities for community-managed forests in Hawai‘i. Rebekah received her B.A. in Anthropology in 2009 from Humboldt State University (HSU), and in 2013 she completed her M.A. in Social Science at HSU’s Environment and Community Program, focusing on the social and ecological considerations of tropical forest conservation in Ecuador. For two semesters, Rebekah served as a Teacher’s Assistant and Field Guide for HSU’s Primate Field School at the Organization for Tropical Studies in Costa Rica. She is the CEO for the Akaka Foundation for Tropical Forests.

Dr. Indira Paudel is a post-doctoral scholar in the Department of Forestry and Natural Sciences at Purdue University. Indira is a native of Nepal. Before she joined Purdue, she completed her graduate studies from Hebrew University of Jerusalem, and her first post-doc fellow training from the Weizmann Institute of Science, Israel. She is working on the response of hardwood species to climate change, focusing on effects of precipitation and temperature variability. In addition, she is studying the ecophysiology of Acacia koa in response to resource variation across elevational gradients in Hawai‘i.
Dr. Kyle Rose is a research scientist with Tropical HTIRC (part-time) and the Conservationist Manager with the New Mexico State Land Office in Santa Fe, New Mexico. Kyle was a Peace Corps Volunteer in Honduras before receiving his MS from Michigan Technological University and PhD from Purdue University. In Hawai’i, Kyle studies developmental heteroblasty, plasticity of koa, and how silviculture can be used to promote increased survival and performance of koa on harsh and favorable sites. He is also interested in income generation through the development of silvicultural systems for afforestation of abandoned pasture land and rehabilitation of degraded native forests. Ultimately, he hopes that his work provides solutions for forest management while balancing the complex social, ecological, and economic decision space of Hawai’i. He is also leading projects related to clonal propagation of koa and sandalwood restoration.

Bee Redfield began her PhD program in January 2020 in the Department of Forestry and Natural Resources at Purdue University, where she also earned her undergraduate degree. She received her Master’s in Biology from Miami University’s Project Dragonfly, during which time she studied forest restoration and native bird populations on the Big Island of Hawai’i. She also served as an entomology and forest health research assistant at the Morton Arboretum for many years. Bee is interested in the role that birds play in forest restoration, the way that forest restoration impacts native bird populations, and how to maximize the effectiveness of both through our management strategies. Her research examines plant-animal mutualisms such as seed dispersal and pollination in island ecosystems, and the human dimensions of developing programs to boost public perception and support for our conservation initiatives.
Kylle Roy began her PhD in fall 2020 at Purdue University in the Department of Forestry and Natural Resources. She is both an Alfred P. Sloan Scholar as well as a Purdue Doctoral Scholar. Kylle is studying the chemical ecology of beetles, fungi, and ʻōhiʻa trees in association with Rapid ʻŌhiʻa Death (ROD). She hopes to develop management strategies for controlling the spread of ROD. Born and raised in Hawaiʻi, Kylle has a general interest in conservation of Hawaiian forests, especially in relation to entomology, disease, and molecular tools. Kylle continues to work for U.S. Geological Survey Pacific Island Ecosystem Research Center in Hawaiʻi Volcanoes National Park, HI, and most recently began a pathways position there. She has a MSc in Tropical Conservation Biology and Environmental Science from the University of Hawaiʻi at Hilo and a BS in Biological Sciences and a minor in Environmental Science from Chapman University in Orange, CA.

Emily Thyroff is a PhD student at the University of Hawaiʻi at Mānoa. She earned a BS in biology from James Madison University and a MS in forest biology from Purdue University. In 2019, Emily began building a foundation to work on tropical dry forest restoration with regeneration of endemic Santalum species, known as ʻiliahi or Hawaiian sandalwood. In 2020, Emily will be installing greenhouse and field experiments to better understand relationships between ʻiliahi and native forest communities.
Tawn Speetjens is a master’s student with the Department of Forestry and Natural Resources at Purdue University. He was born and raised on the Big island of Hawai‘i and graduated from the University of Hawai‘i, Hilo in 2009 with a BS in Biology focused on Ecology, Evolution, and Conservation Biology. He has worked extensively throughout Hawaii’s diverse ecosystems. Some highlights include working for the USFWS on Laysan Island in the northwestern Hawaiian Islands, banding forest birds at the Hakalau National Wildlife refuge, and conducting watershed management with the Kohala Watershed Partnership. Prior to his enrollment at Purdue University, he worked as a Biologist with the Hāloa ʻĀina Reforestation Project where he was introduced to the unique challenges of growing Hawaiian sandalwood species (ʻIliahi). Tawn has a passion for growing Hawaii’s native plants and is interested in the development of propagation techniques for ʻIliahi. His research examines 1) the effects of chelated iron treatments, controlled release fertilizers, and hosts on ʻilaihi seedling morphology and haustoria development and 2) the effect of established koa hosts and haustoria presence on the success of ʻIliahi field planting.
1. Improve the genetic quality of tropical hardwoods, especially *Acacia koa*, through use and refinement of traditional methods and molecular genetics.

2. Develop advanced nursery propagation and seed production technologies to improve the field establishment success of tropical hardwood reforestation / restoration and allow for efficient production of genetically improved trees.

3. Establish a system of native species research and demonstration trials (e.g., on the Hawai‘i Experimental Tropical Forest) for education and training of consultant and industrial foresters, nursery practitioners, conservation biologists, and public and private landowners in silviculture and regeneration techniques.

4. Educate future leaders in tree improvement, management, and protection of tropical hardwood forests.

5. Engage our stakeholders and address their needs by communicating research findings and management recommendations.
We aim to address these themes in an interconnected way for native Hawai‘i forest trees including koa, ‘ōhi’a, and ‘Iliahi.
Koa Cold Tolerance

At high elevation sites in Hawai‘i, exposure of planted seedlings to winter frost may reduce survival and result in failed restoration projects. Our objectives in this project are to determine 1) the degree to which koa develops cold hardiness as a mechanism to tolerate frost, 2) whether populations of koa from higher elevations show greater cold tolerance than koa populations from lower elevations, 3) the extent to which exposure to environmental conditions to induce hardening may affect cold tolerance, and 4) the genetic diversity and the gene expression of cold hardy genes across elevations.

