ACACIA KOA IN HAWAIʻI: FACING THE FUTURE

2016 KOA SYMPOSIUM PROCEEDINGS

HOSTED BY

TROPICAL HARDWOOD TREE IMPROVEMENT AND REGENERATION CENTER

OCTOBER 5, 2016

UNIVERSITY OF HAWAIʻI AT HILO CAMPUS

EDITORS:

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Tropical Hardwood Tree Improvement and Regeneration Center

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Special thanks to Oriana-Rueda Krauss, Douglass Jacobs, Ph.D., and J.B. Friday, Ph.D. for organizing this event.

Acacia koa in Hawai‘i: Facing the Future

2016 KOA SYMPOSIUM PROCEEDINGS INTRODUCTION

The Tropical Hardwood Tree Improvement and Regeneration Center (TropHTIRC) hosted the "*Acacia koa* in Hawai‘i: Facing the Future" Symposium 2016. The focus of the symposium was to convey the current state of scientific knowledge in management and ecology of *Acacia koa* with the purpose of informing present and future management under a changing environment. This event featured recent scientific and management advancement of *Acacia koa*.

The "*Acacia koa* in Hawai‘i: Facing the Future" Symposium 2016 took place at the University of Hawai‘i at Hilo (Room 301) on October 5th, 2016 from 8:30 am to 5:00 pm, followed by a reception at the Hilo Yacht Club.

Attended by approximately eighty people, the symposium featured 16 speakers, presenting on four themes: Commercial Forestry, Silviculture, Tree Improvement, and Ecology and Ecophysiology. Speakers included local and national foresters, scientists, researchers, conservationists, and graduate students. Attendees included local and national scientists, managers and landowners. In addition to the invited talks, the symposium included a moderated panel discussion focused on commercial forestry.

The symposium provided an opportunity for networking and collaboration among stakeholders and was a platform for the presentation of emerging koa-related research. Informational posters featuring the work of speakers and attendees were available for viewing and discussion during the breaks between sessions.

This event was hosted by Tropical Hardwood Tree Improvement and Regeneration Center (TropHTIRC). Sponsors included: Akaka Foundation for Tropical Forests, University of Hawai‘i at Mānoa College of Tropical Agriculture and Human Resources, County of Hawai‘i Department of Research and Development, Hawai‘i Forest Industry Association, Institute of Pacific Islands Forestry, State of Hawai‘i Department of Land and Natural Resources and Division of Forestry and Wildlife, USDA Forest Service, and USDA Natural Resources Conservation Service.

The following proceedings provide a summary of each of the presentations.

Acacia koa in Hawai'i: Facing the Future

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Acacia koa in Hawaiʻi: Facing the Future

Abstracts and Papers

COMMERCIAL FORESTRY

CONSERVATION EASEMENTS & SELLING OF KOA LOGS

Gregory D. Hendrickson, Esq., (The Law Offices of Gregory D. Hendrickson, Hokukano and Kealakekua Ranch)

Conservation easements are an effective way for private koa forest landowners to protect traditional forest values, ensure long-term sustainable management of the forest, and advance the landowner's financial objectives. Forestland conservation easements can be used to protect forest landscapes that yield forest products, are used for education and recreation, or that are managed to provide ecological benefits. These easements have been used to conserve land as small as a few acres, to landscapes that are several tens of thousands of acres. Forestland conservation easements have been utilized by individuals, families, industrial corporations, and even non-profit landowners. By facilitating forestland conservation easements, communities benefit by securing their economic forestland base, improving air and water quality, ensuring the preservation of important viewscapes, and maintaining recreational open space.

The Parties to the Easement

Conservation easements are private agreements between a landowner and a holder of the easement, which is either a non-profit organization (i.e., a land trust) or a governmental entity. They are generally perpetual in duration and are regularly monitored for compliance. Given the long-term nature of a conservation easement, a positive relationship between the owner and the holder is critical to future collaboration, interaction and coordination. A landowner must work with an organization that has consistent values and shares the landowner's objectives for the conserved forestland. A holder must feel that it can trust the landowner and that there is a commitment to abiding by the terms of easement. Trust, respect and communication are vital to the success of the easement over time.

The landowner can only donate the easement to an organization willing to receive it. A non-profit might decline the donation because of the costs for monitoring and management in the future.

Furthermore, the landowner will only be able to claim a tax deduction for the easement if the receiving organization is "qualified" by the IRS on the basis of its mission and capacity as well as non-profit status. Non-profit entities in Hawaiʻi that hold conservation easements include: the Hawaiian Islands Land Trust, the North Shore Community Land Trust, The Nature Conservancy, and the Trust for Public Land.

Terms of the Easement

Conservation easements are negative servitudes, meaning that they are primarily comprised of restrictions agreed to between the landowner and the holder. These restrictions are carefully crafted to fit the individual circumstances of each property and the goals of the landowner. They must also fit the mission and objectives of the holder of the easement. The centerpiece of any easement is the acknowledgement of specific conservation values present on the property. Recognized conservation values include: (1) recreational and educational uses by the general public, (2) the protection of important habitat; (3) open space uses that advance clearly stated governmental objectives (such as the protection of flood plains, farmland, or productive forestlands); or (4) land that has significant cultural or historical features. Since the easement is a perpetual document, the terms of the easement need to be flexible enough to accommodate changes in management technique and in technology, while restrictive enough to ensure the protection of the conservation values.

These easements generally: eliminate subdivision of the conserved property; limit the construction of structures (including dwellings); prohibit mining; proscribe the manner in which roads, fences, and other infrastructure can be developed on the property; restrict high-intensity recreational uses; and control the introduction of invasive species. Of particular significance to koa landowners that intend to manage their property for forest products, the easement will outline the requirements for sustainable harvest of the trees. The document will also detail the manner in which the holder may monitor and enforce the terms of the easement.

Easement Economics

The potential financial benefit of a conservation easement can be substantial for a koa forest landowner. The value of the easement is determined by establishing the fair market value of the land before the easement is in place and then subtracting the value of the land encumbered by the easement (a before and after valuation). These values are determined by a qualified appraiser. The impact on value of the restrictions in the easement is generally related to the loss of subdivision and development rights, along with any tree harvest limitations. For example, let's say that lumberjack Phil does an easement on 300 acres of koa forestland with the Island Wide Land Trust. Though zoned AG-5 and currently composed of 6 individual parcels, the easement restricts all subdivision (and separate sales of the existing individual parcels) on the property, and Phil is only permitted to build two modest homes. Though moderately stocked with koa timber, Phil agrees to an easement that restricts harvest to 2.5% of his merchantable inventory every year. If the property were sold without the easement, the appraiser determines that it would sell for about $3 million dollars. With the easement in place, however, the fair market value of the property is only $1.2 million dollars. The value of the easement is, therefore, $1.8 million dollars ($3 million - $1.2 million = $1.8 million).

To realize financial benefit from the value of his easement, Phil would either need to sell his easement, or gift his easement to the holder and seek favorable tax treatment. There are a few programs, such as the Forest Legacy Program (a Federal/State cooperative forestland conservation program) that will pay for the purchase of conservation easements. The Forest Legacy Program is administered by DOFAW in Hawai'i and information is provided on their website. Other programs include the Legacy Land Conservation Program, and the Army's Compatible Use Buffer Program. Payments are often a percentage of the total easement value.

The tax code also provides financial benefits to those that contribute conservation easements to tax-exempt entities. The code enables many landowners to take a tax deduction for the value of the easement. Since the easement value is often much more than the income of the landowner, the code allows for the deduction to be carried forward to subsequent years. For specific information on the potential financial benefit of a tax favored easement, please contact an attorney or accountant with experience in advising on easement donations.

Conclusion

Conservation easements provide forest landowners the opportunity to protect important values they cherish on their land, perpetuate their thoughtful stewardship, and establish a lasting legacy for generations to come. Hawai'i's beautiful forests are an integral part of its magical landscapes, and an important contributor to its economy. Koa is a treasured species, highly valued for its remarkable wood and essential to Hawai'i's ecology. A conservation easement is an incentive-based tool for landowners and their communities to work together in ensuring the bright future of this important native tree species.

COMMERCIAL FORESTRY

HARVESTING OF PLANTED KOA: A CASE STUDY FROM HALEAKALA RANCH

Steve McMinn (Pacific Rim Tonewoods)

Paniolo Tonewoods is a joint venture between Taylor Guitars and Pacific Rim Tonewoods, and was formed in 2015 specifically to supply koa guitar components to Taylor and other instrument companies. It is our desire to promote, encourage and invest in koa forestry, and it is our intention to build a small, efficient milling operation in Hawai'i in the coming years. Haleakala Ranch, ("HR"), on Maui, has two stands of Koa that were planted in 1985, in conjunction with "A Million Trees of Aloha", a program started by Jean Ariyoshi, then Governor Ariysohi's wife. The two stands, A and B, are of about 20 acres and 8 acres, (8 and 3 hectares), and are at 5000 feet and 6000 feet of elevation respectively (1500 and 1800 m) (figure 1 and 2).

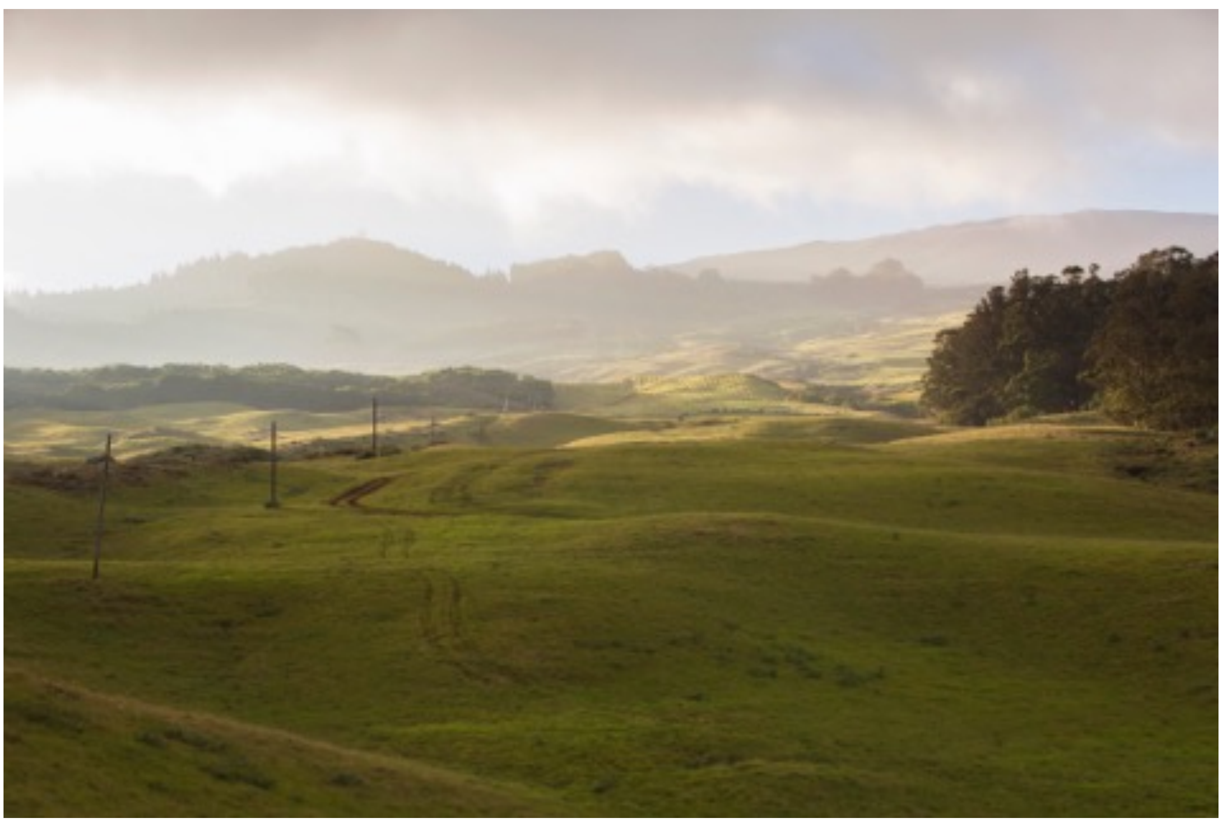

Figure 1: Stand A from below.

