OBSERVATIONS MADE WHILE RECREATING A NATIVE HAWAIIAN FOREST

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ABSTRACT

Since 2007 staff at Limahuli Preserve have been developing practices to effectively reintroduce native plants into a highly degraded environment, creating a forest high in diversity and a safe habitat for some of the rarest plant species on the planet. Initial efforts were focused on the Limahuli Valley and limited progress was made because of the exposed conditions and prevalence of weed species. Relocation of the project to areas with tree cover has resulted in greater success. These successes have been built on to extend the project to the reintroduction of rare and endangered species. The methods used to transform a habitat where non-native and weed species dominate to one in which native, including endangered, species thrive is described. The value of staff with horticultural knowledge and experience of the habitat and climate is stated and ideas for the future of the habitat at Limahuli Preserve are given.

INTRODUCTION

Determining the success of re-establishing entire sections of native forests is difficult at a time when the ability to save rare plant species from extinction is uncertain. In 2007 the conservation staff at Limahuli – one of the five gardens that make up the National Tropical Botanical Garden (NTBG) – began a ten-year programme geared towards the complete reclamation of 4ha of invasive forest. This would require the creation of a diverse forest of native species reaching from the groundcover to the canopy. It was hoped that when completed, the Groundcover Restoration Project would not only show that it is possible to reclaim areas of Hawaiian forest that have been taken over by alien species but also that reclaimed land could provide a suitable habitat for Hawaiian plants that are no longer secure in the wild. A little more than halfway through the project, we now have a much greater understanding of the challenges that face tropical restoration. Tropical habitat restoration has been proved to be possible through the establishment of a method in which native species can outcompete alien species with the help of effective land management policies that involve: (1) inhibiting the growth of invasive species; and (2) planting native species. The implementation of this method of restoration requires a high level of awareness and experience of those working on the project, due to wide variations in soil type, moisture, invasive species density and other conditions at each site targeted for restoration.

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THREATS TO NATIVE SPECIES IN HAWAII

Hawaii is widely known for its natural and untouched beauty, exotic beaches and lush forests. It comes as quite a shock to people – visitors and locals alike – when I explain how threatened our native ecology is and that the biota that most people see in the islands is non-native. Perhaps even more surprising is that plants considered 'Hawaiian', such as pineapples and guavas, are modern introductions to the islands. Each group of people who inhabited Hawaii brought another set of introduced species with them. Alien plants and animals have been introduced for a variety of reasons over the centuries. When the Polynesians first colonised Hawaii they brought plants and animals necessary to support the health and wellbeing of an entire culture. Another batch of species was introduced to the islands when Hawaii was found by European explorers. Some of these introduced species have run rampant, both figuratively – in the case of some invasive plants that have displaced native species creating monotypic stands – and literally, as goats graze native plants down to nubs in the drier parts of the islands and pigs root around, digging up huge tracts along moist sections of the islands.

The spread of invasive species has hit Hawaii particularly hard because of the highly localised nature of native species on the islands. Many of our native taxa have incredibly limited geographic ranges, being genetically or physically isolated to an island or even limited to a single valley. Many new species of plants have been discovered within the last few decades; a lot of these species have been quite rare from the moment they were first found. When looking at the small population size and limited distribution, it is easy to see how a single event such as a hurricane or invasion of introduced species could cause extinction. This is a very critical time for conservation groups and there is a strong reason to take charge in the fight against invasive species. The perpetuation of the Hawaiian flora, preventing extinction not only of individuals but of the entire native Hawaiian ecosystem, depends on the conservation efforts of today. The problem of invasive species taking over the forest is only getting worse as the species have time to spread through the forest and increasing numbers of invasive species are introduced to Hawaii. With so many threats to our forest it is estimated that roughly half the Hawaiian flora is at risk of extinction in the next few decades (Burney, 2009).

CONSERVATION WORK IN HAWAII

Having witnessed the decline in the health of the Hawaiian forests, many groups have been motivated to take action to protect our native species. These efforts include: building fences to protect against feral ungulates (Burney, 2009); creating strike teams to prevent the spread of incipient alien species; and collecting and propagating rare and endangered species before they become extinct (DeMotta, 2010). Our current restoration efforts at Limahuli are based on *inter situ* restoration (Burney, 2009): creating a monitored and maintained population of native species in remote but accessible areas with a species list based on archaeological evidence (Burney and Burney, 2007). It is our belief that through the process of restoring invasive lowland forests into diverse native

environments, we can provide a future for many plant species whose natural habitat is rapidly disappearing.