Aziz Ebrahimi, a PhD student, is developing a comprehensive characterization of allelic differences among koa populations at genes of interest to enable rapid assessment of the cold tolerance of any population and, possibly, the identification of rare genes that can be used to improve the survival of koa at high altitudes where it formerly thrived. In addition to the information in last year’s report, Aziz’s study has continued to focus on: 1) the level of cold hardiness and expression of cold hardiness genes and 2) genetic diversity across the elevation cline with Wide-sequencing data.

**GENE EXPRESSION ANALYSIS THROUGH QPCR**

Leaves exposed to various low temperatures were used for RNA extraction. RNA was extracted with RNeasy Plant Mini Kit (QIAGEN, USA). The first-strand cDNA was synthesized with a High-Capacity cDNA Reverse Transcription Kit (AppliedBiosystems by Thermo Fisher)
Quantitative PCR was carried out using Fast SYBR® Green Master Mix (AppliedBiosystems by Thermo Fisher Scientific, USA) with the four CBFs primers designed for koa. Analysis of variance (ANOVA) was performed with SAS software (SAS Institute, Cary, NC, USA) to calculate significant treatment effects of CBFs gene expression.

GENETIC DIVERSITY OF KOA POPULATION ACROSS ELEVATIONS

Koa individuals from different elevations were used to assess genetic diversity. Koa seeds of each family were grown in previously described greenhouse conditions as part of the whole plant physiology analysis. Fresh leaves of each individual were collected and frozen immediately with liquid nitrogen and stored at -80 °C until processing for RNA extraction. A similar approach for qPCR analysis was used for RNA extraction and for synthesizing cDNA for evaluating genetic diversity. For each individual, cDNA was amplified in separate PCR reactions, and then cDNA products were double stranded with PCR again and submitted for Wide-seq analysis.

FINDINGS

Cold hardy gene expression started at 4 °C for both non-acclimated and acclimated seedlings and stopped at -10 °C for non-acclimated seedlings and -20 °C for acclimated seedlings. For non-acclimated seedlings from middle elevation, the expression level increased 3-to-4-fold compared to low elevation seedlings. As expected, the expression of cold-hardy genes for low elevations was lower than middle and high elevations for both acclimated and non-acclimated seedlings. We conclude that the level of gene expression in acclimated seedlings strongly increased compared to non-acclimated seedlings.

Although the high elevation seedlings were collected from several regions, a low level of genetic diversity was found in these populations. Based on phylogeny results, the level of genetic diversity decreased from lower elevation to higher elevation. We conclude that the level of genetic diversity in low and middle elevation seedlings appears to be higher than in high elevation seedlings.

Koa seedlings from different elevation zones grown in a greenhouse for evaluation of cold hardiness.
Koa Population Ecophysiology

The selection of koa (*Acacia koa*) populations that perform well under the limitation of multiple resources in specific ecotypes may help to benefit restoration efforts. Indira Paudel, post-doctoral researcher at Purdue University, continued her research to study interactions between colimitation of resources (light, nitrogen, and water availability) and growth / physiology response of varying populations of koa collected from three elevations (1017, 4002, and 6463 ft) in wet and dry soils. She hypothesized that populations from dissimilar environments have evolved distinct functional traits due to local adaptation. Adaptive plasticity in functional traits will thus determine seedling performance to co-limitation of multiple resources, and seedlings will perform better when growing in environments best matched to their seed source environments. Light response curves and gas exchange, water and nitrogen status, resource use efficiency, shoot non-structural carbohydrate, and growth, including biomass allocations, were quantified. In 2020, she continued to analyze and interpret her data and has produced a draft manuscript to be submitted for publication in an international journal. Thus, the full results will be available in 2021. Preliminary results indicate that as hypothesized, the limitation of multiple resources is a critical aspect when planning successful restoration efforts. The results further support recent calls for using population-based seed zones in restoration, as seedlings respond to their seed source environments in any resource co-limiting environments.

Leeward side, lower elevation koa.
Koa Seed Scarification

Seeds of many legumes, including *Acacia koa*, require that seeds are scarified (treatment to damage the seed coat to allow water uptake) for germination. Manual scarification is a reliable way to scarify these seeds but it is impractical for treating a large number of seeds needed for large-scale restoration. An alternative, cheap and relatively safe way to scarify these seeds is to use hot water. Yet the optimum conditions for hot water treatment, especially for species like koa that naturally occur along wide environmental gradients, are unknown. Overly benign conditions would be less effective whereas overly severe conditions would kill the seeds and potentially cause seedling development abnormality. Thus, optimum scarification conditions need to consider different processes altogether.

As part of her post-doctoral research at Purdue University, Anna Sugiyama tested whether optimum scarification conditions for koa seeds would be predicted by elevation of their mother (source) trees and studied the effects of repeated exposure to hot water on different processes. These processes were (1) imbibition, (2) days until germination (germination rate), (3) germination, (4) seedling abnormality, (5) early seedling mortality (seedling death before transplant < 3 months), (6) seedling growth, and (7) seedling survival (seedling survival at the end of the study after 4.8 months).

Intact (left), partially-imbibed (center), and fully-imbibed (right) koa seeds.
She found that effects of scarification varied substantially by among seed collection trees. Thus, optimum scarification condition could not be predicted solely based on elevation of mother tree or seed mass. However, overall highest germination was achieved at exposure to hot water at 90-95°C for 1 min and seeds from lower elevations tend to require more rigorous scarification. Some seeds were only partially imbibed after scarification and these seeds germinated without requiring further scarification treatment. Although boiling water was effective in imbibing the seeds, it killed seeds and reduced germination substantially, especially after 1 min. Overall, it is safe to say not to boil seeds, especially after the first attempt, to achieve high germination.