Figure 2: Plaque commemorating the planting of the Haleakala Ranch stands.

Both stands are said to have been planted from seedlings grown from Hawai'i Island seed stock. In both stands, the canopies were closed, and both had a floor that was covered chiefly with leaf litter, although A had some gorse intrusion. B is long and narrow; the trees are more widely spaced. Since B has more edge exposure, it also has more grass intrusion.

Both stands had initially been fenced, but at some point early on, cows got in and ate the top out of every tree, so that the stands resemble an un-tended apple orchard. The trees have short boles with candelabra tops. In only a couple of cases was there a useful bole greater than 7 feet (2.1 m) in length, and most were 4 - 6 feet (1.2 -1.8 m). Overall, tree height was 35 to 55 feet in A (11 - 17 m), a bit less in the higher elevation stand B. Dbh's of the trees were from around 10 inches to 40 inches (250 - 1000 mm), with many of the better trees being around 20 inches (500 mm). The biggest trees were usually near an edge, where there was diminished competition. Rot was starting to occur in the crotches of some trees, particularly the larger ones, as a result of ponding water (figure 3).

In June, 2015, we did a trial cut of 40 logs, and ascertained that we could, with considerable effort, yield material that was useful for guitars. So we struck a deal with the ranch, and in two operations in the following months, cut a total of 500 stems from stand A. The material we deemed useful had a dbh of 13" (330 mm) or better . This was around 32,000 board feet, Scribner Decimal C log scale (160 m^3). Paniolo Tonewoods purchased this wood from HR as stumpage, and we did the cutting ourselves. We worked closely with HR, who engaged contractors and assisted us at every stage in handling and transporting the logs to the ranch headquarters, where the ranch did the loading into containers.

Figure 3: Steve McMinn and Scott Meidell with a better HR tree, *Stand A*.

Prior to felling the trees, in most cases, we cut out the multiple tops, so that the boles could be cut off flush at ground level, leaving no hinge (from a control cut), and no stump. The location of each tree was noted by GPS, and each log and each stump was numbered and recorded, in the event that the tree was highly figured and that sprouts might be used in future propagation of elite koa.

Once felled, we positioned the "logs" with a small excavator and stacked them in a central location so that they could be moved to a loading point at the edge of the stand with a skid steer machine.

Then they were loaded on a farm truck for transport down the mountain. Average weight was about 800 lbs (360 kilos) (figure 4).

Figure 4: Justin El-Smeirat pushing over flush-cut tree.

From our 40 log trial, we knew that, in order to use the sapwood, we had to avoid bruising the logs in handling, and that we had to move quickly so that ambrosia beetles wouldn't have time to bore in (figure 5).

Figure 5: Jordan Jokiel with HR logs.

We shipped the logs in containers to Seattle, and transported them to the PRT mill in Concrete WA. There, we sawed them into 6/4 boards (38 mm), numbering each board in sequence, color coding, and noting the tree number (figure 6).

Figure 6: Boards marked out from 20-year-old koa from Maunawili, O'ahu

Once sawn, we promptly marked outnumbered, matched guitar parts (backs, tops, sides, ukelele tops, binding parts, etc.), trimmed the 6/4 boards to blanks, end sealed them to eliminate checking, and stickered them on non- staining stickers. We placed the stickered piles in front of fans, and air dried - whenever possible - prior to drying to 7 - 8% moisture content in our dehumidification kiln (figure 7).

Figure 7: Meghan Parker marking out wet koa boards.

When dry (~ 4 weeks), we surfaced the blanks and re-sawed them into 6 pieces - 3 sets- using either our Wintersteiger frame saw or one of our band re-saws. In either case, the kerf was between .040" and .050" (1 - 1.25 mm.) (figure 8). Once re-sawn, we sorted the book matched guitar sets, graded them and marked them for trimming.

Figure 8: Frame saw making 18 pieces from 3.

Challenges in using this wood for guitars: Size, Sap, and Stability.

Building a guitar from lumber produced from a 13 – 20-inch diameter tree, (300 -500mm) is a challenge, but it is not impossible. Taylor Guitars changed their manufacturing specifications in order to best use the available koa. With Haleakala Ranch koa, more of the backs in full sized guitars were made from 3, rather than 2 pieces. Much of the wood was used as tops in a line of smaller guitars, and Taylor adapted these to use a 4-piece top, which was glued up from narrow pieces. Taylor was also able to develop special models to use more un-figured wood (figure 9).

Figure 9: Taylor GS Mini Guitar tops glued up from 4 pieces.

Figure 10: Bob Taylor with guitar made of toon (*Toona ciliata*) from Kamehameha Schools lands and koa guitar from 20 year old HARC tree, grown at Maunawili. O'ahu.

Because the sapwood width in these trees is substantial, varying from about 1 to 4 inches of the trees' radius (25 - 100 mm), a builder has to be willing to utilize it. In these HR guitars, this often required allowing a white band in the center of a book match. At times, this was treated as a feature of interest, but at other times it was disguised with a stain, or wash. Occasionally, sapwood was placed at the outside edge of the guitar, where it would be covered by a sunburst finish (figure 10).

Typically, once a guitar builder receives the dried, matched, and trimmed guitar components, they are put on back on stickers, over-dried, and then allowed to "fluff up" again to an equilibrium with the 45% relative humidity in the guitar factory. In the case of this younger koa, the sets were still, after this treatment, unstable and prone to movement, so they couldn't readily be glued up into guitar sized panels. Taylor developed a protocol of sending these guitar sets through their in - house drying regimen three times, at which point they became sufficiently compliant.

This extra drying regimen is the same method that Taylor uses to get Big Leaf Maple to settle down—the third time is a charm. We are hopeful that, through a combination of vacuum and dehumidification drying, we may be able to both dry the sap whiter and to more quickly increase the stability of the wood, rendering this extra drying unnecessary.

In summary, using young koa is a challenge, and vertical integration of our enterprise is the only thing that has made it economically feasible for Paniolo Tonewoods; Taylor Guitars is the main customer for this wood. However, this vertical integration is a model that used to be common with furniture endeavors, when the builder or furniture factory owned the trees that became a product.

If the useful length of these trees hadn't been so severely shortened by cows, if they had been thinned and pruned, and if some of the better tall, pruned, trees had then been allowed to grow for 40 - 60 years, this stand would have been even more valuable. In spite of these caveats, stand A will soon have provided substantial koa components for about 10,000 Taylor guitars, with a retail value in the millions dollars. These are actual sales, not market research.

Thousands of people have purchased these guitars; when buyers are made aware of the fact that these guitars are from deliberately planted trees that are adjacent to the land that HR is actively reforesting, they are pleased. Using younger wood, such as koa, that is locally and ethically sourced, is a sales argument in the minds of many people. The story of HR's commitment to and investment in koa forestry as a possible alternative to their lands being over-run by invasive species, particularly gorse, is equally compelling.

Wood Notes and Future Projects

We did not use a colorimeter to quantify the color of these 500 stems, although the range seemed typical of—if a bit lighter—than the Hawai'i island koa that we have sawn over the last 30 years.

The range of density, when tested, seemed comparable to that of most Big Island koa, with the first couple of inches of growth from the heart out being less dense.

Stump figure and reaction figure was not uncommon, but about 17% of the stems showed continuous figure of the sort that was potentially suitable for a line of "figured" guitars. We took full length photos of the central boards from these "elite" logs, and saved samples of the wood from these. When we had sorted the dried, re-sawn boards, we further refined our selections, reducing our elites to about 10% of the stems from Grove A. Figure in the elites was often visible in what would have been the first 2-3 years of these trees' growth; in some, it was quite prominent at this age (figure 11).

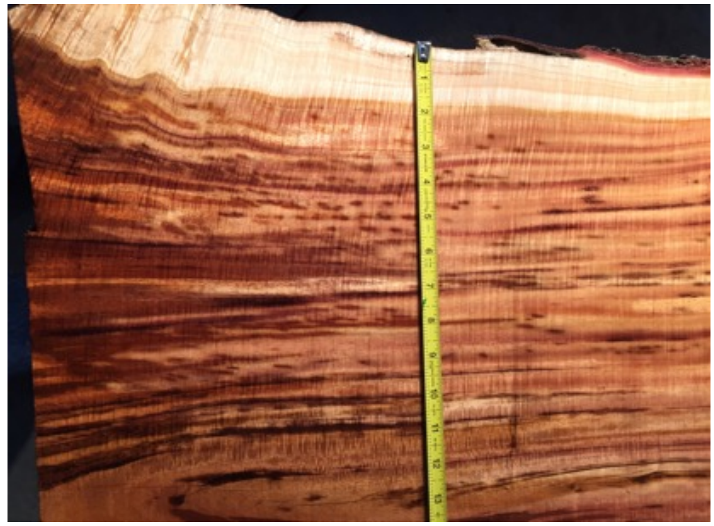

Figure 11: Elite Board

We are interested in testing the extent to which figure in koa may be genetic. Our first harvest, of about 40 stems, was in June of 2015. When we returned in October of that year, we noted that many of the stumps from these trees had sprouted vigorously. When we first realized this, we subsequently marked each log and its stump, so that its location could be tracked later. For the two subsequent harvests, after we had documented the wood quality of our elite logs, we returned to the ranch, GPS-ed and flagged their stumps. It is our intention to try to propagate these; this is a project that we are undertaking jointly with Haleakala Ranch and Maui Native Nursery. If we are successful, we plan to plant these selected lines in trials (and likely a seed orchard) on the ranch (Figure 12). Reforesting in koa has many ecological benefits; it also, with careful silvicultural management and harvesting, presents great economic opportunities.

Figure 12: Stump sprout

COMMERCIAL FORESTRY

TRENDS IN SECURING AND MILLING KOA

Jay Warner (Awapuhi Farms and Mill)

Paper Title: Koa harvests and markets: past and future

My own personal experience with working with and harvesting koa go back to 1982, when I first used koa for furniture and cabinetmaking. Even back in the early 1980's koa lumber that was ready to work was difficult for local woodworkers to obtain. Many of us took it upon ourselves to harvest our own koa along with many other locally grown trees. This is how things have unfolded for the last 35 years.

Figure 1: Large logs from dead trees are brought to the mill. These logs may resist rot for many years.

Koa timber has for the most part been harvested on private land for the last few decades with a few small sales on state land under control of the Department of Hawaiian Homelands. The large majority of all trees harvested have come from private ranches at upper elevations, from 4,000' to as high as 6,500'. Salvage logging would be the best way to describe how any harvesting is done. Almost without exception all the koa is harvested from old growth forests that had been converted to pasture slowly but surely over the last 150 years by simply letting the cattle graze and roam at will. Most of these forests are missing complete generations of young, healthy trees. The grazing cattle have eliminated any hope of seedlings making any headway.

Figure 2: Lumber of different dimensions is sold mainly to furniture manufacturers. Only heartwood is sold currently; there is little market for sapwood.

The trees I have harvested and brought to the mill have been from dead, down, and dying trees. Occasionally healthy trees are harvested if the landowner sees fit. Almost all the trees have been old growth, which to me means they are of an age of 75 years to perhaps as old as 400 years. I have harvested and sawn younger koa trees in the range of 25-45 years old, and I have helped with scientific studies to try to get a better idea of what these young trees might provide to woodworkers of the future.

Having harvested, sawn, edged, trimmed, and graded hundreds of thousands of board feet of koa I have come to a very straightforward conclusion: lumber from old growth trees is far superior to that from younger trees. This is not some earth-shaking news to any woodworker here in the Hawaiian Islands, and that does not mean that there is not value to be had in those young trees. Thirty-five years ago no one ever thought of making use of the smaller branches or stumps of the harvested trees as we do now. Thirty-five years ago truck loads upon truckloads of short lengths of koa lumber were bulldozed into slash piles because they were too short to market. Such waste does not happen now as we have asked our customers to be more realistic about what they really need and can make use of. If a woodworker specializes in making rocking chairs they can make use of short lengths of lumber: there are very few 16-foot-long rockers out there.