NTBG has been working to protect and preserve the native Hawaiian flora for decades. I was first inspired to get involved with conservation after hearing the stories of Ken Wood and Steve Perlman, two of NTBG's field botanists, who had to dangle off cliffs to pollinate plants on the brink of extinction in the mid-1990s. Their dedication to the forest resulted in the discovery of dozens of new species, drawing attention to the importance of conserving the unique biota in Hawaii. The field botanists would collect seeds from wild individuals and bring them into the NTBG nursery where they would be germinated and eventually planted within the NTBG Living Collection. Some species were easily grown and quickly became secure within a horticultural context, even in cases where wild individuals dwindled or became extinct. Other species are still a challenge to propagate, requiring specific mycorrhiza to live beyond germination such as in the case of *Joinvillea ascendens*, a native rush. With the ongoing supply of plant material coming in from our field botanists and the continuing success in growing tricky native species, NTBG has been able to establish restoration projects that are ever increasing in size and diversity.

The mission of Limahuli Preserve is to protect the integrity of remnant native forests and reclaim parts of the Preserve that have been taken over by invasive species. Limahuli is the perfect testing ground for restoration practices thanks to the highly diverse conditions found within the valley and the ability to work undisturbed in relative isolation. Over the past five years, our crew at Limahuli has been developing practices to effectively reintroduce native plants into a highly degraded environment; in much of Limahuli Preserve invasive species have completely taken over, with only a few native plant individuals found per hectare. Once an area has been cleared of non-natives we can plant an array of native species, creating a forest high in diversity, and in many cases a safe habitat in which to grow some of the rarest plant species on the planet. By creating a restoration in a lowland environment, we are able not only to involve volunteers, school groups and members of the community, but also to share conservation practices with a wider group and connect people to species they never knew existed.

THE GROUNDCOVER RESTORATION PROJECT

When we first envisioned the Groundcover Restoration Project (often simply known as 'Groundcover'), the idea was a straightforward replica of the practices of our predecessors: to clear the non-native trees and shrubs and then plant a higher number of native species with a much higher density of species that would cover the ground so thickly that they could compete with the weedy species. Roughly 2ha of invasive forest received the initial clear-cut-and-plant treatment; the result was a collection of native trees spaced anywhere from one to five metres away from one another. We were inspired by seeing these young trees take hold, which allowed us to follow through with a second sweep and establish species that would create the lower levels that we envisioned in the forest.

For the first couple of years we worked between the young and scattered native trees that had been planted in the early years of our restoration efforts, trying to fill in bushes and groundcover plants that would grow with the trees and create a cohesive native system. One of the goals of the groundcover project was to see how little herbicide could be used while still creating a long-lasting restoration, so the practice of spraying foliar herbicide to control the grass was rejected. In the blazing sun we hand-weeded the thigh-high grass that covered the ground after the initial clearing of the restoration site. Using sickles to slice at the roots allowed us to slowly peel the clumps of grass back into tight rolls before hauling them to the edge of the site. This created large piles that would flatten down in a couple of months. Once the ground had been cleared of all weedy grasses we would select plants and hand-carry the trays of young plants into the Preserve, a 20-minute hike along a rough mountain trail.

Despite the installation of irrigation it was often difficult to establish many species because of the direct sun and strong winds that would whip around the exposed hillside of the restoration site. The shape and direction of Limahuli Valley causes the frequent winds to be funnelled through the valley, rolling back and forth as they sweep against the valley walls. I am sure that when the restoration location was first being selected, it was not appreciated that the site was placed at one of the windiest spots in the entire Preserve. The winds were often so strong that we could see gusts whip across the valley

Fig. 1 The peak of Maunahou can be seen from much of the restoration site frequently through heavy rainfall. Limahuli Preserve typically receives approximately two metres of rain each year. Photo: Emory Griffin-Noyes.

before they hit our site. Larger or brittle plants break easily under these conditions and exposed soil quickly dries out. Any cleared ground became loose, sloppy mud after the frequent rains at Limahuli (Fig. 1), but would dry and crack after a few days of sun and wind. These fluctuating conditions frequently stressed our new plantings, reducing our success with many species, particularly in the summer months.

There was a seemingly endless supply of grass in the seedbank of the soil. Grass sprouted quickly in the sun and we soon found that by fertilising and watering our own plants we were also giving the weeds everything that they needed. We were hard-pressed to establish enough of our own plants to inhibit the naturally more aggressive invasive species. The bright direct sun and strong wind caused many of the tree species to develop very bushy characteristics. There was no need for them to stretch for sunlight so they remained short and squat. This worked against our hope that they would grow into a canopy above the other new plants. There was no way to outcompete the alien grasses under conditions in which the weeds were biologically designed to excel. After a couple of years of hand-weeding grass from our restoration, we distressingly found thousands of new seedlings sprouting up alongside our fresh plantings – at that point we knew that we needed a new approach to restoration.