Repeated number of exposures to hot water reduced germination when seeds were boiled, and slightly reduced seedling growth across all treatments. On the other hand, seeds that did not imbibe after the 15th attempt showed high germination when they were manually scarified. Seeds that imbibed after the 1st attempt also showed higher germination overall than those that required more repeated attempts and seeds that required more than 4th attempts when boiled never germinated. Thus, the number of trials it took to imbibe seeds can potentially be used to screen seeds before sowing them. Although abnormality in seedling development resulting from exposure to hot water was a concern, abnormality was very rare and when it happened, it occurred in seeds from only a few specific trees and mostly from seeds that imbibed after the 1st attempt. This is likely because these seeds are killed before germination. Finally, when all seven processes are considered altogether across tested trees, the optimum scarification conditions were manual scarification > exposure to 100°C water for 1 minute > exposure to 95°C water for 1 minute > boil for 0.5 min > exposure to 90°C water for 1 minute > boil for 1 min > boil for 2 min. Anna is finally in the process of preparing a manuscript for this work.
Koa Breeding for *Fusarium* Wilt Resistance

For his MS degree at University of Hawai‘i, Achyut Adhikari studied the contribution of individual koa parents into their offspring for vascular wilt resistance. Vascular wilt caused by *Fusarium oxysporum* is one of the most significant challenges of koa silviculture. This disease can be severe at elevations between 1668 ft to 3937 ft. The soil-borne pathogen enters the plant through the root system, colonizing vascular tissues and disrupting water uptake and transportation of solutes throughout the plant. Disease symptoms include wilting, foliar chlorosis, and shoot necrosis. Shi Xuebo and James Brewbaker had reported 30-90% mortality rates of koa at an altitude of 700 m in their publication in 2004. The development of management tools for *Fusarium* wilt and dieback has become imperative for the regeneration and establishment of native forests in Hawai‘i.

**CROSS-POLLINATION**

The selection of resistant families is one of the sustainable and attainable solutions for disease management. Collection of seeds from mother plants and their screening for wilt resistance is a major strategy to identify the resistant provenance. However, this approach can be oblivious to the contribution of the male parent to disease resistance. Therefore, controlled pollination of koa flowers was done among five thriving trees at the University of Hawai‘i, Hāmākua Research Station (Lat: 20.00 N, Lon: 155.39W, elevation 2528.72 ft). The select flowers in the plants E, F, G, H, and I were restricted for the entry of pollinator insects by completely covering them with a meshed bag. Hand pollination was done by brushing the male flowers of one tree with viable pollen against another tree’s female flowers.

Among 403 controlled cross-pollination, 37 pollinations were successful, leading to 469 seeds from 66 seed pods. The rate of success of hand pollination was 9.18%, whereas that of open-pollinated controls was 1.7% in 56 control flowers. Differences were observed among mother trees, with the highest pollination success rate of 25% observed on female flowers of ‘H’ when ‘E’ was used as male parent (Family H*E). Similarly, 20% success in pollination was observed in G/E (Table 1). Families E*F, G*F, and H*F showed approximately 15% success. The number of seeds developed from these crosses varied from 12 to 103.

**DISEASE SCREENING**

Six families were screened under *Fusarium oxysporum* disease pressure and their performance was compared with a susceptible and a susceptible check. When 4-month-old seedlings were inoculated with the *Fusarium oxysporum* inoculum in October 2020, differences in disease symptoms were found among families, indicating that selection was effective, and parents had different impacts on progeny’s disease resistance. Disease symptoms were evaluated 1 month after inoculation. Symptoms were scored as follows: 7 for dead; 6 for wilting or dying; 5 for heavy defoliation; 4 for the dead tip (Apical meristem and leaf tips); 3 for the stunted root systems; 2 for yellow leaves or small yellow leaf freckling; and 1 for no symptoms. Families F*I, I*E, I*F showed lower disease
scores, whereas families E*G, G*E, and G*F were not different from the susceptible check. Based on this observation Families F*I, I*E and I*F are recommended to be multiplied through vegetative propagation. Based on their performance in this assay, Parent I can be declared as the best parent to be used for Fusarium wilt resistance.

Examination of Chitinase as a possible marker for Fusarium wilt resistance: The use of marker genes reduces the amount of time to screen individuals for the trait of interest. The objective of this study was to compare the expression of Chitinase genes at the baseline and three different times after infection with the disease severity as depicted in the second figure above. Unfortunately, no such correlation was observed and no upregulation of any chitinase genes was seen in the absence of disease inoculum.

Four individuals from each family were sampled and Ribonucleic Acid (RNA) was extracted from young growing parts of these seedlings at four different times; Baseline, 48 hours after inoculation (hpi), 72hpi, and 96hpi. cDNA was synthesized from individual RNA samples and were subjected to quantitative Polymerase Chain Reaction. Primers for three chitinase genes Akchit1a, Akchit2, and Akchit3 were amplified during qPCR. These genes were previously found to be upregulated in a known resistant family in a study done by Isabel Rushanaedy and Dulal Borthakur in 2012. Gene expression data were analyzed using a relative quantification method called the comparative Ct method, where expression fold change of chitinase genes was normalized with the housekeeping gene 18S RNA. The average difference in fold change in expression with 18S RNA for each gene was calculated, and standard errors were computed using the Students t-test. Relative expression of individual Chitinase genes was found to be sporadic among the families. The lack of visible expression of the chitinase at baseline strongly discourages the usefulness of Chitinase as a marker for koa wilt resistance in the breeding program.
Above: Box-plot showing mean (black solid line) with 25th percentile (lower bound) and 75th percentile (upper bound) for disease severity of fusarium wilt of koa as scored by the protocol from Shiraishi et al. (2012). * indicates significantly different from susceptible control at alpha = 0.05, ** indicates significantly different from susceptible control at alpha = 0.01, *** indicates significantly different from susceptible control at alpha = 0.001.

Right: Relative expression levels of three types of chitinase genes (y-axis), within Acacia koa. Gene expression is derived from qRT-PCR using 18S RNA as a control gene at four-time points, baseline (BL), 48 hours post-inoculation (48hpi), 72 hours post-inoculation (72hpi), and 96 hours post-inoculation (96hpi). Each bar represents gene expression of A) Akchit1a, B) Akchit2, and C) Akchit3 as expressed by each genotype (E*G, F*I, G*E, G*F, I*E, and I*F), and Resistant Control (R08), and Susceptible control (BIS) at a particular time point.
Koa Grafting

To develop a grafting protocol for *Acacia koa* with increased grafting success relative to previous methods (Skolmen 1978) and more suitable for larger root and scion stocks (Nelson 2006), a grafting study was begun in July 2018 by Kyle Rose and collaborators at the New Mexico State University John T. Harrington Forestry Research Center in Mora, NM. This study, building on pilot work done in Earnshaw & McKenna (2018), used contrasting ecotypes of koa (Umikoa, wet; Kona Hema, dry) and two grafting methods (whip and tongue and a mechanical top grafter (A.M. Leonard Inc., Piqua, OH, USA)).