Figure 3: Small pieces of high quality koa wood go to manufacturers of pen sets and other small crafts.

We are running out of old growth koa to harvest at this time. I do not think koa lumber from 25 to 45-year-old trees will ever take the place of old growth lumber, but there will be a place for that material. Many land owners are replanting koa on some of the best parts of their land. While it is encouraging to see this happening, we now will all have to see how these stands of trees are managed and cared for. There are several ways to go about this and I do not think that any one person or group has a perfect plan. I believe that the open sharing of information will be key to having success for all future koa forests.

Figure 4: A "young koa" log from a 25-year-old tree still has a lot of sapwood.

Koa should not be thought of as a "brand" or a "market", and should not be thought of as the only truly valuable wood in Hawaiʻi. Koa is a wonderful wood and koa forests are amazing places. Woodworkers and end users of their work should use koa wisely in the future, and incorporate other local timbers in their work. By making use of the many other introduced and native trees here, we will be able stretch our koa supply and allow the forests the time to recover. I believe the future is bright for koa. With so many people interested and involved with reforestation today the next 100 years look to be very good indeed.

COMMERCIAL FORESTRY

VALUE OF YOUNG GROWTH KOA AND CONSUMER PREFERENCES FOR KOA COLOR AND FIGURE

J.B. Friday, Ph.D. (University of Hawaiʻi at Mānoa, Department of Natural Resources and Environmental Management (NREM), Eini Lowell (USDA Forest Service, Pacific Northwest Research Station), Katherine Wilson (University of Hawaiʻi at Mānoa, NREM), Jan Wiedenbck, Ph.D. (USDA Forest Service, Northern Research Station), Catherine Chan, Ph.D. (University of Hawaiʻi at Mānoa, NREM), Nicole Evans (University of Hawaiʻi at Mānoa, NREM)

Paper Title: Consumer preferences for koa color and figure

Abstract

Today's koa industry relies on harvest of remaining old-growth koa. As this resource is depleted and remaining stands are protected from harvest, the koa industry will turn to harvesting either plantation-grown koa or young koa trees from naturally regenerated second growth stands. The quality of wood from young koa trees, however, is likely to be very different from the quality of wood from old-growth trees. In a previous study, we harvested 31 young koa trees (ages 25 to 32 years), milled them, and distributed both lumber and bowl stock to local woodworkers. They created a number of pieces from the wood and gave us an assessment of the quality of the wood. All agreed that the wood from young koa was lighter in weight (less dense) and lighter in color than the wood they were used to using with little figure. Most noted that the wood was softer than old-growth wood. Opinions differed as to the value of the young koa wood, but all agreed that pieces made from young koa wood would have different markets than pieces made from traditional, old-growth wood.

In the current study we asked the broad question of how consumers value color and figure in koa wood. We created a survey in which respondents chose among photos of koa that varied in color, figure (curl), and price (called a conjoint choice experiment) (figure 1). We also created six identically-shaped koa bowls that differed in color and degree of figure and asked the consumers to choose among these (figures 2 and 3). We surveyed 372 people, including people at the Hawaiʻi

Woodshow, malls on O'ahu, and at trailheads of hiking trails on O'ahu. Both residents and visitors were surveyed.

The results show that there is a lot of variation in what consumers prefer in koa color and figure and what they are willing to pay. The responses could be clustered into five groups as follows:

- 24% liked wood that was medium colored, straight grained, and inexpensive.
- 22% liked wood that was light colored and curly and didn't care about price.
- 20% liked wood that was light or medium colored, curly and didn't care about price.
- 19% liked wood that was light or medium colored and inexpensive.
- 15% liked wood that was dark, curly, and inexpensive.

Profile 1. If these koa bowls were your only options, which would you choose?

Attribute	Option A	Option B	Option C
Figure	Not curly	Curly	Not curly
Color	Light	Medium	Dark

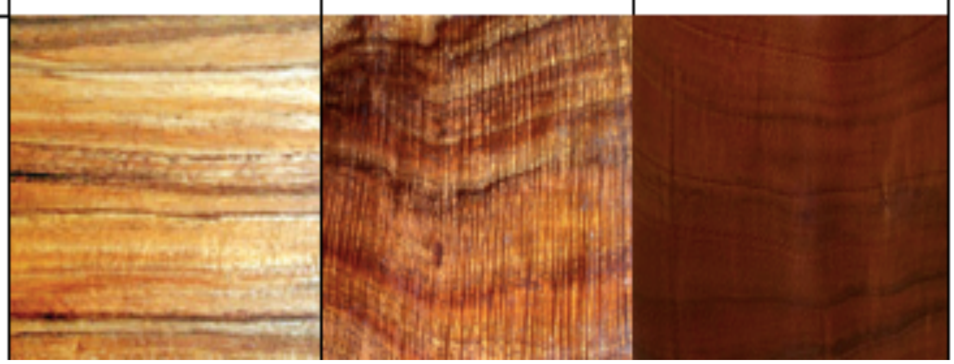

Figure 1: One example of a choice presented to the consumer in the survey. Figure, color, and price were randomly assorted; each respondent was asked to do twelve of these comparisons.

Figure 2: Koa bowl used in the survey showing dark color but little figure.

Figure 3: Koa bowl used in the survey showing medium color and high figure.

For the bowls, consumers generally preferred the bowls with some figure, but responses were about even among those who preferred light, medium, or dark bowls (figure 4).

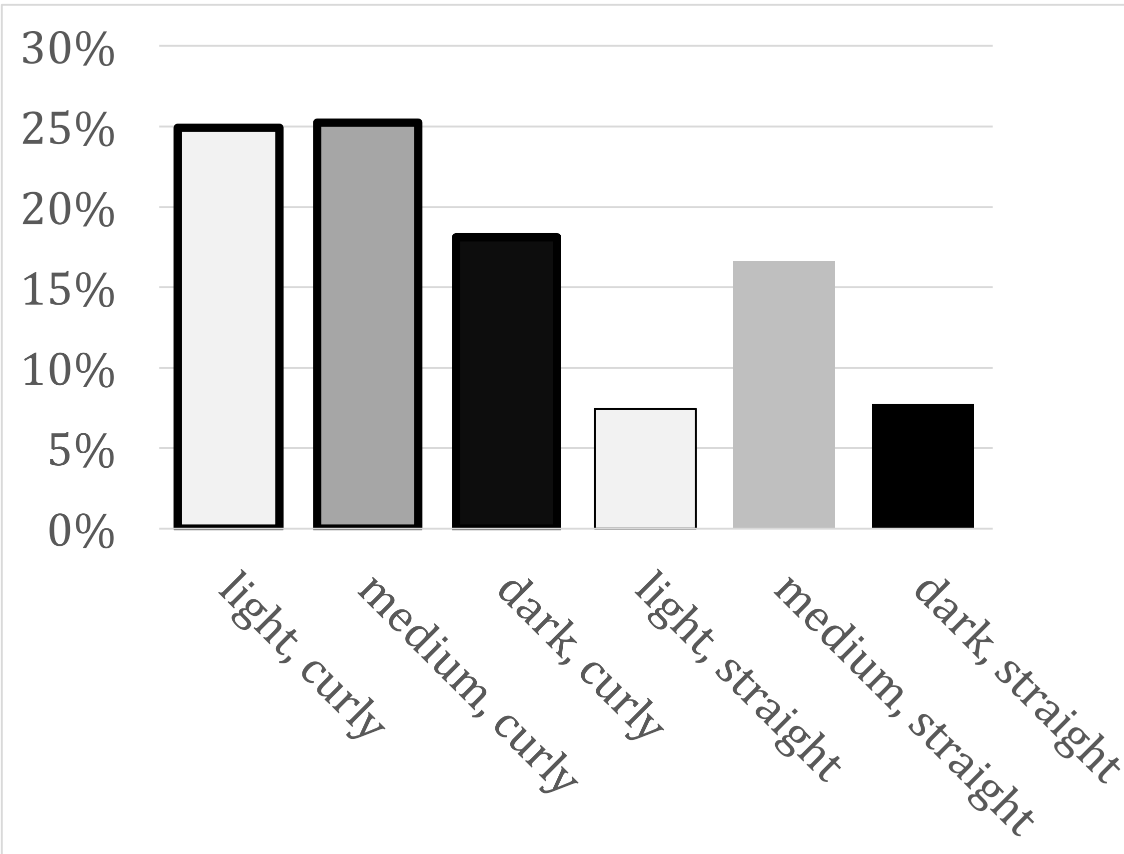

Figure 4: Consumer preferences among differently figured and colored koa bowls.

Our results indicate that there is a significant market for koa wood that is lighter in color and less figured than what is generally considered merchantable today. Tomorrow's koa industry will be able to exploit new markets for what is seen as lower-value wood in addition to maintaining the current market for dark, highly figured timber. Because the lighter colored wood is likely to be less valuable, however, harvesting will have to become more efficient in order to remain economically viable. Woodworkers may choose to use the young wood to create products requiring less labor that can be sold at a lower price. The possibility of new markets for young koa opens up new possibilities for landowners to sell some young koa trees to generate income during intermediate harvests while reserving the best trees on the land for final harvest of old-growth wood.

SILVICULTURE

APPLYING THE TARGET PLANT CONCEPT TO REGENERATION AND RESTORATION OF KOA

Douglass Jacobs, Ph.D. (Purdue University), Anthony Davis, Ph.D. (Oregon State University), Kas Dumroese, Ph.D. (USDA Forest Service Rocky Mountain Research Station), Diane Haase (USDA Forest Service State and Private Forestry), and Jeremy Pinto, Ph.D. (USDA Forest Service Rocky Mountain Research Station)

Abstract

Applying the Target Plant Concept (TPC) is an important step in determining the best quality seedlings for regeneration and restoration programs. The TPC emphasizes the importance of selecting plant morphological, physiological, and genetic characteristics as defined by the project objectives and conditions of the outplanting site. As such, there is not a "one size fits all" when describing an ideal seedling.

There are five key components of the TPC for determining the desired quality characteristics for a given project on a specific site. First, the project's objectives and constraints must be considered. For example, optimum plant characteristics can differ greatly for projects designed to achieve conservation, timber production, or wildlife habitat. Second, the source of the plant material is an important factor. It is recommended to use material of an appropriate species and genetic source for the site to maximize environmental adaptation and minimize stresses. Depending on the project objectives, using an improved source with pest resistance or superior growth form may also be desirable. Third, limiting factors on the outplanting site will influence the target morphological and physiological characteristics. Accounting for factors such as seasonal drought, temperature extremes, nutrient deficiencies, grazing animals, and vegetative competition is important for selecting seedling characteristics suited to those conditions (along with site preparation to mitigate limiting factors whenever possible). For instance, seedlings destined for a site where water is limiting may be cultured at the nursery to have a relatively large root:shoot to be able to access a greater volume of soil water. Fourth, stocktype and plant quality choices have a significant influence on subsequent growth and survival. A multitude of container types are available for producing nursery stock, the varying sizes and dimensions will affect seedling morphology. Plant quality can also be tailored using fertilization, irrigation, pruning, and other culturing methods to

achieve targets. Fifth, the outplanting methods and follow-up practices must also be used to help set plant targets. The optimum planting window for the site, the planting tools to be used, treatments to be applied at the time of outplanting, and subsequent project maintenance activities should be accounted for when choosing plant characteristics for each site.

Successfully applying the TPC requires a collaborative effort between nursery managers and their customers. At the onset of a project, the two parties must agree on plant specifications based on the five components of the TPC. Once the target seedling is grown in the nursery, its fitness for purpose needs to be verified by outplanting trials to monitor its performance for up to five years. This information can then be used to fine-tune target specifications for future projects.

Figure 1: Good quality koa seedlings staged for planning into a well-prepared site on Mauna Kea.

