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Interactions Between Fire and Nonnative Species in Hawaiian Forests and Shrublands

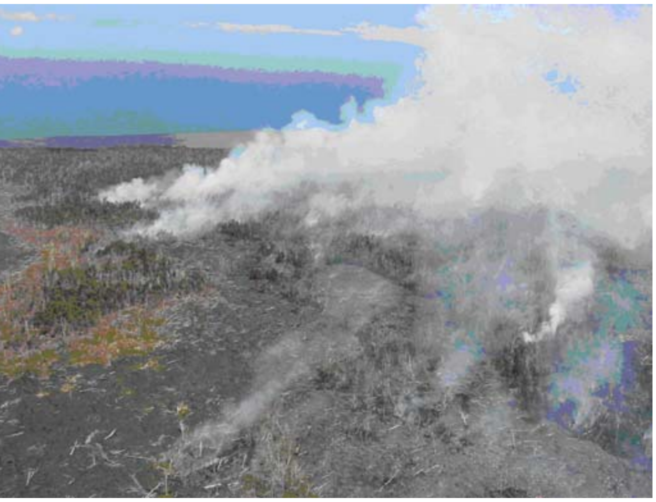
By Alison Ainsworth[1], J. Boone Kauffman[2], and Creighton M. Litton[3]

The effects of nonnative species in Hawai‘i on fuel properties, fire behavior, and post-fire plant community composition are poorly understood. While wildfires occurred historically in all Hawaiian forests, they were infrequent in wet forests, likely occurring only every 700-1,000 years (Mueller-Dombois *et al*. 1977). However, the occurrence and intensity of wildfires is projected to increase in Hawai‘i, and throughout the tropics, as a result of: (1) nonnative, invasive species that alter fuel loads and fire behavior (LaRosa, *et al*. 2008); and (2) increased temperatures and/or decreased precipitation from global climate change (Clark 2007). Importantly, fires may create conditions that facilitate the establishment of nonnative species in sites previously dominated by native forests. Once established, these invasive species can slow or alter the recovery of native Hawaiian forests by creating a positive feedback loop between invasion and fire (D’Antonio and Vitousek, 1992).

We documented the post-fire survival and establishment of native and nonnative plants for two years following the 2003 lava-ignited wildfires in Hawai‘i Volcanoes National Park on the Island of Hawai‘i (Figure 1). These fires burned across a steep environmental gradient encompassing two recently burned shrub-dominated communities (formerly woodlands) and three ‘ōhi‘a (*Metrosideros polymorpha*) forest communities (Figure 2). We established replicate plots in burned and unburned areas of the following plant community types: (1) native shrubland with nonnative grass understory, (2) native shrubland with nonnative sword fern (*Nephrolepis multiflora*) understory, (3) native ‘ōhi‘a mesic forest with nonnative sword fern understory; (4) native ‘ōhi‘a mesic forest with native uluhe fern (*Dicranopteris linearis*) understory; and (5) native ‘ōhi‘a wet forest with a subcanopy of native tree ferns (*Cibotium glaucum*). In each plot we quantified species richness (number of plant species in each plot), percent understory cover (< 2m), shrub and tree density, and, for trees, diameter, mortality, mode of sprouting, and sprout volume. In addition, we quantified fuel and microclimate variables, and modeled fire behavior for the native ‘ōhi‘a mesic forests with both a native and nonnative fern understory (#s 3 and 4, above).

Fires were stand replacing, with >95% of the dominant canopy ‘ōhi‘a trees top-killed. Despite the high canopy mortality, 57% of these trees survived fire vegetatively via basal sprouting. ‘Ōhi‘a survival differed among size classes such that smaller trees (diameter at

Figure 1: New lava flows from Kilauea Volcano provided the ignition source for the Luhi wildfire in 2003 at Hawai‘i Volcanoes National Park. Photo provided by Hawai‘i Volcanoes National Park.