Preliminary results have suggested no maturity (true leaves only vs. phyllodes) effect, no size effect, no effect of grafting method, no effect of source, and no interactions between factors. The grafting methods achieved between 55% and 64% success, with no statistical difference detected. Further analyses are currently underway, which we expect will help to optimize future work and elucidate more about potential differences dependent on grafting method and ecotype. These analyses include 1) growth rates of successful grafts by ecotype and grafting method, 2) non-structural carbohydrates (NSC) of roots, scions, post-graft stem growth, and leaves of successful grafts, and 3) hydraulically active xylem above and below the graft union. Samples to determine NSC and the proportion of xylem that was physiologically active are currently being processed. While grafting success has been assessed as binary, performance results are expected to aid in determining the effect of size at grafting on post-graft performance. These results will also aid in estimating time needed before outplanting. NSC results will be assessed relative to performance to assess the effect of performance on post-graft carbon partitioning. The proportion of hydraulically active xylem above relative to below the graft union is hypothesized as an explanation for why some grafts experienced higher growth rates following the successful graft. We expect to publish results from this study in early 2021.

**CITATIONS**


Koa grafting study installation at the John T. Harrington Forestry Research Center (left). Staining methods to determine hydraulically active xylem above and below the graft union (right).
Koa Seed Collection

JB Friday and colleagues have begun collecting koa seed from one of the seed orchards that has been part of the Tropical HTIRC koa tree improvement program. The “HARC A” seed orchard was established in 2003 by Nick Dudley and Aileen Yeh of the Hawai‘i Agriculture Research Center (HARC) on lands managed by the Department of Hawaiian Home Lands (DHHL). The goal of the orchard, which is located on the Mana-Keanakolu Road at 6,600 ft elevation on the windward side of Mauna Kea, is to produce high quality koa seed that is locally adapted for reforestation of windward Mauna Kea. The initial orchard consisted of 660 selected mother trees, including 30 trees each from 22 families. In 2011, Purdue University MS student Oriana Rueda Krauss analyzed the genetic variability of the stand and selected the best trees to keep for a seed orchard as part of her MS thesis. Thirty-two trees, representing 11 of the original 22 families were retained and the rest rouged out. Seed trees were evaluated as potential crop trees and selected on the basis of straightness, height to first fork, crown health, and diameter growth. Although the trees have been slow to produce seed in the cold, dry environment at this elevation, they began producing a good crop of seed this year. Separate collections are being made from each mother tree. Seeds are cleaned and stored for use by DHHL for reforestation work and for use by Tropical HTIRC as part of the seed bank for future experimental work.

In 2015 a second set of seed orchards was established, also on lands managed by DHHL, representing 20 koa families from...
across windward Hawai‘i Island. The “HARC B” seed orchard, planted adjacent to an old conifer trial established by HARC at about 6,800 feet, continues to be maintained. Although the trees are not yet producing significant quantities of seed, some of the faster-growing trees have reached over 15 feet in height. Lilian Ayala Jacobo showed significant differences in height growth, diameter, and height to live crown among the koa families in her MS thesis at Purdue University in early 2020. The plan for the site includes thinning and rouging out the poorer families once the tree crowns close.
Community-Based Forest Management

During spring 2020, Rebekah Ohara completed her preliminary and oral exams, advancing to doctoral candidacy. With the support of her PhD graduate committee, she continues to make progress on three chapters that explore the central research question of this work: What are the pathways and opportunities for the development and successful implementation of community-managed forests in Hawai‘i? This research has been influenced by involvement with an emerging community-based forest management area, the Pu‘uwa‘awa’a Community-Based Subsistence Forest Area (P-CBSFA). Supporting the P-CBSFA effort has informed and shaped the research questions and design of this dissertation, which aims to support on-the-ground efforts.

The Hawaiian Islands have legislation that supports community-based management of marine resources; however, no such legislation currently exists for community-based management of forest resources in Hawai‘i. This research explores the underlying conditions for the successful implementation of community-based management of forests in Hawai‘i, exploring the emergence of CMFs across the Pacific Islands, and opportunities for CMFs within different land tenure arrangements in Hawai‘i.

This research explores the potential for community-managed forests in Hawai‘i, asking:

1. How is community-based natural resource management of forests emerging in the Pacific Islands?

2. How can the lessons learned from international and local collaboratively managed forests and community-based subsistence fishing areas be applied to the development of community-managed forests in Hawai‘i?

3. What are the opportunities for the development of community-managed forests in Hawai‘i? How do these opportunities differ depending on land tenure? and

4. How is community-based natural resource management emerging in Hawai‘i?

Chapter one will provide a synthesis of CMF literature that shares contextual characteristics with Hawai‘i through a systematic literature review of Pacific Island examples of community-managed forests. The goal of this chapter is to better understand how CMFs are emerging across Pacific Islands, and how various approaches might inform CMFs in Hawai‘i. The second chapter explores pathways and opportunities for CMFs in Hawai‘i, looking specifically at lessons learned in current community-based stewardship efforts in Hawai‘i, and through interviews with leaders of the three largest landholding groups in Hawai‘i. Finally, chapter three explores how communities in Hawai‘i are working within existing mechanisms to manage or steward forests in Hawai‘i.