At a point of extreme frustration we did what many people do to blow off some steam – we went for a walk. Walking away from the restoration and deeper into the Preserve we found a stand of a couple of dozen native trees, which, compared to the wind-damaged remnant trees found scattered in the current restoration site, was an encouraging sign in itself. As we looked around this forested area our excitement grew just thinking about working in a restoration site that did not include a constant battle against invasive grass. At this point we revised the groundcover project so that we no longer worked in exposed and clear-cut areas, but selected dense forested areas that could be cleared of trees to a degree that we felt was appropriate.

RELOCATING THE GROUNDCOVER PROJECT

The crew were delighted that the shade from the canopy prevented the more aggressive species of grass from sprouting and taking over. For the first time in years we were able to clear and plant with regular forward momentum instead of being stuck in a constant weeding treadmill. Despite having to leave a large number of non-native trees to ensure a complete canopy we held the strong belief that competition from any of the weedy trees would be an easier fight than the grasses we had been dealing with. Over the next year we were very careful to keep the canopy intact and the ground shaded so that any grass seeds brought into the site on our shoes or clothing would not have the right light levels to thrive.

Leaving the canopy had the added benefit of creating much more stable soil conditions and the ground remained cool and moist for longer periods after each rain. The relocation of the restoration site also meant that it was no longer in the wind tunnel of the previous site and wind damage was further reduced thanks to the intact canopy acting as a buffer, protecting the understory from most of the wind.

The more hospitable conditions of this new site allowed us to establish species that we had been unable to grow in the preceding years. In previous years we had been able to plant roughly 3,000 plants annually; the new methodology allowed us to establish plants much more easily and we were able to plant nearly 9,000 plants annually. For the first time in the project our largest limiting factor was not controlling the weeds but the number of plants we could carry into the restoration site. By increasing the sheer number of plants brought into the restoration site it allowed us to have enough of the plants needed to regenerate the forest. We had species that reliably took hold and would have a strong chance of competing with invasive species and we were able to start experimenting with species that were less reliable or grew more weakly. The diversity of the restoration made a huge leap forward as we were able to take more and more chances with species that we had never worked with before.

Like any other change in practices to our restoration, it took a year or two to get a good sense of how effective the changes really were. The dense canopy inhibited the growth of weeds, but the majority of native species also had a very difficult time growing. In two years most of the native ferns were able to establish easily and in some cases spread through the site, but the bushes and trees had grown very little in that time. It is very important to remember that most of Limahuli Preserve has been completely taken over by weedy tree species. Remaining native trees have been reduced to small, isolated populations or would occur as single trees surrounded by weeds, acting as a memory of the species that once existed in the area. Discovering any naturally occurring native species within the site was so uncommon that it brought us great joy each time. Our rough estimate is that even in the 'nice' parts of our restoration there would be about 50 native trees per hectare. If we were to clear out all of the non-native trees, leaving only the few remaining native species, we would have huge open areas with a few dozen scattered trees providing little shade to suppress the grass, leaving us in the same situation that we were so desperate to leave.

REMOVAL OF THE CANOPY

With the trees overhead, the ground-level weeds were no longer a constant issue, but we were now dealing with an extremely shaded environment, so we needed to start adjusting the amount of canopy cover to give the native species enough light to grow and gain some advantage in the restoration but not enough light for the most aggressive weeds to be able to thrive in that environment. Most of the 'new' groundcover site was a thick mass of mature trees and thousands of saplings; the majority of the deep shade was created by two distinct layers of canopy. The tallest trees consisted of kukui (*Aleurites moluccana*), mountain apple (*Syzygium malaccense*) and octopus tree (*Schefflera actinophylla*), creating a patchy canopy up to 20m above the ground. The dense lower canopy was a concentrated mass of leaves consisting almost entirely of coffee (*Coffea arabica*). This visible layer of foliage, set between three and six metres above the ground, would prevent any sunlight from hitting the ground. To give an idea of how thick the coffee had

Fig. 2 Weed piles are created when areas are cleared. The ground around the piles will be heavily planted with the native fern *Microlepia strigosa*, the sedge *Machaerina mariscoides* and tree species *Polyscias racemosa* and *Hibiscus wimeae* subsp. *hannerae*. Photo: Emory Griffin-Noyes.

become in this section of Limahuli, we removed an average of 7,000 adult coffee trees each year when clearing the site. Despite having to drop each tree, cut it into moveable pieces and then haul the green waste into huge piles (Fig. 2), it was still faster than trying to compete with the grass in the previous locations. We began prioritising the removal of the non-native trees based on the threat posed by each species, compared to the quality and density of shade it provided.