▲ Figure 2: Wildfire burned over 2,000 hectares across a steep environmental gradient in Hawai'i Volcanoes National Park in 2003. Photo provided by Hawai'i Volcanoes National Park.

In addition to 'ōhi'a, 18 native Hawaiian tree, shrub, and tree fern species persisted in the post-fire environment via basal sprouting, epicormic sprouting, and/or seedling establishment.

breast height < 20 cm) were more likely to sprout than larger trees. In addition to ‘ōhi‘a, 18 native Hawaiian tree, shrub, and tree fern species persisted in the post-fire environment via basal sprouting, epicormic sprouting, and/or seedling establishment. Importantly, 17 of the 29 native woody species present in the study sites prior to the fire colonized the post-fire environment via seedling establishment (Ainsworth and Kauffman 2009).

Context-specific factors such as community type also greatly influenced individual plant recovery following fire. Although ‘ōhi‘a survival was similar across forest communities, sprout growth following fire varied greatly, primarily as a result of post-fire invasion by nonnative species (Ainsworth and Kauffman *In review*). The native uluhe mesic forest community had greater basal sprout volume, due to faster sprout growth, two years following fire than the nonnative sword fern and native tree fern forest communities (Figure 3). ‘Ōhi‘a tree recovery via sprouting in the two latter forest communities was likely limited by the widespread regrowth and invasion of nonnative ferns and grasses in the understory following fire (Figure 4). In the nonnative sword fern forest, sword ferns recovered rapidly and reoccupied >80% of the forest floor within one year following fire. In the native tree fern forest community, the pre-fire understory was relatively sparse (<25% cover), presumably due to low light levels under the dense tree fern canopy. However, after fire, invasive grasses quickly colonized and dominated the understory with >80% cover (Figure 4). These results indicate that the widespread occurrence of invasive ferns and grasses following fire likely hinders the post-fire development of native species in these communities via competition for limiting resources such as light and soil nutrients.

Once established, nonnative understory species can also change fire behavior. Using the BehavePlus fire modeling system (Andrews 2008) and *in situ* measurements of fuel loads and microclimate, fire behavior was modeled in mesic forests that differed in understory dominance (native (DF) *vs*. nonnative ferns (NF)). Both of these forest types have very high understory fuel loads (up to 70 metric tonnes/ha, associated primarily with live and detrital fern biomass) that result in model predictions of intense (>90,000 kW/m) and rapidly spreading (>30 m/min) fires under a scenario of ideal microclimatic conditions for fire occurrence (high temperatures, high wind speeds, and low relative humidity). While fire was predicted to burn 19% more intensely in forests with understories dominated by native ferns, forests with understories dominated by nonnative ferns resulted in a 26% increase in modeled spread rates and total area burned (Ogle 2008).

Although many native plants demonstrated the capacity to survive and/or establish in post-fire forest communities, nonnative plants established even more rapidly. Their early dominance of understory vegetation will likely alter post-fire succession and recovery of these forests, and affect future fire occurrence and behavior. In contrast to the three forest communities, fire in the recently burned, lower elevation shrubland communities had little effect on vegetation composition and structure. Notably absent from these communities were young native tree species, suggesting that native forest recovery has been arrested. Together, these results indicate that this ecosystem, formerly an ‘ōhi‘a woodland, has been pushed along a novel trajectory to a new stable state that is characterized by frequent fire, a few disturbance-adapted native shrubs, widely scattered adult ‘ōhi‘a with no regeneration, and highly flammable nonnative grasses and ferns. These highly modified communities demonstrate how nonnative plant invasions, coupled with repeated fires, can selectively eliminate fire-sensitive native species, promote fire-tolerant nonnative species, and maintain these community in an arrested state of ecosystem development.