Rebekah aims to complete her dissertation in Fall 2021.
Bird-Mediated Forest Restoration

Bee Redfield is studying endemic species management and ecosystem restoration in a number of island environments, including Hawai‘i. For the upcoming field season, she will be collaborating with the Smithsonian Institution to evaluate methods being used to restore oak/pine woodlands on Santa Cruz Island, approximately 40 km offshore of Santa Barbara, California. Like Hawai‘i, Santa Cruz Island has a similar history of anthropogenic disturbances, ecosystem decline, and native species extirpation. This includes roughly 150 years of ranching with non-native ungulates, which created a large decline in native woody vegetation and subsequent loss of soil, as well as widespread non-native grass growth. However, over the past century ranching has ceased and non-native species have been removed, allowing researchers to maximize their ecosystem restoration efforts. This provides a model system in which to evaluate the possible outcomes for habitat restoration, since the island is also part of a protected National Park and is largely uninhabited.

Bee’s work focuses on the importance of considering plant-animal mutualisms as a critical component of habitat restoration. This is particularly important for ecosystems such as those found on islands, where much of the pollination and seed dispersal is animal-mediated. Like Hawai‘i, most seed dispersal on Santa Cruz Island is performed by birds, particularly Aphelocoma insularis or the Island scrub-jay, a species in the same Corvidae family as the ‘Alalā. Previous research has shown that bird-mediated seed dispersal can benefit ecosystem restoration and native tree species in many ways. Birds help to disperse seeds both within and between patches, and often for much further distances than unaided dispersal would. Within patches, this can result in reduced density-dependent mortality. Between patches, this long-distance dispersal can result in greater gene flow, range expansion and/or shifts more responsive to climate variation, and the establishment of novel populations. Additionally, birds can increase dispersal quality through their natural behaviors. Birds tend to be selective when choosing seeds, often rejecting seeds with damage or infestation by insects or fungi. They also cache seeds in positions optimal for germination, while also reducing secondary predation and desiccation. And recent research being conducted on Santa Cruz Island shows that the jays preferentially cache seeds in recently burned habitat, showing promise for the role of birds as facilitators for post-wildfire forest recovery.

In the fall of 2021, Bee will be conducting research to demonstrate the role that birds on Santa Cruz Island are playing in native oak woodland recovery. While still under development, she is hopeful that her research will highlight the importance of considering plant-animal mutualisms as a key component of ecosystem recovery efforts. She also plans to develop a theoretical framework that can be applied to recovery and possible reintroduction efforts on other island ecosystems, such as Hawai‘i.
ʻIliahi Biology, Ecology, and Management

Approximately 16 sandalwood species (Santalum spp.) occur worldwide and at least six sandalwood species and several varieties are endemic to the Hawaiian Islands, where it is known as ʻiliahi. ʻIliahi is economically and culturally important because of the heartwood’s aromatic essential oil and high value wood for carving. During the early 19th Century, Hawaiian sandalwood was heavily exploited until supplies were depleted. Two species are now relatively common, including S. paniculatum, which is the only species commercially harvested on a limited scale; however, the species have not regained their former abundance or size.

There is increasing interest in restoration and commercial management of ʻIliahi. The aim is to demonstrate that ʻIliahi can be harvested sustainably by ensuring adequate regeneration and responsible forestry practices. While the recent burgeoning interest in growing ʻIliahi for restoration and commercial forestry is an exciting development, in order to transition from interest to successful implementation, major steps towards understanding ʻIliahi cultivation systems are required. Effective cultivation of sandalwood has been established in other sandalwood producing countries (India and Australia), but cultivators in Hawai‘i are unable to directly adopt many of these practices due to differences in cultivation area, host species, sandalwood species and logistical limitations. The development of cultivation systems tailored to Hawai‘i’s unique environment is vital to the success of sandalwood restoration and commercial sandalwood forestry operations.

Sandalwoods are particularly complex because they are hemi-parasitic, meaning that individuals can photosynthesize, yet require host plants to acquire resources for long-term survival. Thus, it is necessary to either interplant ʻIliahi alongside other plant species to act as hosts or underplant among already established hosts. In this new project initiative, we are working collaboratively with different partners on several research phases to answer questions that will help to develop effective management recommendations through a deeper understanding of the mechanisms by which ʻIliahi acts as a parasite to acquire resources from host species, and how this interaction varies across site environments.

ʻIliahi outplanted adjacent to koa.
ʻILIAHI-HOST PLANT INTERACTIONS

Several native Hawaiian species have been recommended to serve as host plant species. However, the optimum spacing and layout of ʻiliahi and secondary hosts is unknown. As part of his summer Research Scientist position, Kyle Rose led the establishment of a field experiment in June 2019 at Kealakekua Mountain Reserve to assess the establishment success of ʻiliahi in relation to host plant species and planting density. Two host plant species (koa and ʻaʻaliʻi) were planted in June 2019 at four distances from the planted ʻiliahi (adjacent, 0.5, 1, and 2 m). A control was included, where ʻiliahi was planted without a host plant. The experiment was established as a completely randomized design with 40 replicates (individual trees) per treatment (9 treatments × 40 reps = 360 total ʻiliahi trees). The total number of trees planted within the study area was 720 (360 ʻiliahi + 320 koa/'aʻaliʻi + 40 koa buffer trees).

Baseline measurements for seedling morphology and leaf nutrient status were performed at the time of planting. Six months (December 2019) and fourteen months (August 2020), seedling survival and morphology were recorded. Overall, ʻiliahi experienced 90 % survival with minimal differences as to which host species (koa, ʻaʻaliʻi, or control) or distance (adjacent, 0.5, 1, and 2 m) affected survival. Potential trends: 1) ʻiliahi is investing in diameter and below-ground biomass compared to above-ground height biomass, as was particularly seen for ʻiliahi with no host 2) for some distances, koa appears to support greater percent growth than ʻaʻaliʻi. Finalized results will be available after quality assurance and control on data as well as running statistical analyses. Results from this phase will aid in the development of prescriptions to create compatible ʻiliahi and host species plantation designs.