SILVICULTURE

NURSERY HARDENING TO PROMOTE KOA FIELD ESTABLISHMENT

Bradley Kaufmann (University of Hawai'i at Mānoa Department of Natural Resources and Environmental Management)

Abstract

After centuries of habitat loss, the distribution of *Acacia koa* (koa) has largely been relegated to high-elevation, fragmented populations. In addition to being one of the most valuable trees in the world, koa provides critical habitat for endangered plant and animal species and is revered in Hawaiian culture. Invasive plant competition, animal browsing, drought, and climate change challenge establishment of koa seedlings. Climate change induced decreases in available soil moisture in conjunction with increases in solar radiation and temperature will greatly stress outplanted seedlings. Ensuring the survival of nursery-grown seedlings on sites that contain limited soil-moisture necessitates the employment of horticultural techniques in the nursery that modify morphological and physiological attributes of field-bound seedlings. Nutrition and container-type influence the survival and growth of outplanted seedlings. The root-to-shoot ratio (R:S) is a standard measure of seedling morphology, which is commonly used to predict drought avoidance potential and establishment success. High-quality seedlings have shoots that are not so

Figure 1: Comparing koa seedlings grown in RootMaker® (left) and Deepot™ (right) and containers of the same volume both 410 cm³.

large as to have a transpiration requirement that cannot be met by the roots at the time of planting. Nitrogen hardening is a horticultural technique in which the amount of applied nitrogen is reduced in the weeks prior to outplanting to decrease height and shoot growth, while increasing root growth and R:S. Deeper containers train roots to soil depths that can contain increased soil moisture, while air-pruning containers create a fibrous root system with an increased quantity of root tips. To test the efficacy of Nitrogen hardening koa for outplanting, seedlings were grown for 13 weeks in DeepotTM (25.4 cm deep) and RootMaker® (10.2 cm deep) containers (both 410 cm3), with and without Nitrogen hardening. Seedlings were outplanted into a field site in the Northwestern Koʻolau Mountains in January, 2016. At the end of nursery culture, Nitrogen hardened and DeepotTM seedlings exhibited a significantly increased R:S. Nitrogen hardening did not confer survival or growth benefits to seedlings in the field in this instance. All seedlings exhibited a high survival rate 8 months after planting (>95%). Container-type was the most influential factor, with DeepotTM containers demonstrating a significantly increased height (+9.4%) and root-collar diameter (+12.5%) after 8 months of field growth compared to RootMaker® containers.

Figure 2: Root structure in a 12-week-old koa seedling grown in RootMaker® container.

SILVICULTURE

CHEMICAL SITE PREPARATION AND INTERACTIONS WITH KOA NURSERY STOCKTYPES AND EDAPHIC CONDITIONS

James Leary, Ph.D. (University of Hawaiʻi at Mānoa Department of Natural Resources and Environmental Management), Jeremy Pinto, Ph.D. (USDA Forest Service Rocky Mountain Research Station), and Anthony Davis, Ph.D. (Oregon State University)

Abstract

Restoring Hawaiʻi's native koa (*Acacia koa*, A. Gray) forests are top conservation and forestry priorities; providing critical habitat services and high-value timber products. Efforts to restore koa forests, however, are directly impeded by extensive kikuyu grass (*Pennisetum clandestinum* Hochst. ex Chiov.) swards occupying deforested montane landscapes. In a field study, we implemented a combination of grass suppression and seedling stocktypes to measure outplanting performance in a naturalized site on Ulupalakua Ranch property on Maui. Seedlings were grown in a nursery in two different root container sizes (111, and 207 cm3) and subsequently outplanted into grass-dominated plots that were either untreated or suppressed with a high-rate herbicide combination of imazapyr and glyphosate (1.7 kg a.i. ha-1, respectively), 30 days prior to planting. Across all treatments, seedling survival was high (>95%). The larger stocktype was persistently larger and at 30 months after planting was 10% taller with an 18% greater root collar diameter. Concurrently, initial grass suppression resulted in trees that were 34% taller with 66% larger root-collar diameters, 30 months after planting. Corresponding to the larger sizes, were significantly higher leaf area indices (2.6 vs. 1.8 m^2 m^{-2}), indicative of higher photosynthetic capacity and canopy closure. Grass suppression increased soil temperature and soil moisture in the first year, followed by a dramatic drop in soil moisture on the second year, which corresponded with an apparent log-phase growth response of koa after the first year in establishment. These results demonstrate how the combination of fundamental silvicultural practices in the nursery and the site can accelerate tree growth to meet restoration goals in shorter time intervals. This is a first report of koa (a leguminous species) tolerance to a high-rate, pre-plant application of the herbicide active ingredient imazapyr.

SILVICULTURE

STAND MANAGEMENT OF KOA: THINNING AND FERTILIZATION

Travis Idol, Ph.D. (University of Hawaiʻi at Mānoa Department of Natural Resources and Environmental Management), Paul Scowcroft (USDA Forest Service, Institute of Pacific Islands Forestry), J.B. Friday (University of Hawaiʻi at Mānoa Department of Natural Resources and Environmental Management)

In many areas of Hawaiʻi, *Acacia koa* (koa) has been naturally regenerated through soil scarification or other disturbances such as fire, resulting in single-age cohorts of dense but patchy stands. Managing these stands for timber production usually includes thinning to maintain growth potential and prevent suppression through intraspecific competion. Other treatments, such as fertilization or grass control, may have additional positive effects on the selected trees ("crop trees").

A growing body of research offers insights into responses to thinning and other treatments for dense, naturally-regenerated koa stands. Scowcroft and Stein (1986) studied a 10-year-old koa stand on Maui situated at 1100 m above sea level (asl) on nutrient-poor soil that received on average 2500 mm mean annual precipitation (MAP). Stand density at 10 years was 2100 stems ha^{1} and a majority of trees were considered dying or weak. Experimental treatments included thinning to 50% residual density and fertilization with N-P-K (10-30-10) at 460 kg ha^{-1} and $MgSO_4$ at 170 kg ha^{-1}. Thinning significantly increased stand relative growth rate for the first 2-3 years, until an outbreak of koa looper moth (*Scotorhythra paludicola*) defoliated the stand. Fertilization had no significant independent or additional effect to thinning.

Pearson and Vitousek (2001) studied a 9-year-old koa stand on Hawaiʻi Island situated at 1500 m asl on a 2000-3000 year-old lava flow soil (Mauna Loa) that received on average 2500 mm MAP. Stand density was 16,000 stems ha^{-1} with a basal area of 21 m^{2} ha^{-1}. Experimental treatments included thinning to 50% residual basal area and fertilization with 70 kg ha^{-1} of nitrogen (N) as ammonium nitrate. Thinning increased mean annual stem diameter (DBH) increment from 0.4 to 1.1 cm. Fertilization had no significant independent or additional effect to thinning.

In the same location, Scowcroft et al. (2007) studied a 23-year-old koa stand. Stand density was approximately 900 stems ha-1. Experimental treatments included thinning around selected crop trees (all trees with overlapping or touching crowns), herbicide grass control, and fertilization with 750 kg ha-1 of phosphorus (P) as triple super phosphate. The full combination of treatments resulted in a significant increase in annual DBH increment from 0.5 to 1.09 cm. This difference was due to a significant decline in DBH increment over time in the control plots vs no difference over time in the fully treated plots.

Baker et al. (2008) studied 30-year-old koa stands on Hawai'i Island situated at 1500 m asl on a 1500-300 year-old lava flow soil (Mauna Loa) that received on average 1200 mm MAP. Experimental treatments included thinning around selected crop trees to different set distances, representing residual stand densities from 900 to 200 stems ha^{-1}, and herbicide grass control. After 3 years, stem DBH increment was twice as great with thinning to 900 stems ha^{-1} and almost 4 times as great at 200 stems ha^{-1}. Grass control had no significant independent or additional effect.

Idol et al. (2017) studied a 9 year-old koa stand situated on Hawai'i Island at 1500 m asl on a deep ash soil (Mauna Kea) that received on average 2000 mm MAP. Experimental treatments included thinning around selected crop trees to a residual stand density of 500 stems ha^{-1} (4.5-m radius), fertilization with 600 kg ha^{-1} of P as triple super phosphate, and herbicide grass control. Thinning increased annual stem DBH increment from 1.0 to 2.0 cm. Fertilization and grass control had no significant independent or additional effect on DBH increment. For thinned trees, P fertilization significantly increased height growth from 0.5 to 1.0 m over 2 years. Gap closure after thinning progressed at a rate that was projected to result in full canopy closure after approximately 5 years.

Conclusions and recommendations from this study include the following :

1. The time of first thinning should take place at 6-8 years of age, depending upon initial density and average crop tree size.

2. Crop tree selection thinning is recommended to focus efforts on trees with the best timber potential. The thinning intensity (radius) should be as wide as practicable, up to the expected crown area requirement of trees at the first commercial thinning or harvest.

3. Thinning at a young age should approximately double stem DBH increment, maintaining growth potential of trees in otherwise overstocked stands.

4. Fertilization with P is recommended at a rate of at least 500 kg ha^{-1}. This appears to be more important for older stands, but there may be improvements in height growth even for younger stands.

5. Given the greater expense of thinning vs fertilization and the potential increase in height growth, repeated P fertilization may improve the canopy dominance of crop trees and reduce or eliminate the need for additional pre-commercial thinning as thinned gaps close in.

Figure 1: A 12-year-old potential crop tree on Mauna Kea responds with healthy crown development four years after release

Figure 2: All less vigorous or forked trees were felled within a 15-foot radius of each potential crop tree in this study in a 9-year-old stand on Mauna Kea.

Figure 3: The young koa stand on the left was regenerated by scarification by bulldozer and fencing to exclude cattle. A healthy seed bank had been built up in the soil by the remaining overstory koa trees in these pastures on Mauna Kea.

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SILVICULTURE

AN INTEGRATED PROGRAM FOR KOA PLANTATION ESTABLISHMENT (MECHANICAL, CHEMICAL, FERTILIZATION, PRUNING, THINNING)

Nicholas Koch (Forest Solutions)

Paper Title: Koa Silviculture

Method of Regeneration

Two methods of koa regeneration, soil scarification and seedling planting, are contrasted in terms of the differing silvicultural inputs. Where scarification relies on natural seed as the primary driver of stocking, planting takes a direct approach. Scarification works well on sites that already have some koa canopy cover to provide seed, where stocking gaps are acceptable and where planting is difficult, such as in rocky terrain.

Planting offers certainty in stocking, control over cohort genetics and works best where existing seed bank is unreliable for regeneration or soil quality justifies additional investment, as in ex-pasture loam soils. Planting features higher and earlier costs relative to scarification yet results in more even tree distribution and, as a result, higher growth and yield.

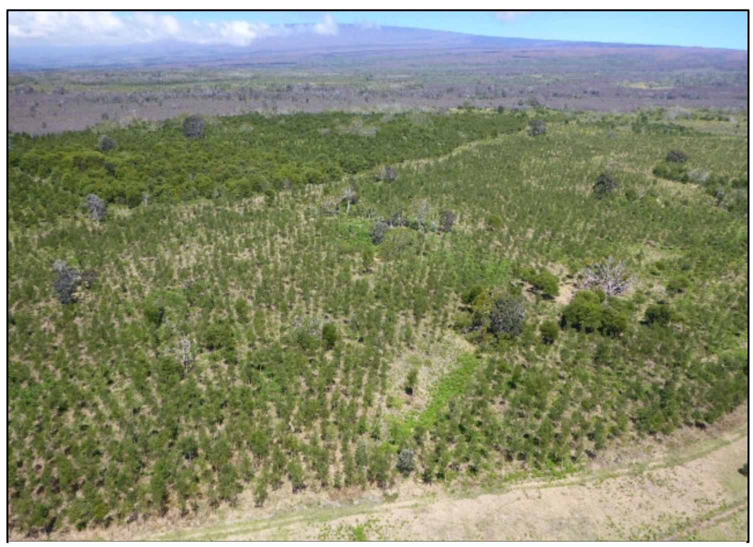

Figure 1: Koa planting makes business and ecological sense, providing a ROI of 6% or higher over a 60-year rotation. Image is of 3 year (foreground) and 4 year (background) planted koa on Mauna Loa.