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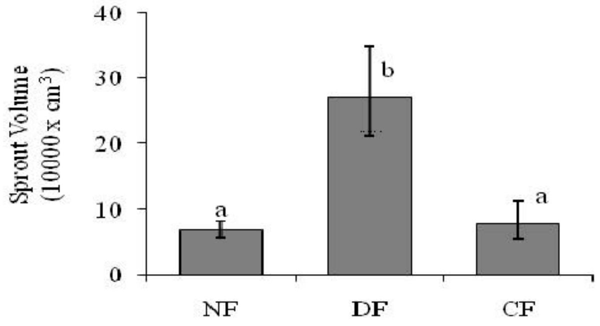
Figure 3.



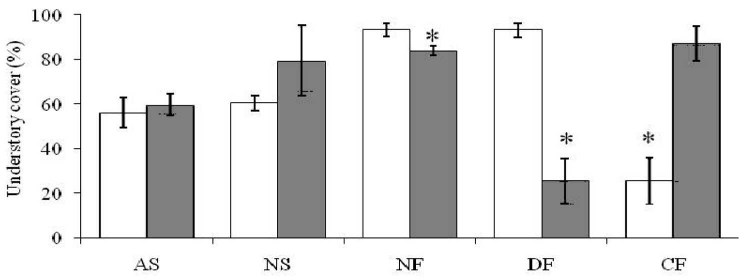
LEGEND

NF – nonnative sword fern mesic forest
DF – native uluhe mesic forest
CF – native tree fern forest

Lowercase letters above bars indicate significant differences among communities.

▲ Ōhi'a basal sprout volume (Mean ± 1 S.E.) two years following fire in three forest communities.

Figure 4.



LEGEND

AS – nonnative grass shrubland
AS – nonnative grass shrubland
NS – nonnative sword fern shrubland and forest communities
NF – nonnative sword fern mesic forest
DF – native uluhe mesic forest
CF – native tree fern wet forest.

Asterisks indicate significant differences between understory cover in unburned and burned forests within a specific communities.

▲ Total understory cover (Mean ± 1 S.E.) in unburned (white bars) and two year postfire (shaded bars) shrubland.

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Research Updates in Rangeland and Natural Area Weed Management

By James Leary

In today's economy, weed management strategies need to be efficient and cost-effective. Weed control in Hawaii's rangelands and natural areas requires the dedication of professionals and volunteers in the field. While many tools are tried and true, the adoption of new concepts and technologies can contribute to safer and more efficient management. This article briefly describes new field technologies for rapid monitoring, improved chemistries, and application techniques designed for more effective weed suppression strategies.

Managing kikuyu grass to restore the native watershed

Kikuyu grass (*Pennisetum clandestinum*) is the most valuable forage species in Hawai‘i. However, when a site is left fallow and efforts are made to restore native vegetation, kikuyu grass then becomes a major impediment. Over the last several years, collaborative research has focused on how to enhance koa (*Acacia koa*) regeneration with cost-effective grass suppression. Historically, physical scarification and sod removal with heavy equipment has been deployed. In many cases this has been quite successful in stimulating koa seed bank germination, but in just as many cases it has also proven to be a poor method of grass suppression. Herbicides are a very useful tool as a sole method for grass suppression or in combination with scarification techniques. In an initial field study that tested the active ingredients glyphosate and fluazifop-p-butyl, we found that glyphosate provided excellent short-term grass suppression as a pre-plant application but could not be applied after koa outplanting due to sensitivity to this broad-spectrum herbicide. On the other hand, fluazifop-p-butyl had good grass selectivity as a post-plant application but was less effective as an herbicide due to the lack of having strong systemic activity. Thus, multiple applications were necessary to maintain adequate suppression. Regardless, it was determined that a combination of the pre- and post-plant herbicide applications made within the first 18 months of establishment resulted in koa growth rates that were 2-4 times greater than untreated plots where the grass continued to dominate. In subsequent studies we looked at the use of another chemical, imazapyr, which is also broad-spectrum herbicide similar to glyphosate but with longer residual activity. An interesting note about imazapyr is that it is generally regarded as not being very effective on legumes. With this discovery we have realized a new herbicide strategy for koa regeneration that has residual power exceeding glyphosate, yet has the selectivity of fluazifop-p-butyl as a post-plant application, when reestablishing native legumes like koa. Small pilot studies conducted on Mauna Kea have in fact shown koa to be tolerant of imazapyr while kikuyu grass is highly sensitive. We've also expanded on these results with a larger 10-acre (4-ha) demonstration using an aerial application over both young and mature koa with excellent selectiv-