As part of her PhD studies at the University of Hawai‘i at Mānoa, Emily Thyroff is designing a set of greenhouse and field experiments for 2020 to better understand relationships between ʻiliahi and co-occurring native forest tree species:

THREE-POT EXPERIMENT

This study is designed to better understand ʻiliahi-host plant interactions in controlling acquisition of water and nutrients. For Santalum species native to other regions, it is hypothesized that water and nitrogen
UNDERPLANTING ‘ILIAHI

Koa is commonly planted in single-aged stands across Hawai‘i, often as a first step in reforestation and restoration plantings, but also to serve as a commercial plantation with economic goals. The resulting overstory gaps (whether through naturally variable survival or pre-commercial crop tree thinning) provide an opportunity to diversify initial planting efforts by enriching the site with other native plants, such as ‘iliahi. Furthermore, established overstory and neighboring hosts may increase the probability that planted ‘iliahi will develop early, and abundant, hemiparasitic connections. In August 2020 the first underplanting site was established by planting 324 ‘iliahi under 10-year-old koa. Hemispherical photos were taken at each seedling to capture the overstory environment, grass competition cut back manually, and 6-month measurements soon to be taken. In Spring 2021 a second underplanting site will be established after crop tree thinning a naturally regenerated koa stand. In addition to testing overstory structure effects on seedling performance, gas exchange will be captured to create light response curves and better elucidate which management practices will yield high performing ‘iliahi.

NURSERY STOCKTYPES

We will compare the relative success of different stocktypes outplanted at sites with differing soil conditions in order to develop prescriptions that tailor seedling quality to optimize performance on a given outplanting site. We are using four nursery stocktype containers (i.e., SideSlit 150, SC10, D25, D40 – see photo) to raise ‘iliahi for outplanting at two different sites (rocky vs. deeper soil…"
Top: Experimental grid design for underplanting ʻiliahi beneath an established koa overstory, creating a range of understory light conditions. Bottom: Hemispherical photos to capture the overstory environment.
site). In August 2020 ‘iliahi germinates were transferred into the D40 containers followed by D25 germinates in November 2020. The final two stocktypes will receive germinates in Spring 2021. Koa will be outplanted as hosts at the field sites in Spring 2021 and the ‘iliahi planted a few months later.

As part of his MS studies at the Purdue University, Tawn Speetjens is evaluating fertilizer and hosting treatments required to grow healthy ‘iliahi seedlings in the nursery and what types of hosting schemes are necessary to maximize ‘iliahi seedling survival when planting in in barren monotypic pasture landscapes. Tawn has been working to understand and develop the systems required to grow ‘iliahi in Hawai‘i during his past four years working for the Hāloa ‘Āina reforestation project. He has experimented with various strategies to grow healthy ‘iliahi seedlings and has unearthed several findings that have helped to direct his research while at Purdue University.

**FERTILIZER AND HOST TREATMENTS**

The first portion of Tawn’s research will focus on fertilizer and host treatments that have produced healthy growth in ‘iliahi seedlings during the nursery culture phase of propagation. Past trials have established that pot host are not necessary to grow healthy ‘iliahi seedlings if they are treated with controlled release fertilizer (CRF) and chelated iron. Additionally, he has found that ‘iliahi seedlings that have attached to a nitrogen fixing A. koa pot host, display healthy growth under limited fertilizer regimes. The objective of this experiment is to understand how CRF, chelated iron and pot hosts interact to affect ‘iliahi seedling morphology and haustoria development.

The experiment design will be a 3 x 4 factorial experiment with three host treatments and 4 fertilizer treatments. The experiment will be a randomized complete block design with six repetitions. Each of the twelve treatments will contain 32 sub-samples, 10 of which will be destructively sampled at the end of the growing period while the remaining 20 will be left available for selection to use in the following field planting trial. After a growing period of 10 months the seedling will be destructively sampled collecting morphological measurements (shoot height, collar diameter, root length, and total dry weight), tissue samples for nutrient analysis, leaf color data and a count of haustoria.
FIELD PLANTING

The objective of the second portion of Tawn’s research will be to examine the effect of ‘iliahi haustoria abundance and host introduction timing (nursery vs field vs both) on the survival and growth of ‘iliahi seedlings when planted in the field. The experiment will be a split plot complete randomized block design with six repetitions. The whole-plot factor will be pre-established hosts vs no pre-established hosts. The within plot factors will be pot-host and haustoria abundance. Four of the twelve treatments from his preceding nursery trial will be selected using the following descriptions: 1) koa hosted with high haustoria, 2) koa hosted with low haustoria, 3) no pot host high haustoria, 4) no pot host with low haustoria. The four treatments will be planted in the blocks with half being planted in a split plot with field host and the other half planted in the split plot with no field hosts. This design will result in 8 separate treatments and will examine the effect of pre-established field hosts when pot hosts are present or absent, as well as the effect of haustoria presence and abundance under these conditions. The pre-established koa hosts will be one year old when ‘iliahi are introduced. The ‘iliahi survival, collar diameter, and shoot height will be assessed after one year.

‘ILIAHI SEED GERMINATION

Beginning in Spring 2020, Tawn and Emily took the lead on writing an article titled, Propagation Protocol for ‘iliahi (Santalum paniculatum), a Hawaiian Sandalwood...
Species. We share 1) background information that introduces ʻiliahi biology, ecology, and history. We then describe steps for ʻiliahi 2) seed harvesting and processing 3) seed germination 4) seedling transfer, and 5) field planting. The last section, 6) concludes the propagation manuscript and includes ideas for future work. A summary of the manuscript we intend to publish in 2021 is as follows:

All members of the Santalum genus are root hemiparasites meaning individuals can photosynthesize, yet rely on specialized root organs, called haustoria, to connect to hosts for long-term survival and growth. Six of the 19 currently recognized species comprising the genus are endemic to the Hawaiian Islands. Similar to other Santalum species, the Hawaiian species produces a valuable aromatic heartwood which led to an extensive trade. The subsequent overharvesting in the early 19th century greatly reduced ʻiliahi abundance across the islands. With limited natural regeneration, reliable propagation systems are required for reforestation and expansion of ʻiliahi’s current remnant range. To help guide future propagation efforts, we present an account of methods for seed harvesting, processing, germination, seedling transfer, growth, and field planting that have successfully produced robust ʻiliahi seedlings. Seed
ʻIliahi seed germination.