Financial Analysis

Regardless of regeneration method, koa silviculture is analyzed in the context of inputs and outputs, using a single-acre discounted cash flow as a method of analysis. The economics of koa silviculture include establishment, the basic growth and yield of koa trees over time and the changing value of the wood produced during a proposed koa growing rotation of 60 years on a minimum 50 acre project scale. For modeling purposes, growth rates (mean annual increments) were assumed to peak at 600 bdft/ac/yr (approximately 7.5 m^3/ha/yr) at 15 years and then gradually decrease to about 200 bdft/ac/yr (approximately 2.5 m^3/ha/yr) by age 60. These growth rates are conservative relative to several permanent sample plots (PSPs) recorded annually over the first 10 years post establishment resulting in log MAI between 1,600-2,400 bdft/ac/yr (20-30 m^3/ha/yr).

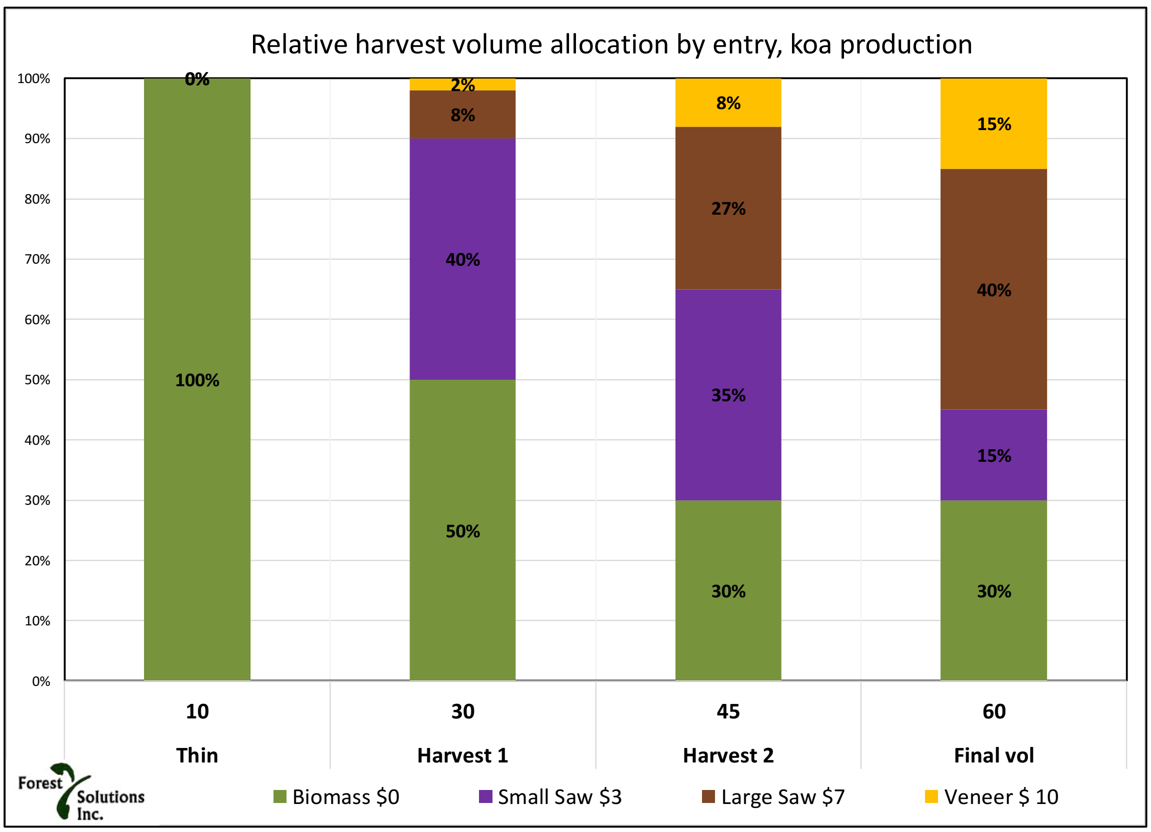

Figure 2: Different log quality allocations were used in each harvest entry, assuming thinning from below. Each harvest entry thus results in a higher quality product mix. Relative percentages are based on author experience.

An establishment cost of US$ 2,450 per acre (US$ 6,050 / ha) was used, together with three different stumpage values for small saw-timber ($ 3, <20"), medium saw-timber ($7, 20"+) and veneer ($10). The relative production of the three stumpage classes varies by harvest entry with higher value material appearing later in the rotation. The result of the rotation calculations including three harvest entries is that koa forest planting turns a predicted 6% ROI or LEV of US$1,700/ac (US$ 4,200 /ha) using an annual discount of 5% on upland (3,000 foot+/900 m+) sites used as a base scenario for evaluation. It is very likely that real world returns will be substantially higher than those resulting from this model due to higher observed growth rates (PSPs) and lower plantation establishment costs. Koa cultivation and silviculture on upland sites in Hawai'i thus make both business and ecological sense.

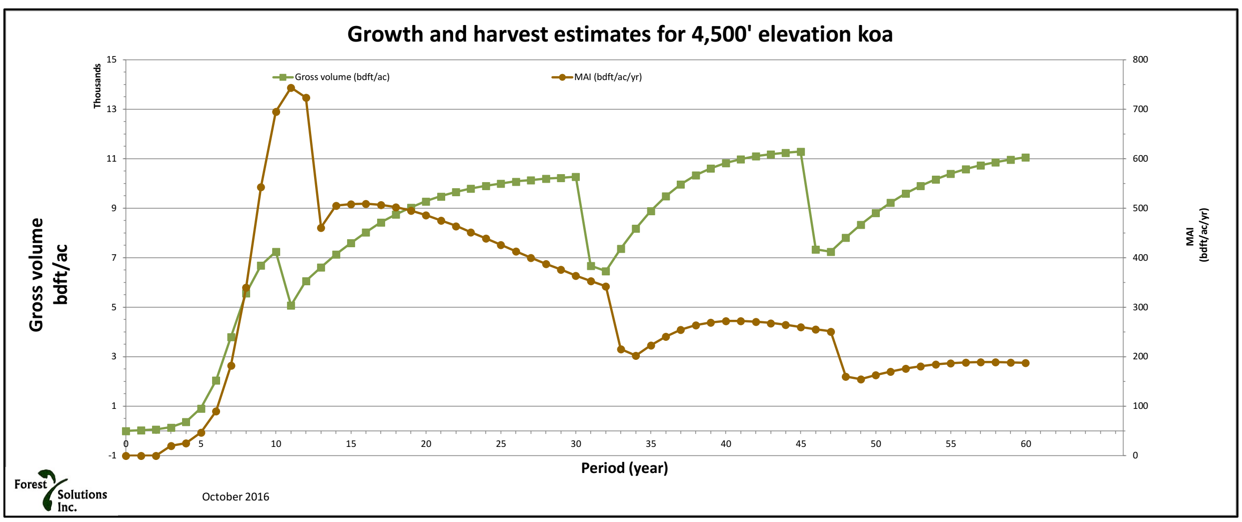

Figure 3. Predicted growth rates for planted koa slowly decline over the projected rotation due to ageing trees and reductions in stocking resulting from 3 harvest entries. Data beyond the first 12 years of growth is extrapolated from the first curve and compared to other stands of known age in

TREE IMPROVEMENT

BREEDING WILT RESISTANCE IN KOA

Richard A. Sniezko, Ph.D. (USDA Forest Service, Dorena Genetic Resource Center), Nick Dudley (Hawai'i Agriculture Research Center), Tyler Jones (Hawai'i Agriculture Research Center), and Phil Cannon, Ph.D. (USDA Forest Service, Pacific Southwest Region, Forest Health and Protection)

Paper Title: Koa wilt resistance and koa genetics – key to successful restoration and reforestation of koa (*Acacia koa)*

Koa is a very important tree species ecologically, economically and culturally in Hawai'i and there is a huge demand for planting degraded lands with koa. However, the high susceptibility of koa to a wilt disease, caused by the *Fusarium oxysporum* fungus, has made many land managers cautious about planting this species. In the early 2000's an effort was begun to examine koa and the work needed to meet the short, mid- and long-term needs for the restoration of koa forest ecosystems and the development of commercial koa plantations. Obviously developing a way to minimize the impacts of the *F. oxysporum* wilt would be necessary if these initiatives were to be successful.

One of the most important defense mechanisms to a disease caused by any fungus is genetic resistance. The very large differences noted in survival (4.0 to 91.6%, 48 months after planting) of a koa seed source field trial planted in 1999 at HARC's Maunawili Research Station provided us with an indication that we would be able to find the genetic resistance to koa wilt needed for future restoration and reforestation needs. In 2003, Nick Dudley and Richard Sniezko outlined a long-term strategy for exploring and utilizing genetic resistance to koa, including integrating other components of tree improvement such as the development of seed zones. The program was patterned after disease resistance programs with other tree species that were already being conducted by the USDA Forest Service's Pacific Northwest Region. Over the succeeding years, a core team of scientists and foresters were utilized to implement different phases of the strategy and to refine it further (Dudley et al. 2012, 2015, 2017).

Figure 1: High surviving, high growth Seedlot #4 in 1999 koa progeny test at Maunawili (8/2013)

A first step in the koa resistance program was to develop a system to rapidly screen koa trees for their genetic resistance to koa wilt. This was accomplished, using young seedlings of individual koa parent trees and subjecting them to inoculum of *Fusarium oxysporum*. In the first resistance trial, in 2007, the seedling progeny of different parent trees varied in mortality from 4.2 to 91.7%, 90 days after seedling inoculation. By 2016, the progeny of nearly 600 parent trees from various koa populations had been evaluated for their genetic resistance and survival ranged from 0 to 96%, (with mean survival ~38.5%). Further screening is underway. Field trials have also been established to confirm the results of the seedling assay and to monitor the durability of resistance (Figure 1). Initial results are very encouraging as they show that seedlings from parent trees scored as "resistant" commonly survive in the field at rates of 70% or greater through year 3 (Figure 2) (Dudley et al. 2012, 2015, 2017).

Figure 2: Koa field trial being planted on Oahu in 2012. The susceptible family now has 0% survival, while the resistant families have 70% survival.

To help to the diverse environments found in Hawai'i, provisional seed zones have been devised and the first seed orchards have been developed (Dudley et al. 2012, 2015, 2017). The goal is to be able to provide land managers with seed that will produce seedlings with koa wilt resistance that is suited for the areas they are interested in planting while still maintaining sufficient genetic diversity to buffer against other any future abiotic or biotic threats to the species. In the case of koa, genetic resistance to koa wilt was the first key trait to evaluate and incorporate, but ongoing tree improvement efforts are being made to incorporate growth and wood quality components as well. The objective continues to be to develop genetically diverse and adaptable populations of koa to meet the long-term restoration and reforestation needs of Hawai'i and to make this seed available to all land managers.

Needs for the future include establishment of more field trials and orchards, additional seed collections from trees in natural stands to test for resistance, the continued development of seed orchards producing koa wilt resistant seed, and the selection for other traits of importance in koa (eg growth rate, form and wood quality). Needs also include basic research on koa to support tree improvement efforts and include improving seed production levels in seed orchards and even better nursery and silviculture practices (Figures 3 and 4). The koa wilt resistance program has made substantial progress in a relatively short period of time. Partners and cooperators will continue to be of key importance as the program advances.