By removing the layer of coffee we greatly increased the light level but still provided enough shade to inhibit the growth of the most sun-loving weeds. The dappled sun gave the new plantings enough light to be healthy and many of the native tree species responded to the moderate light levels by quickly stretching to reach the canopy, creating tall straight trunks in the process. As the trees reached up for the sun and the bushes filled in around them, the restoration started to resemble a natural forest in ways we had not seen previously. Various species started to fill in the different niches, the shade-loving ferns happily grew under the thick bushes and the sapling trees poked up above everything else.

Each time we increased the light levels we were able to grow a more diverse selection of species, however, a greater number of weeds would also be able to thrive. The selection of which trees to remove became increasingly important, forcing us to clear the forest in stages, first removing the highest priority weeds (and in some cases

that meant creating open clearings) and then selecting individual trees to cut down to achieve the exact light level that we wanted. As I mentioned before, sometimes it takes a couple of years before we see the full impact of our choices. Areas that we had cleared to what we considered at the time to be a perfect light level by previous standards started to feel dark and cramped after two years. At first we thought it might have to do with the season; we had cleared the site in the summer and so the lower light levels had to do with winter conditions.

Looking back it seems so obvious. Not only does thinning out the trees affect our new plantings and the weeds, it also reduces the competition for light for the remaining canopy trees. We had not considered how dynamic the restoration site had become. A couple of us took on the challenge of trying to predict how the various species of canopy trees would behave a year or two hence, and started clearing accordingly. For once we did not have to make a drastic change to our practices but just had to refine how many trees we would need to cut down for the specific conditions of each year's work. One of our long-term volunteers commented on our most recent approach to creating the ideal light level, saying: "You cut 'til you think you've cut too much … then you cut a bit more." This approach always seems a bit drastic at first, but after six months when the trees had flushed out and the shaded areas between the trees moved closer and closer to one another, we knew that we had left enough. Perhaps we had even left a couple of trees too many? As we looked up at the canopy and saw the light filtering down, it felt a lot less like science and a bit more like art.

We started examining the conditions of each hill and swale, having to tweak light levels and species planted to maximise growth in the considerably different areas found within a couple of dozen metres of each other. Each year the site may have several microclimates to be considered; the process of re-vegetating a perennial spring is very different from planting in between boulders and we had to take on the challenges of both within months of each other. Some parts of the restoration area were covered in large rocks, making it easy to weed them and keep them cleared, but there were fewer places to plant. In these areas we learned that we could establish our plants most easily by creating higher light levels and that we should plant proportionally more trees and bushes. By utilising fast-growing shrubs to quickly grow up around the rock and having very little available soil accessible to the weeds, our 'sunny' zones were able to flourish with much less maintenance than any of the 'grassy' zones.

Perpetually moist zones were given the opposite treatment, leaving a higher degree of nursery trees (non-native species which were left temporarily) to greatly reduce the growth of weeds while the slower-growing ferns and sedges could fill in the understory. As the groundcovers filled in we were able to increase the light levels and introduce more sun-demanding bushes and trees. If we accidentally dropped a tree on a patch of ferns there was typically little damage done and in some cases it would actually clear a little spot that we would fill in with a tree or bush.

In every case the canopy trees continue to grow no matter how carefully we remove the layers of nursery trees, and so there is an ongoing process of removing trees as the

light level slowly decreases. The trick to success was to match the appropriate native species that would fill in the gaps we created in removing the alien trees and at a pace that meant we were able to meet our goals.

USING RARE AND ENDANGERED PLANTS IN THE RESTORATION PROCESS

Now that we had created a relatively stable forest our next step was to start incorporating a higher degree of rare plants, many of which are not being grown in any other place on earth. The years of playing around with site selection and species composition had given us a lot of anecdotal evidence of which groups of plants we were able to grow and how much maintenance each type would require. In 2012, 9,000 individuals of approximately 100 different species have been planted in the Limahuli Preserve. Twenty-four of these 100 species are endangered.

Increasingly the restoration took on the role of safe haven for many species on the brink of extinction. One group of such plants is the genus *Cyanea*. This genus is in Campanulaceae, sub-family Lobelioideae, referred to as lobeliods. They form the largest genus within the Hawaiian flora, and a huge number of them are becoming incredibly rare or are already extinct. We are particularly attached to these plants, since it was only a few years ago that we watched as one of these species died out.