▲ Waipunalei restoration site one week prior to aerial spray application with imazapyr at 0.5 lbs a.i. per acre.

▲ Waipunalei restoration site 60 days after imazapyr application.

ity. There are some words of caution in using imazapyr for landscape restoration. First and foremost, other native species are highly sensitive to this herbicide. However, we did find that native outplants were successfully established 200 days after application. Secondly, managers need to become accustomed to the delayed response of weeds to this herbicide. While many managers are accustomed to seeing herbicide results within 2-3 weeks, it is more common to see results from imazapyr in 10-20 weeks.

An important component of all invasive weed management strategies is to efficiently and effectively mitigate the spread of incipient satellite populations and prevent them from becoming major infestations.

Testing an integrated mowing/ herbicide application with Wetblade® technology

Mowing is a tool that has been utilized for decades, but is often relegated to right-of-ways and residential environments for maintenance and beautification. Weeds often aggressively respond to mowing and become a never-ending battle; thus, it is rarely effective as a single tool. On the other hand, a combination of mowing followed by herbicide applications to cut stumps has proven effective, but this two-step process is often too labor intensive for most operations. We are currently testing the WetBlade® technology that integrates mechanical mowing with an herbicide wipe application in a single operation. The Wetblade® that is currently on island is a 6-foot diameter rotary design with distal swivel-mounted blades made of 0.25-inch hardened steel and when in motion are centrifugally extended with an herbicide coating maintained on the underside. As the mower blade cuts the vegetation the herbicide residue is simultaneously applied to the freshly cut surfaces, similar to a cut stump procedure. Early results for this technology are proving successful on guava (*Psidium guavaja*) and rauvolfia (*Rauvolfia vomitoria*). Ultimately, this technology could be used in pasture renovation, conservation site preparation, plantation and orchard row maintenance, and fire break establishment. New research is currently being planned to determine how this technology might be utilized in preparing a forestry operation where Guinea grass (*Urochloa maxima*) is dominant.

Developments in Herbicide Ballistic Technology

An important component of all invasive weed management strategies is to efficiently and effectively mitigate the spread of incipient satellite populations and prevent them from becoming major infestations. Many natural areas in Hawaiʻi consist of extremely steep, densely vegetated, or otherwise inaccessible terrain, thereby requiring a significant amount of time and energy to access each weed target for administering herbicides with conventional application methods. In some cases, rappelling is required to access certain areas, which is dangerous, but necessary work. New technologies are being developed at the University of Hawaiʻi that can accurately deliver effective herbicide doses from safer long-range distances. The recreational paintball industry has contributed to the technological advancements of liquid encapsulation and pneumatic ballistics. These technologies have been adopted for developing a new tool in invasive weed management called Herbicide Ballistic Technology (HBT). The basic concept is to encapsulate aliquots of herbicide into 0.68-caliber starch gel projectiles that can be delivered to specific weed targets with a pneumatic applicator. The first prototype batch of HBT capsules was highly effective in trials targeting Australian tree fern (*Sphaeropteris cooperi*), banana poka (*Passiflora tarminiana*), and kahili ginger (*Hedychium gardnerianum*) from over 100 feet (30 m) away. HBT is a new technology for assisting field crews with safer pesticide handling, improved application technique and an enhanced management strategy. Encapsulated HBT projectiles are by design

▲ Koa root suckering one year post-application with imazapyr.

ready-to-use and will eliminate the need for handling and mixing liquid pesticides in the field. Furthermore, there is a reduction in water requirements needed in field operations, which is a major constraint for weed control operations in remote areas. We have also successfully demonstrated the use of HBT from a helicopter platform, which could be a highly effective tool for early detection and rapid response eradication.