Additional information on progress on the koa resistance program can be followed at the following websites:

https://www.ctahr.hawaii.edu/forestry/disease/koa_wilt.html

http://www.harc-hspa.com/forestry.html

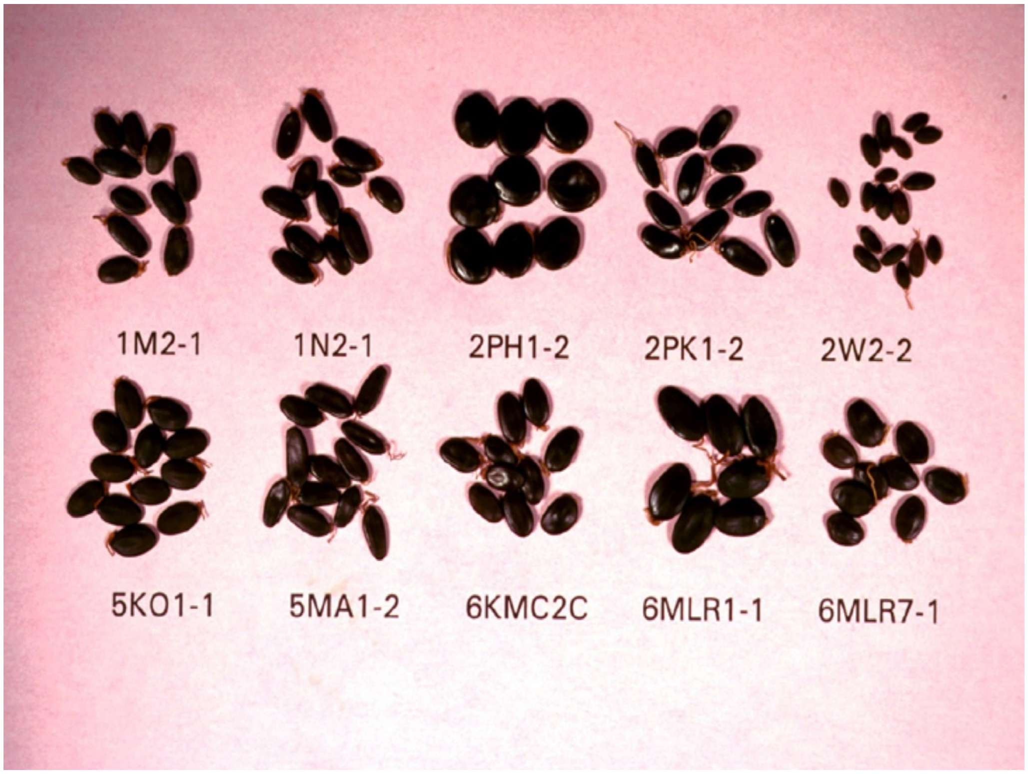

Figure 3: A range-wide collection of A. koa seed

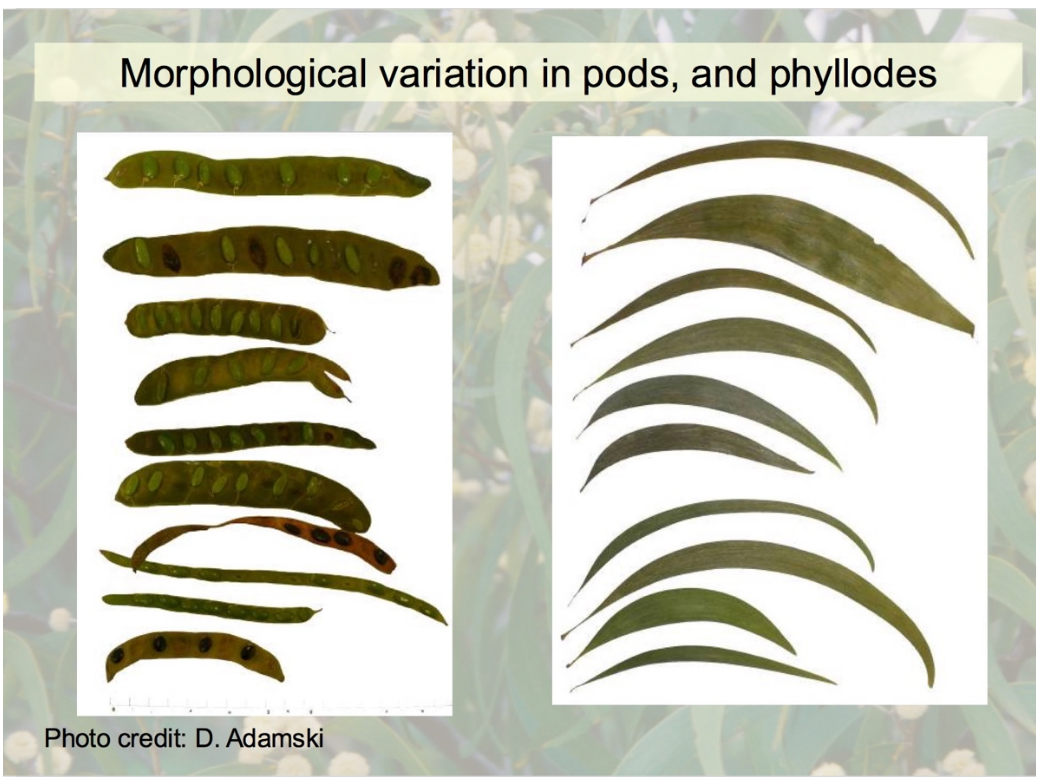

Figure 4: Morphological variation in pods and phyllodes

Acknowledgements

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TREE IMPROVEMENT

DEVELOPMENT OF PRELIMINARY SEED ZONES FOR KOA

Christina Liang, Ph.D. (USDA Forest Service, Institute of Pacific Islands Forestry), Jessica W. Wright, Ph.D. (USDA Forest Service, Pacific Southwest Research Station), Nick Dudley (Hawai‘i Agriculture Research Center), and Paul F. Gugger, Ph.D. (University of Maryland Center for Environmental Science, Appalachian Laboratory)

Paper Title: Koa seed zones: What do we know? What do we need to know?

Abstract

Acacia koa A. Gray (koa) exhibits a high degree of phenotypic variation, and understanding the underlying natural genetic variation that currently exists in the species has applications for conservation, restoration, and reforestation. Understanding the genetic variation also can be helpful in identifying and refining seed zones for koa that can be used for these multiple purposes. A seed zone is a single geographical or ecological unit within the range of a species based on ecological and genetic criteria. Ideally it allows for the identification and selection of high quality seed sources for planting efforts. A general seed zone map (used for multiple species) has been developed for many regions of the United States; seed zones can be further refined for individual species based on additional genetic or ecological information. A general seed zone map does not currently exist for Hawai‘i, nor does a seed zone map specifically for koa. Our goal in this study is to provide a framework to identify and guide the development of koa seed zones throughout the state of Hawai‘i.

Koa is found in a wide range of environments that include subalpine, montane, wet and lowland forest eco-zones. It is found naturally on all the main Hawaiian Islands except Ni‘ihau and Kaho‘olawe, but contiguous and dense forest is generally only on Hawai‘i, Maui, O‘ahu, and Kaua‘i. Because of the high variability in koa, the current recommendation is to plant locally-sourced seed to ensure the high quality of seedlings. The question arises, however, of “how local is local?” Seed or planting zones for koa are not well defined, partially because of the limited information available on koa population genetics.

To start to address this question, we sampled 311 koa trees from across the 4 main islands in order to study the naturally occurring genetic variation within the species. We sequenced the DNA and obtained 11,002 diallelic single-nucleotide polymorphisms (SNPs) using the next-generation genotyping-by-sequencing (GBS) method. SNPs are molecular genetic markers and are found throughout the genome in both coding and non-coding regions. We used the SNP allele frequency to calculate pair-wise F_{ST} values for preliminary seed zones that we first identified. F_{ST}, known as the fixation index, is a common metric used in population genetics to measure the amount of population differentiation due to genetic structure. We also used the SNP data to estimate genetic clusters using the Admixture program, which estimates individual ancestries based on maximum likelihood. While calculation of F_{ST} in tetraploid species such as koa using SNP data that are coerced to be diploid can be problematic, as assumptions about allele frequency calculations are not necessarily met, our goal is to compare the relative differences between preliminary seed zones. We believe that the assumptions about allele frequency are reasonable given the large number of SNPs, and the mechanism of inheritance in koa likely does not vary across regions.

We preliminarily defined seed zones for the state based on eco-regions. Zones first were proposed for each island, and then by aspect within each island which was generally windward and leeward. Elevational sub-zones then were defined, with low elevation from sea level to 600 m (1968 ft) elevation, mid-elevation from 600 m to 1200 m (1968 ft to 3937 ft) elevation, and high elevation from 1200 m to 1800 m (3937 ft to 5905 ft) elevation. Zones for special situations also were defined, such as for the koai'a population in north Hawai'i and the lowland population in west Maui. Once the eco-region seed zones were defined, we assigned these zones to the trees that we sampled for our GBS analysis. We identified 10 seed zones from our samples. We then calculated the pair-wise F_{ST} values for these seed zones using the SNP allele frequencies. Results from this analysis showed the highest levels of differentiation between the Hawai'i and Kaua'i populations, which also are the most geographically and chronologically distant. Lower differences within islands were found, with the greatest difference between the two Maui seed zones and smaller differences between the Hawai'i island seed zones. Overall, these results suggest that there are genetic differences between all four main islands as well as within each island.

As an exploratory analysis of genetic structure in relation to eco-regions, we modified the seed zones on Hawai'i and Maui based on our genomic data. We used the SNP data to estimate genetic clusters using the Admixture program, and assigned individual trees on Hawai'i and Maui to the cluster from which they derived their highest ancestry. We recalculated the F_{ST} values using these modified seed zones, and found a higher level of differentiation within each island using the modified seed zones compared to the seed zones defined by eco-region alone.

The seed zones we identified are preliminary, as further analysis is needed to better define the actual zones. However, our goal with both the eco-region seed zones and the eco-region plus genomics seed zones is to show that there is genetic differentiation between and within islands, especially within Hawai'i island. We suggest that further refinement of preliminary seed zones is necessary to account for the genetic differences, as the location of origin of koa trees within islands appears to be associated with genetic differentiation. This provides the basis for further koa seed zone development based on genetic characterization and environmental variation.

Looking forward, we suggest further developing seed zones for koa. In general, there are three types of data that can be used to define seed zones: (1) environmental or ecological data, such as climate and geography, (2) quantitative genetic data that identifies heritable traits, such as the information gained from common garden experiments, and (3) molecular genetic data that identifies DNA sequences, such as SNPs or microsatellites. Research in all these areas would help to refine koa seed zones across the state.