The case of *Cyanea kuhihewa* serves as an ongoing reminder to us at Limahuli of how serious the threat of extinction is and how quickly it can happen. This species was discovered in a very remote section of Limahuli Valley in 1991. The tiny population size, limited range and difficulty of access put its future at risk. Seeds were gathered from the last wild individuals before the wild population finally disappeared because of initial damage from Hurricane Iniki (1992) and the lingering impact the severe storm had on the habitat. The seeds were grown in the NTBG greenhouse but in 2007, an unknown disease hit the only horticultural collection of *C. kuhihewa*, killing the last individuals. It was added to the list of endangered species in 2010 (US Fish and Wildlife Service, 2012), years after the last known individuals had died.

When *Cyanea kuhihewa* became extinct the groundcover project was still in its fledgling stages and was not set up to handle such rare species. It has been a major goal of ours to create a sufficiently stable environment for our plants so that we could start to incorporate rare plants and thus prevent similar extinctions. In 2010 we started extensive work with a couple of common *Cyanea* species to explore the feasibility of using the groundcover project as a destination for some of the rarer species (Fig. 3). After a couple of hundred individuals had established and began setting fruit, we knew that we were approaching our goal.

In 2012 we started planting *Cyanea rivularis* (Fig. 3) within the groundcover project. This species has been reduced to six mature individuals discovered by the author and confirmed by Wendy Kishida (Kishida, pers. comm.) in a stream in the valley next to Limahuli (Hanakapiai). This marked the first time that this species had been cultivated and set in any sort of restoration or wild habitat. In the six months since we have started

Fig. 3 *Cyanea rivularis*: this species has been reduced to six mature individuals in a stream in the valley next to Limahuli. Over 50 individuals have been planted as part of Groundcover in 2012 and 20 of them have flowered and set fruit. Photo: Emory Griffin-Noyes.

working with this species we have been able to establish over 50 individuals, 20 of which have flowered and set fruit. It is too early to know if we will get viable seed this season, but based on the high level of success in keeping this species alive in the nursery and restoration site we are confident that we will see these plants reproducing in years to come.

UTILISING HELPING HANDS

The amount of physical work required to clear out invasive species, establish native plantings and continue to hand-pull weedy sprouts in the restoration far exceeds what our small crew can accomplish each year. It is with the help of dozens of volunteers, contributing thousands of hours, that we are able to meet our goals each year (Fig. 4). Our volunteers range from one-time visitors, often tourists on vacation, youths on a school field trip or community service project, to weekly or even twice-weekly regulars. Each type of volunteer brings something different to the restoration. We have had visitors who have previous experience and bring applicable practices that are being used for conservation work on the US mainland or beyond. After years of experience in the restoration our regular volunteers have become highly skilled at plant identification and restoration practices to a point that they have our complete trust in working with incredibly rare and sensitive species. Some of the most rewarding days are when we can

work with local children and teach them about the forest and the responsibility we all have to protect it. The vast majority of people (students and adults alike) are unable to name five native Hawaiian species – even naming three is a stretch – and so it is very important for us to teach others about these unique species and the need to work for their preservation. It has been a real joy educating friends or running into previous volunteers along trails and witnessing how much more aware of their natural environment they have become thanks to their experience volunteering at Limahuli.

> *As a visitor to Kauai I used to marvel at the beauty of the plants but it was only after moving to the island and volunteering at Limahuli Preserve that I realized how much effort goes into the preservation of native species. Learning about how endangered many of the Hawaiian plants have become it's very rewarding to know that I can be part of the solution by clearing out invasive species and making a native forest in its place.*
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> Frank Witman, Volunteer, August 2012

The conservation efforts at Limahuli reach far beyond preserving individual species or recreating a forest; they also include passing on knowledge so that the importance of these species and forests will be cherished for generations to come. More information and images of the environment at Limahuli can be viewed on a short video made by staff and friends at NTBG at: http://vimeo.com/30416724

Fig. 4 A group of volunteers discuss the day's work plan to remove *Coffea arabica* (coffee) trees from the site. Note the stark contrast in light levels between the areas where the coffee persists and where it has been removed. Photo: Emory Griffin-Noyes.

CONCLUSIONS

Much of the long-term success that we can expect for this species is thanks to the safe habitat that has been created through the groundcover project. The groundcover restoration is much more than an effort to reclaim the forest in the name of native species; it also provides hope for many species that are being threatened in their wild state by invasive species and loss of habitat. It has been many years in the making, and has entailed learning from failed attempts, but every year we end up with a forest that is more stable and diverse than what we were able to produce in previous years. Our last goal with this project is to keep improving on what we know, providing more and more species with a place where they can proliferate for generations to come.

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