To learn more about the progress of some of these on-going projects, please visit the UH website at *http://www.ctahr.hawaii.edu/LearyJ/videos.html* or on youtube at www.youtube.com/user/hawaiiRREA.

▲ A Wet Blade® application to a recently cut guava stem.

▲ Wet Blade® mower.

Leucaena Is Not Koa Haole

Koa is not koa haole, a fact evident to all in Hawai‘i. Leucaena is also not koa haole, a fact that is much less clear.

By James L. Brewbaker

"Koa haole" is *Leucaena leucocephala* (Lam.) de Wit subsp. *leucocephala,* a fodder tree introduced to Hawai‘i in the 1800s. "Haole" refers to its white flowers and similarity to the yellow-flowered koa (*Acacia koa* Gray). This subspecies is a member of an American genus of 22 species (Hughes, 1997) that is probably an evolutionary derivative of the genus Acacia, which has 1200-species. Leucaenas have base chromosome numbers of 26 and 28 and acacias have base numbers of 13 and 14 (*Acacia koa* being a rare tetraploid). In Hawai‘i, the name "Leucaena" refers to *Leucaena leucocephala* (Lam.) de Wit subsp. *glabrata* (in reference to its smooth or glabrous stems, unlike koa haole). Introduced to Hawai‘i by CTAHR in the 1960s, these large trees with large leaves, fruits and seeds are indeed relatives of koa haole. But, just as no one confuses subspecies like dogs and wolves or cabbage and broccoli, no Hawai‘i forester should confuse these Leucaena subspecies. Early taxonomists in fact designated them as distinct species (as was true of dogs and wolves).

Koa haole needs no description to those in Hawai‘i. It is a seedy shrub or small tree that originated in southern Mexico or Guatemala. Hawaii's single variety gained subspecific status by traveling around the world beginning ~1600 AD. It came by way of Spanish galleons from western Mexico to the Philippines, where it was named "ipilipil", resembling the arboreal legume ipil (*Intsia bijuga* (Colebr.) Ktze., which is a legume that does not fix nitrogen. Koa haole is an important animal feed and fuel wood in almost all tropical countries. Highly self-fertile and seedy, it is said to "defy the woodcutter" and is commonly referred to as an invasive species. Its impressive nitrogen-fixation is largely diverted to seeds and fruits. Almost 50% of the annual dry weight gain of koa haole trees in Hawai‘i is in pods. Unfortunately, it is often referred to as the "Hawaiian type".

Leucaena is arboreal type (Fig. 1) with the glabrous foliage noted by its subspecific name. Our six U.H. expeditions in Latin America from 1967-1997 amassed a collection of about 500 accessions of leucaena (among a total of 1100 accessions held by Hawai‘i Foundation Seeds). They grow to mature heights of about 45 feet (14 m) in four years and have high-quality wood and fodder. They vary in fluting, with cross-sections marked by irregular perimeters but not quite as widely as does *Acacia koa*. Leucaenas have become increasingly important internationally for wood, forage, and human consumption, along with cold-tolerant relatives like *L. trichandra* from highland Latin America (Fig. 2). Hawaii's leucaena varieties dominate the production of Queen-

▲ Figure1: Yield trial of leucaenas at Waimanalo.

sland's 300,000 acres (120,000 ha) of legume-supplemented grass pastures (Dalzell et al., 2006). Over 25 tons of seed have been released in India as "subabul" by Bharatiya AgroIndustries Foundation for growth as fuelwood and for India's growing paper industry (one ton = 20 million seeds) (N. Hegde, BAIF, personal correspondence). They are widely grown as food (green beans) in Latin America. High quality furniture and flooring are made in the Philippines and other countries from Hawaiian varieties such as K8 (Brewbaker, 1975) and K636 or "Tarramba" (Dalzell et al., 2006). These Hawaiian varieties are often referred to as the "Salvador type".