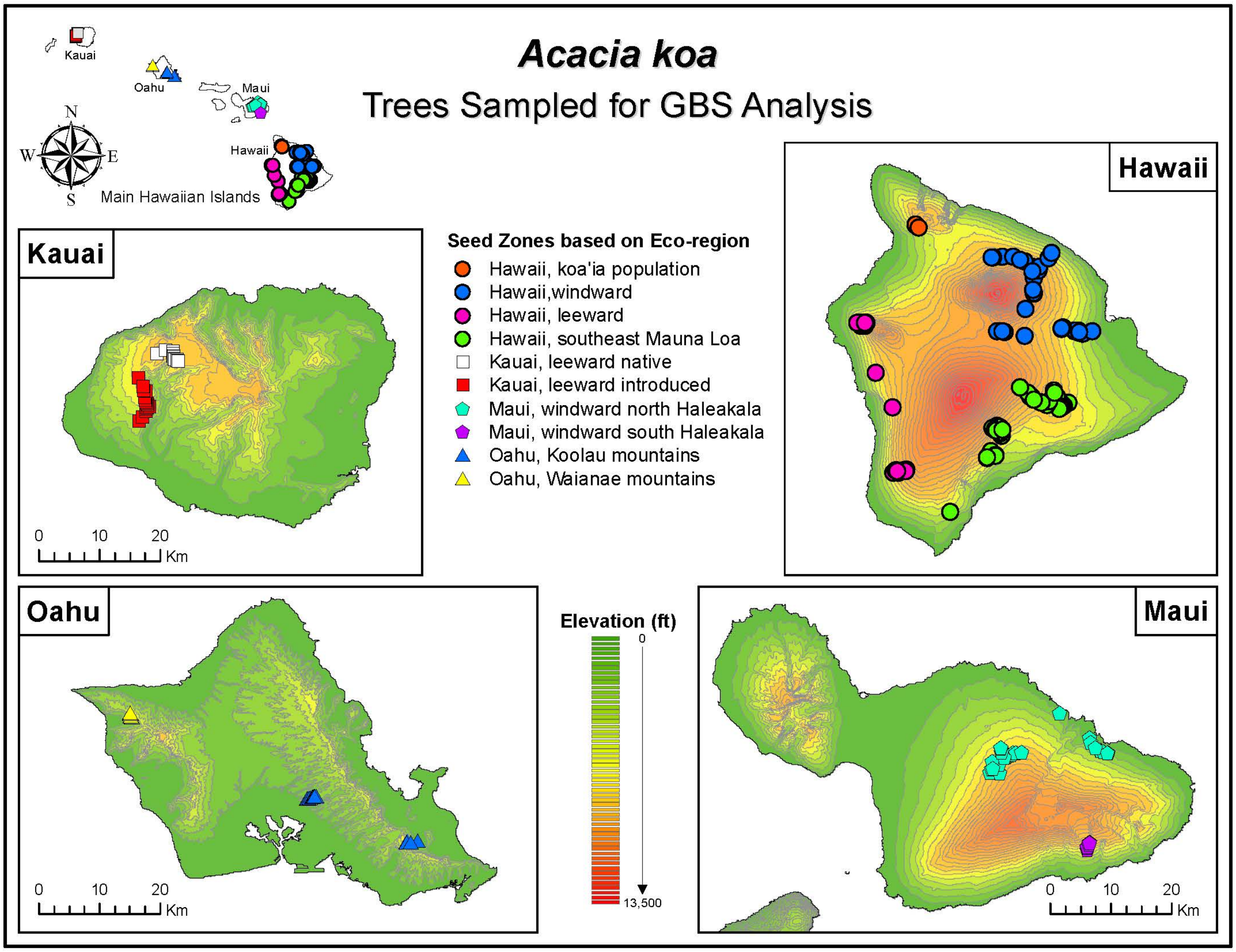

Figure 1: Preliminary *Acacia koa* Seed Zones based on Eco-region

TREE IMPROVEMENT

DESIGNING A LONG-TERM TREE IMPROVEMENT PROGRAM FOR KOA

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Paper Title: Making a Good Tree Better: How to "Improve" *Acacia koa* Through Traditional Selection and Breeding

The primary goal of a tree improvement program is to develop seed orchards that produce quality seed for reforestation. Tree improvement programs start by selecting trees from natural populations. Seeds of various mother trees are collected and tested in common gardens to determine their relative worth. Tree improvement programs have been successful at improving the quality of seed from native trees with high ecological value as well as for commercial species and are highly applicable to *Acacia koa* in Hawai'i.

Tree planting in Hawai'i dates back to the early 1900s, but attempts to make genetic improvements originated in the late 1980s. The prior work of Brewbaker, Sun, Dudley, Krauss and others demonstrated that traits are heritable, and resulted in the establishment of common garden tests at multiple sites across Hawai'i. Most common gardens utilize a multi-site, randomized complete block design so that each genetic family (trees that share a common mother) experiences the full suite of environmental conditions within a given site and across sites to enable calculations of genotype by environment (gxe) interactions. This 'gxe' interaction is useful to test whether families are broadly adapted (no gxe interaction), or adapted to specific sites or conditions.

How do we select genotypes from a common garden study for inclusion in a seed orchard? Traits are assumed to be normally distributed, but binary traits can be incorporated as well. Traits that are skewed can either be transformed or analyzed non-parametrically. Breeding values, akin to a least-squared mean for each family, are calculated. The orchard manager chooses a threshold value: all families exceeding the threshold breeding value are selected for a new orchard. By selecting from one end of the distribution, we can shift the mean in one direction provided that the heritability exceeds zero. The extent of improvement from selection is measured with the "breeders' equation," which measures the response (expected change in mean) to selection. The response, or genetic gain, is symbolized as Delta G, ΔG (Δ= Greek Delta, or the change, G=gain).

Genetic gains can be calculated as the product of the phenotypic standard deviation (how much variation is present in the trait), the heritability (the percent of similarity among half sibs), and the selection differential (i), expressed as the number of standard deviations beyond than the mean.

Genetic gains are expressed in the same units as the trait. For example, if $\Delta G = 1.05$ meters in height, then selected families are expected to be 1.05 meters taller than the unselected sources at that age. Usually, ΔG is expressed as a percentage of the mean for simplicity. Heritability values in a high elevation population of *A koa* at nine years ranged from 0.1 (height to first fork) to 0.9 (survival) (Krauss 2013). Straightness and branch angle were lower than diameter and height, but greater than 0.1. In recent years, a program to improve resistance to wilt disease has been developed with promising early results.

A tree improvement program that incorporates multiple traits requires a large base population. When multiple traits are desirable for inclusion, genetic correlations between trait pairs are necessary to calculate possible tradeoffs. In other words, improvements for one trait (for example height) could be in tandem with frost resistance (positively correlated), in which case trees that are tall may also contain frost resistance. Alternatively, if genetic correlation between traits are negative, then the breeder must choose one trait over the other. In the example provided, stem straightness was correlated positively with basal diameter, implying that selection for *A koa* that combine both good diameter growth and straightness is possible.

Tree improvement programs require a great deal of coordination to succeed. These programs are often administered in a cooperative model to facilitate a standardized strategy for record-keeping, and regular communication among vested cooperators. Coordination between silviculturists and geneticists is necessary to ensure that genetic gains in progeny tests are expressed in actual field settings. Since koa seeds can be stored for many years, progeny tests should contain a large number of families replicated across a range of elevation and climate gradients. Orchards should be developed for different seed zones, largely based on elevation gradients. Lastly, nursery growing practices should be optimized so that planted trees are as healthy and vigorous as possible when planting.

Figure 1: Eight-year-old *Acacia koa* seed orchard (HARC A) on Mauna Kea at initial planting density before thinning.

Figure 2: Nine-year-old *Acacia koa* seed orchard (HARC A) on Mauna Kea after 90% of the individual trees were removed to keep the top half of all families planted and top tree in each family.

ECOLOGY AND ECOPHYSIOLOGY

ADAPTIVE SIGNIFICANCE OF CHANGES FROM TRUE LEAVES TO PHYLLODES IN KOA

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Paper Title: Adaptive significance of changes from true leaves to phyllodes in koa from ecophysiology to management: the significance of heteroblasty in koa

During the first months to years after germination, koa (*Acacia koa* Gray) leaves transition from bipinnately-compound and horizontally-oriented true leaves to vertically-oriented phyllodes. Previous work has elucidated the similarities and differences between the two. They are similar in gas exchange rates and plasticity of photosynthesis in response to light availability (Walters and Bartholomew, 1990; Pasquet-Kok et al, 2010), but the horizontal orientation of true leaves in the juvenile phase allows for higher amounts of light capture in partially shaded conditions. They differ in their capacity to withstand drought conditions; phyllodes exhibit more stomatal control, reducing stomatal conductance with reducing soil water potential, and are able to maintain photosynthesis at lower soil water potentials than can true leaves (Pasquet-Kok et al, 2010). These results have led to hypotheses that true leaves are adapted to partial shade and phyllodes, to drought and full sun conditions. This has been supported by unpublished data (Walters and Bartholomew) suggesting that koa would not transition at light intensities below 70% full sun. Past research, however, demonstrating differences in the rate of transition in response to light (Walters and Bartholomew, 1990) and between koa from different islands (Daehler et al, 1999) suggests that, although similarities and differences between the leaf types have been described, the adaptive significance of heteroblasty (two or more leaf forms during development) in koa has not been characterized.

In order to address these knowledge gaps, we have conducted a series of studies. First, we investigated the influence of light intensity, light quality, water availability, and population on the rate of transition. We also tested whether the transition trigger was chronological in nature (e.g. days since germination) or a function of body size (e.g. total dry biomass). Finally, we aimed to characterize effect of the treatments on the phenotype at the time of transition. In order to do this, we conducted a split-plot experiment where light was the whole-plot factor with four levels (FULLSUN, 70% FILM, 25% FILM, and 25% CLOTH; the red to far-red ratio (R:FR) and light intensity were reduced with the neutral density film (Lee Filters, Hampshire, UK) and was reverted to full sun R:FR with shade cloth) and reduced water availability, the sub-plot factor. Two populations were included in the study: Honomolino and Umikoa from a dry and wet site, respectively. At the time of transition, when at least one fully-formed phyllode was formed, the seedling was harvested measured for a host of morphological parameters expected to vary in response to light intensity and quality. We hypothesized that the rate of transition would increase with greater light intensity, an elevated R:FR (a light quality ratio reduced by photosynthetically active radiation passing through leaves and signals to plants the presence of a canopy (Tao et al., 2008)), and reduced water availability. We also hypothesized that the dry site population would transition more quickly than the wet site population. Preliminary results suggest that the rate of transition is dependent on perspective. From a chronological perspective, the rate of transition increased significantly with increasing light intensity. Water availability did not have an effect, but the dry site population transitioned more quickly than the wet site population. From the perspective of body size, however, light intensity did not affect the timing of transition. Water availability did affect timing, however, with the reduced water transition treatment resulting in trees transitioning at a smaller body size. The population effect also disappeared when looking at transition rates as a function of total biomass. We were not able to detect a significant light quality effect on the timing of transition, although this might have been because the trees outgrew the greenhouse, eliminating the potential to observe the final number of transitioning individuals in the lowest light treatments. Light quality had a significant effect on the phenotype, where the height to the first branch and slenderness (height:basal diameter) were significantly increased for the 25FILM relative to 25CLOTH. Light intensity also influenced the phenotype; reduced light intensity reduced allocation to root biomass relative to shoot and leaf biomass and had the opposite effect on shoot biomass, in which the 25FILM and 70FILM treatments were significantly different than the FULLSUN treatment, but the 25CLOTH treatment was not. These results suggest the rate of transition in plastic in response to light availability; shade-adapted true leaves can be retained with decreasing light intensity. In spite of transitioning at equal rates in response to light intensity as a function of body size, the resulting phenotype is significantly different between light treatments at the time of transition. These phenotypes are consistent with traits associated with increased adaptiveness to the light treatment conditions (Forster and Bonner, 2009; Forster et al., 2011).

We also wanted to verify whether the disparate phenotypes in response to light availability were consistent with koa responses to shade in field plantings. Moreover, we asked whether these phenotypic responses could be harnessed by silviculturalists to improve the form of koa in plantations and managed forests. Results from two plantings on Hawai'i Island suggest that canopy architecture interacts with the shade avoidance response (Tao et al., 2008). In one planting, where two populations were planted under a variable canopy of koa at Pu'u Wa'awa'a, transition at one and a half years was delayed, and slenderness increased, by increased shading, but survival decreased concurrently. Survival was under 25% in the most shaded planting locations and above 85% in the most open planting sites in the absence of rust infection. These results suggest that the adaptiveness of plasticity of transition and phenotype in response to shade is limited. Our results from another study at Humu'ula on the Big Island, where koa was planted between rows of sugi pine (*Cryptomeria japonica*) with a clear path to the canopy, suggest that these plastic responses are can be adaptive to gap conditions, rather than partially shaded conditions. At Humu'ula, survival after one and a half years was not significantly affected by shade, but height increased 100 cm (39.37 in) in the most shaded planting sites when combined with fertilization. Future work at Humu'ula will assess the long-term effects on form.

The results from these three studies suggest that koa's response to partial shading is an adaptation to gap-regeneration and recruitment. The factors affecting the timing of transition, however, are not fully elucidated. Our evidence suggests an interaction between the microclimate and the provenance of the population. The factors instrumental in triggering transition, moreover, are dependent on perspective. These results have the potential to influence nursery culture of seedlings before outplanting, allowing for improved tailoring of the seedling to the planting site. They also have applications for design of koa plantations and restoration sites. Finally, further research comparing abiotic triggers of transition using populations across a range of ecoregions could improve our understanding of the adaptiveness of heteroblasty and the plasticity of phase change.