Maturation timing, as signaled by transition to dark purple pulp, is variable depending on population. Once harvested, seeds should be cleaned, dried, processed, and sown as soon as possible or properly stored. Seed germination preparations include treating with gibberellic acid (GA3) to improve germination rates and success, sterilizing seed surface, coating with antifungal powder, regulating media moisture, and preventing fungus gnat infestation to reduce embryo rot. Seedlings are transplanted from germination tray into containers after developing 4-6 true leaves. Seedlings should be grown for 10-12 months in well-drained media with balanced (14-14-14 or 15-9-12) controlled release fertilizer integrated at medium bag rates and chelated iron applied every 2-3 months. Seedlings in the nursery can be successfully grown with or without a pot host. Seedlings will ultimately need to parasitize hosts following planting in order to successfully become established. There are several potential future research avenues including fertilizer response, host species suitability, regeneration stand improvement, and introduction of host timing. Additional research is vital to improve propagation and early development of ʻiliahi seedlings in both nursery and field conditions.
‘Ōhiʻa Disease Resistance

‘Ōhiʻa (*Metrosideros polymorpha*) covers nearly one million acres across Hawaiʻi, is the backbone of Hawaiʻi’s native forests, and serves as a foundational species for Native Hawaiian cultural practice. Starting in 2010, ‘ōhiʻa trees began dying on Hawaiʻi island, undergoing rapid wilting and browning of the canopy. After intensive investigation, researchers identified the fungal cause of the new disease and named it Rapid ‘Ōhiʻa Death (ROD). Because of this early work, we now know that ROD is caused by two novel species of fungi, *Ceratocystis lukuohia* and the less aggressive *Ceratocystis huliohia*, which have killed 100,000+ ‘ōhiʻa trees across 180,000+ acres on Hawaiʻi island. Unfortunately, ROD was discovered on Kauaʻi in 2018, and Oʻahu and Maui in 2019.

While the widespread ‘ōhiʻa mortality is troubling, there is evidence that some ‘ōhiʻa genotypes on Hawaiʻi island show resistance to ROD. During preliminary ‘ōhiʻa screening trials, where ‘ōhiʻa individuals were artificially inoculated with *Ceratocystis lukuohia*, we found that most individuals died within a few months. Critically, however, a handful of inoculated individuals did not die following inoculation; some have even survived a second round of inoculation. These results point to the promise of finding ‘ōhiʻa and other Hawaiian *Metrosideros* species that are naturally resistant to ROD. To date, the extent of this resistance in natural populations is poorly understood. For this reason, we launched the ‘Ōhiʻa Disease Resistance Program (ODRP), with the goal of identifying...
Collecting seeds from survivor 'ōhi'a in areas heavily impacted by ROD (top left). Seeds collected from survivor 'ōhi'a are grown at the USDA Forest Service Institute of Pacific Islands Forestry to be screened for resistance to C. lukuohia and C. huliohia (top right). Photo credits: 'Ōhi'a Disease Resistance Program.

ROD-resistant plants vital to the restoration of forest areas impacted by ROD. Our goal is to support private landowners and conservation land managers who want to perpetuate 'ōhi'a across their lands.

In the two years since the founding of the ODRP, we have: 1) developed seed and cutting sampling protocols for sampling survivor trees in South Hilo and Puna; 2) sampled from over 200 survivor trees from South Hilo and Puna resulting in the collection of over 10,000 cuttings and millions of seeds; 3) established a partnership with the Leilani Estates Community Association and multiple community members to deploy a community-centered sampling design of lone survivor trees; 4) established a partnership with Laukahi: The Hawai‘i Plant Conservation Network to select and propagate the next generation of seedlings for expanded screening 'ōhi'a genotypes from across the state; 5) secured and sowed 1000’s of seeds from additional seeds families from multiple Metrosideros taxa from O‘ahu and Kaua‘i; 6) improved upon developed methodologies via comparison of rooting products and plant growth enhancers; 7) developed a workflow document to guide decisions at each step of a plant’s life cycle from initial propagation to testing; 8) established a stock plant garden housing clones with low rooting success to further propagate and increase the number of representatives for those clones; 9) propagated cuttings from one containerized tree that has survived C. lukuohia infection.
for over 2 years; 10) implemented drone-based remote sensing technologies to improve detection of survivor trees in areas with high ROD mortality on Hawai‘i island; 11) initiated development of plane-based hyperspectral imaging techniques that will distinguish between survivor trees that are escapes and truly ROD-resistant; and 12) produced two peer-reviewed journal articles describing the promising results of our initial C. lukuohia screening work, and an outreach piece about ‘ōhi‘a disease resistance work in a special ‘ōhi‘a issue of Hawai‘i Landscape magazine.

We are now entering a critical phase of our work. The 1000s of plants we have produced are ready for screening. To prepare for the eventual screening of these individuals, we are developing efficient inoculation methods with the goal of also improving the accuracy of our inoculation-based test. We hope that 2021 allows us to identify the additional ROD-resistant ‘ōhi‘a. We will outplant potentially resistant individuals from our initial 2016-2017 efforts, while initiating our field-testing phase, both of which will put us closer to identifying ‘ōhi‘a resistant to C. lukuohia. Lastly, we will complete an ODRP framework for publication in mid-2021, which will guide ODRP development in the coming decade. The severity of ROD poses a significant threat to native ‘ōhi‘a forests throughout the state, and full investment into the strategies listed above will be critical for perpetuating ‘ōhi‘a across Hawai‘i. None of this work would be possible without financial support from the USDA Forest Service (Washington Office, Region 5, and Special Technology Development Program) and the Hawai‘i Community Foundation.

For more information, please visit Akaka Foundation for Tropical Forests’ website (www.akakaforests.org) where you can find a brochure about the ODRP, detailed information about our community outreach and engagement efforts, and ways to support the ODRP.
Chemical Ecology of Rapid ‘Ōhiʻa Death

Rapid ‘Ōhiʻa Death (ROD) is an emerging and deadly disease caused by the fungal pathogens *Ceratocystis lukuohia* and *Ceratocystis huliohia*, and its spread has recently been linked to ambrosia beetles, particularly those of *Xyleborini* tribe. The fungal pathogens are decimating the ecologically- and culturally- foundational tree, ‘ōhiʻa (*Metrosideros polymorpha*) in Hawaiʻi, and it has been estimated that ROD has killed at least one million ‘ōhiʻa trees on Hawaiʻi Island alone since its emergence in 2010. ‘Ōhiʻa is the dominant woody species in multiple Hawaiian ecosystems from sea level to tree line and has important cultural value.