Figure 1. One-year-old *Acacia koa* seedings planted in partial shade of sugi pine (Cryptomeria japonica) at Humuʻula on Mauna Kea, Hawaiʻi Island. Seedlings increased in height when fertilized and grown in partial shade. The seeding in the foreground still has juvenile leaves while the seeding in the background has transitioned to mature leaves (phyllodes).

ECOLOGY AND ECOPHYSIOLOGY

STATE AND TRANSITION SIMULATION MODEL (ST_SIM) CURRENT / POTENTIAL LANDSCAPE DISTRIBUTION OF KOA AND ASSOCIATED CARBON DYNAMICS

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Paper Title: The potential carbon benefit of reforesting Hawai‘i Island non-native grasslands with endemic *Acacia koa* trees

Background/Question/Methods

Large areas of forest in the tropics have been cleared and converted to pastureland. Hawai‘i Island is no exception, with over 100,000 ha of historically forested land now dominated by non-native grasses. Passive forest restoration has been unsuccessful because these grasslands tend to persist even after grazers have been removed, yet active outplanting of native tree species can be cost-prohibitive at the landscape scale. It is therefore essential to seek co-benefits of forest restoration to defray costs, such as accredited carbon offsets from increased carbon sequestration. We developed a reforestation scenario for non-native grasslands on Hawai‘i Island by outplanting endemic koa (*Acacia koa*) trees paid for with carbon offsets via the California Cap and Trade Program. This scenario entails reforesting 53,531 ha of non-native grassland at 2500 ha y^{-1} over 22 years. We estimated planting costs at \$6,178 ha^{-1}, a total cost of approximately \$331,000,000. We used the Land Use and Carbon Simulator (LUCAS) model to estimate island-wide ecosystem carbon sequestration with and without koa reforestation using 100 Monte Carlo simulations per year over a 60-year period. Income from carbon offsets was set at \$13.57 per ton of CO_2 equivalent, the current California Cap and Trade Program carbon market price.

Figure 1: Koa reforestation on Mauna Kea, Hawai'i Island

Results/Conclusions

Koa reforestation on Hawai'i Island was projected to increase island-wide annual net ecosystem production (NEP) by two to four times, with a peak in annual NEP two years after the entire 53,531 ha planting area had been reforested (simulation year 24). During this peak year, terrestrial ecosystems of Hawai'i Island were projected to sequester 422 kilotons of carbon (>1.5 million tons CO_2), approximately 60% more than projected with no reforestation. Also during that peak year, the koa reforested area alone was projected to offset 5% of statewide CO_2 emissions. Reforestation of non-native grasslands to koa forest on Hawai'i Island sequestered a total of 25 million tons of CO_2 over the entire 60-year simulation period, providing a projected total income of ~$340,000,000 at the current California Cap and Trade Program market price. Although this income from carbon offsets would cover all original planting costs, incorporating projected costs of financing, verification audits, and ungulate fencing would render such a large-scale restoration effort far from profitable. Nevertheless, our results demonstrate that koa reforestation of non-native grasslands on Hawai'i Island would greatly increase ecosystem carbon sequestration, and that a substantial portion of landscape-scale reforestation costs could be defrayed through accredited carbon offsets.

ECOLOGY AND ECOPHYSIOLOGY

INFLUENCE OF RESTORED KOA IN SUPPORTING BIRD COMMUNITIES

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Paper Title: Forest restoration for wildlife: *Acacia koa* in Hawaiʻi

Extended Abstract

Deforestation of Hawaiian forests has adversely impacted native wildlife, including forest birds, bats and arthropods. Restoration activities have included reforestation with the native koa (*Acacia koa*), a dominant canopy tree species that is easy to propagate, has high survivorship, and has fast growth rates. We review recent research describing the ecological benefits of koa restoration on wildlife colonization/use, plant dispersal, and native plant recruitment. In general, planting monotypic koa stands can provide forest habitats for species that need them but does not automatically lead to natural regeneration of a diverse forest species assemblage and may require additional restoration activities such as outplanting of other native plants and alien grass control to achieve more natural forest systems. Although early signs of forest and wildlife recovery have been encouraging, the goals of restoration for wildlife conservation versus commercial grade harvesting require different restoration methods.

The flora of Hawaiʻi lacks many plant groups common to other island and continent ecosystems; thus the natural vegetation, which serves as habitat for wildlife, is largely made up of relatively few dominant tree and shrub species (Pratt and Jacobi 2009). The montane mesic forests are dominated by koa and ʻōhiʻa (*Metrosideros polymorpha*), and typically occur between 1,000 and 2,000 m elevation (3,200 and 6,600 ft, respectively). Early Hawaiians extracted select koa trees from these forests but otherwise there is little evidence that they altered this habitat. After Western contact, people expanded into these forests where they established permanent agriculture fields that resulted in deforestation, erosion and conversion of many of these forests to grasslands by exotic grasses. Koa was the preferred wood for timber, and its extraction was typically concurrent with forest clearing for pasture improvement. As noted by Pratt and Jacobi (2009:146) "today, almost treeless pastures of alien grasses cover the upland slopes of windward Mauna Kea and Waimea, Hawai'i Island, as well as the west slope of Haleakalā, Maui," where koa- and koa/'ōhi'a-dominated forests were converted to pastures for livestock grazing. It is in many of these areas that forest restoration for conservation is focused.

Although historic forests were a mix of koa and 'ōhi'a, restoration of wildlife habitat has focused on koa (Price et al. 2009) because it is an easy species to propagate by seed, has high survivorship, can survive mild frost, and grows more quickly than 'ōhi'a (Yelenik 2016). Koa forest restoration methods have taken three general approaches that are dependent on the severity of degradation. The first is a passive approach that relies on the natural regeneration of native species, particularly koa, after ungulates and select alien plants have been reduced or removed. An example of this approach is the fencing and removal of ungulates in the State of Hawai'i Department of Land and Natural Resources' Kahikinui Forest Reserve and adjacent Nakula Natural Area Reserve, Maui (note: the state has recently included outplanting of native plants in this area to boost restoration). The second approach involves scarification where a bulldozer is used to scrape the surface soil to remove the dense grass cover, which leads to high density koa recruitment where seeds persists or vegetatively from adjacent living trees (McDaniel et al. 2011). This approach has been successfully applied on Kamehameha School's Keauhou Ranch and the Kahuku Unit of Hawai'i Volcanoes National Park, Hawai'i. Finally, in areas that have been heavily degraded, the planting of seedlings of canopy trees and understory species is required. This is the approach taken in the former pastures of the U.S. Fish and Wildlife Service Hakalau Forest National Wildlife Refuge, Hawai'i. An alternative objective has been to replant and manage koa as a silvicultural species for timber production following timber harvest or cattle grazing on private lands.

Through a number of surveys we are seeing two general patterns emerge as birds and insects respond to koa restoration. The colonization rate, or process by which a species spreads into restored areas, is dependent on time since reforestation and distance to intact forest. The rate is species specific with some bird/insect species able to move into the restored area rapidly when koa are still small—more shrub-like than tree-like. As time passes and the koa develop into trees, the restored areas support more species and greater numbers of individuals, presumably because larger trees are better habitat for wildlife. At both Hakalau and Keauhou we see a few native bird species using young koa, such as Hawai'i 'amakihi (*Chlorodrepanis virens*) and 'apapane (*Himatione sanguinea*), but as time passes the number of species and individuals increase (Camp et al. 2010, Paxton et al. in review). This pattern is most clearly seen in the endangered birds at Hakalau where they are absent during the first 10 to 15 years after koa planting before eventually moving into the restored areas. Sakai (1988) noted that no birds were present in the restor8ed, scarified koa area at Keauhou for the first several years, but two decades later there were approximately equal numbers of birds in the restored area as in the adjacent intact forest (Camp et al. 2010). At Hakalau, Goldsmith et al. (2007) observed that the numbers of longhorned beetles (*Plagithmysus* spp) in younger koa (3-8 yrs old) were about a quarter of the number found in older koa (12-15 yrs old). However, beetles collected in older koa in the restoration area were only slightly less abundant than those collected in the adjacent intact forest. Thus, for some species, koa reforestation areas can support similar numbers as adjacent intact forest, but other species still lag and may take much longer to colonize.

In addition to a time lag for the habitat to become suitable, the distance from adjacent intact forest plays a role. This pattern was more pronounced at Hakalau than at Keauhou due to the size and configuration of the restored areas. For example, during the first decade after planting koa, Hawai'i 'elepaio (*Chasiempis sandwichensis*) ventured no further than 1-km (0.6 mi) upslope from the forest at Hakalau. However, 25 years after the initial koa were planted, Hawai'i 'elepaio had moved more than 2.5-km (1.6 mi) upslope (Paxton et al. in review). Hawai'i 'amakihi and 'apapane also demonstrated this pattern and now occur throughout the reforested area.

Todd et al. (2016) showed that Hawaiian hoary bats occurred in remnant koa forest cleared of understory for pasture in Kahikinui FR and Nakula NAR, Maui. Interestingly, after the area was fenced and ungulates were removed, koa started to regenerate but bat occupancy declined. Gorresen et al. (2013) observed a similar pattern at Hakalau, where Hawaiian hoary bats were not common in the koa restoration area. They also observed that bat occurrence was lower in intact forest sites where koa was a dominant or co-dominant tree, even though koa hosts the koa moth (*Scotorythra paludicola*), an endemic moth that is a prey of Hawaiian hoary bats. Gorresen et al. speculate that "koa does not offer sufficient shade cover for day-roosts, and may not be sufficiently important in affecting overall prey availability other than for brief periods and episodic koa moth outbreaks." Thus, Hawaiian hoary bats appear to require a more diverse habitat than provided by koa dominated forests.

An important goal of habitat restoration for wildlife is the rapid progression from young pure koa stands to a dense forest consisting of an understory of native shrubs, and a subcanopy and canopy of koa and other native trees. This forest composition and structure would offer varied resources (nesting and foraging sites, prey, fruits, etc.) that can support wildlife species diversity and abundance. Yelenik (2016) showed that forest succession from an early restoration community can stall when koa is the only canopy tree and the understory consists of exotic pasture grasses and scattered shrubs. Recent data has shown that there is equivalent seed rain under trees in koa restoration stands as in the adjacent forest. In addition, birds, such as the native ʻōmaʻo (*Myadestes obscurus*), are dispersing seeds from fruiting shrubs and trees into these koa restoration areas (USGS unpublished data). There was, however, almost no native seedling emergence within koa stands. Thus, the understory of exotic grasses may stifle succession by prohibiting native seedlings from establishing and growing.

In conclusion, a number of factors—lag time since restoration started, distance from adjacent forest edge, and composition of replacement plant community—influence the diversity, abundance and timing of wildlife colonization. There is a general trend toward increasing wildlife species diversity and abundance as koa stands mature and in sites close to existing forest. Seed rain surveys indicate that ample propagules are being delivered by birds to restoration stands, but native plant regeneration may eventually be limited by weeds, especially exotic grasses. To advance restoration beyond a simple koa-grass system, weed management under trees could promote the establishment of understory species being dispersed by birds. Forestry and ecosystem restoration goals may not always be in line with each other. For example, koa trees that are profitable for timber production do not necessarily benefit wildlife, and, conversely, gnarled and twisted trees that benefit wildlife are not necessarily marketable. In the end, management objectives should drive restoration methods.

Figure 1: Outplanting of *Acacia koa* seedlings in abandoned pasture areas such as this one at the Hakalau Forest National Wildlife Refuge is only partly successful in restoring wildlife habitat. At this site volunteers also outplanted native understory species such as naio (*Myorporum sandwicense*), 'ōlapa (*Cheirodendron trigynum*), and 'akala (*Rubus hawaiiensis*) to provide understory cover and food for frugivorous birds.

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