Although the epidemiology of ROD is not fully understood due to its recent discovery, it is likely similar to other *Ceratocystis* diseases where pathogen spread is associated with wounding and the movement of ambrosia beetle frass containing viable fungal propagules. Ambrosia beetles in the *Xyleborini* tribe can directly transmit *Ceratocystis* fungi, and their frass contains viable *Ceratocystis* propagules that can kill ‘ōhiʻa. There is a critical need to develop ambrosia beetle management strategies to mitigate the spread of ROD, and such information could also be applied to manage these beetles in other agricultural systems throughout Hawaiʻi.

Understanding the chemical ecology of the disease could lead to tools to aid in early detection and behavioral manipulation of the beetles to protect high-value tree stands and individual ‘ōhiʻa. Kylle Roy began her PhD program at Purdue University in 2020 and her overall research objective is to develop advanced management strategies based on the volatile organic compounds (VOCs) related to ROD that may act as behavioral chemicals. To meet this goal, Kylle has begun culturing and isolating VOCs of *C. lukuohia*, *C. huliohia*, closely related outgroups, and the ambrosia fungi of ROD-associated beetles. Kylle plans to begin collecting VOCs from

Top left: *Xyleborus simillimus* crawling on ‘ōhiʻa bark. Top right: *Xyleborus simillimus* extracted from an ‘ōhiʻa tree infected with *Ceratocystis lukuohia*. 
Isolate of fungi cultured from *Xyleborus simillimus* mycetangia.

ʻōhiʻa inoculated with both ROD pathogens as well as artificially stressed trees in summer 2021. Ultimately, these compounds will be isolated and tested in the field for any attractant or repellent properties.

Kylle has created what she calls her “dream team” dissertation committee including her primary advisor, Dr. Matthew Ginzel, as well as committee members Dr. Doug Jacobs, Dr. Catherine Aime, and Dr. Jenny Juzwick to help her in this work. In addition to working diligently to complete her required coursework, Kylle has already begun designing projects and running pilot studies related to her proposed research. She looks forward to sharing more of her research as her project progress.
ABSTRACT
Restoration of abandoned, high-elevation pastures is needed across many ecosystems. Diverse abiotic and biotic stressors often limit establishment of native trees species, however, justifying the need for novel approaches to alleviate such stressors. Freezing damage often negatively impacts survival of planted trees across temperate landscapes and on some high-elevation tropical restoration sites, such as for *Acacia koa* (koa) in Hawai’i, USA. Koa performs poorly under forest canopies, a potential limitation to the use of nurse trees for establishment on frost-prone sites. Using a heterogeneous canopy of a non-native conifer, *Cryptomeria japonica*, we underplanted koa seedlings along a simulated range of canopy shelter levels in combination with field fertilization. We tested the effect of a canopy cover gradient and nutrient availability on frost avoidance and tolerance responses, as well as the potential to harness koa’s developmental plasticity to optimize growth and survival. *C. japonica* canopy cover provided protection from frost damage, with increased sheltering under greater canopy closure. When combined with fertilization, increasing canopy closure reduced frost damage and increased koa growth. Although we observed limited frost damage in our study, leaf-level soluble sugars increased during the winter and in more open microsites, reflecting a potential mechanism for frost tolerance in this tropical species. We conclude that frost-tolerant conifers used as nurse trees represent a potential tool to help establish native tree species on high-elevation, frost-prone sites.
ABSTRACT

Anthropogenic activity has caused persistent and prominent losses of forest cover in dry tropical forests. Natural regeneration of forest trees in grazed areas often fails due to lack of seed sources and consumption by ungulates. To address this, the effective restoration of such sites often requires fencing and outplanting nursery-grown seedlings. In the degraded, dry forests of tropical Hawai’i, USA, an additional challenge to restoration of native forest trees is the introduced kikuyu grass (*Cenchrus clandestinus*). This invasive, rapidly growing rhizomatous plant forms deep, dense mats. We studied the use of nursery cultural techniques to facilitate the establishment of koa (*Acacia koa*) seedlings outplanted amidst well-established kikuyu grass on a volcanic cinder cone on the dry, western side of Hawai’i Island. Seedlings were grown four months in three container sizes (49, 164, 656 cm³) and with four rates (0, 4.8, 7.2, and 9.6 kg m⁻³) of 15–9–12 (NPK) controlled-release fertilizer incorporated into media prior to sowing. After 16 months in the field, seedling survival was >80% for all treatments with two exceptions: the non-fertilized 49 cm³ (78%) and 164 cm³ (24%) containers.

After 10 years, only these two treatments had significantly lower survival (35% and 10%, respectively) than the other treatments. One year following planting, none of the non-fertilized seedlings had transitioned to phyllodes from juvenile true leaves, regardless of container size. For the fertilized 656 cm³ container treatment, 78%–85% of seedlings had phyllodes, with mean values increasing by fertilizer rate. Phyllodes are known to confer greater drought resistance than true leaves in koa, which may help to explain the improved survival of fertilized trees on this relatively dry site. Overall, nursery fertilization was more influential on seedling height and diameter response than container size after outplanting. However, the largest container (656 cm³) with the addition of fertilizer, produced significantly larger trees than all other treatments during the early regeneration phase; early growth differences tended to fade at 10 years due to inter-tree canopy competition. Although koa is able to fix atmospheric nitrogen through rhizobium associations, our data confirm the importance of nursery fertilization in promoting regeneration establishment. Nursery cultural techniques may play an important role in forest restoration of dry tropical sites invaded by exotic vegetation.
Tropical HTIRC strives to ensure that research results are communicated to (and used by) landowners, forest managers, and the scientific community. Our (pre- and post-pandemic) extension / outreach program consists of regular field days, workshops, symposia, and development of publications relevant to managers. We aim to collaborate directly with managers to design research projects to meet their needs.

We continue to communicate new developments with our projects, staffing, and publications through our re-designed Tropical HTIRC website – where you can also access our 2017-2021 strategic plan and annual reports.
Mahalo to Our Partners!