There have been no reports of leucaena as an invasive species. Unlike koa haole, its impressive nitrogen-fixation is largely diverted to wood and leaves rather than pods. Like koa haole, the leucaenas can produce seed and spread, but they are generally self-sterile and poorly seedy, restricting invasiveness. Thus we have released "KX2-Hawaii" in 2008, a self-sterile leucaena hybrid. It relies on bees for pollination and is thus poorly seedy, making the seeds expensive (Brewbaker, 2008). Unlike most leucaenas the KX2-Hawaii variety resists psyllid insects and is much more cold-tolerant. Over the years CTAHR students have created over 75 distinct species hybrids among the 22 species of this genus. Many are seedless and attractive as rapidly grown, high-value hardwoods. However, they must be vegetatively cloned (Shi and Brewbaker, 2006) and will be costly to establish. Outstanding among these is "KX4-Hawaii", a clone to be released next year (Fig. 3).

To summarize, it must be made clear to foresters and environmentalists that the *Leucaena* genus of 22 species includes many very attractive nitrogen-fixing species for tropical and subtropical forestry. The arboreal subspecies of *L. leucocephala* subsp. *glabrata*, commonly called "leucaena", is the most important of these. Improved cultivars from the University of Hawai'i are showing immense potential commercial importance worldwide. These tall trees should not be confused with the shrubby and often weedy subspecies *L. leucocephala* subsp. *leucocephala* that is known in Hawai'i as "koa haole".

Dr. James L. Brewbaker is Professor of Plant Breeding and Genetics in the Dept. of Tropical Plant and Soil Science of the University of Hawai'i. Since 1961, Dr. Brewbaker and has had 52 graduate students working with the leucaenas and crops like maize.

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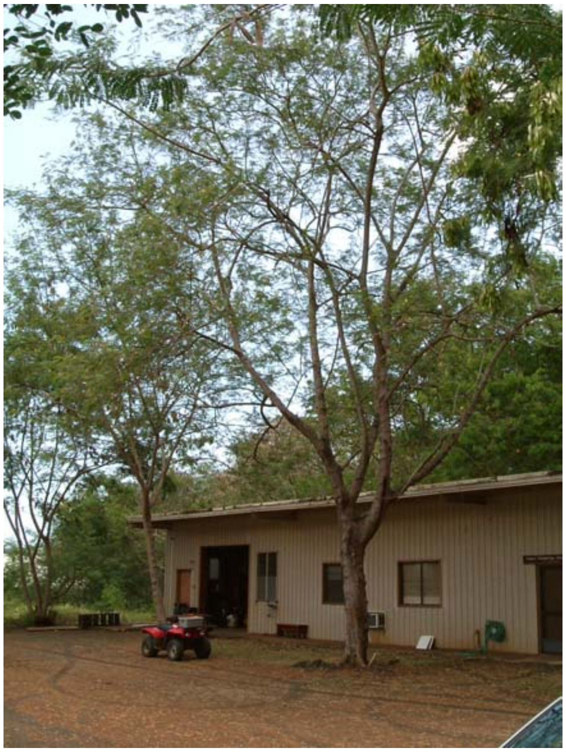
▲ Figure 2: Highland species *L. trichandra* at Kamuela.



▲ Figure 3: Seedless hybrid KX4-Hawaii at Waimanalo.

Using Remote Sensing to Assess Forest Structure and Growth at the Tree Level

By Rodolfo Martinez Morales[1] and Travis Idol[2]

Because of the expense of conducting detailed forest inventories over large areas, considerable research has focused on developing tools to estimate forest canopy attributes using remote sensing techniques. Historical aerial photos have proven useful, but analysis has generally been done manually. With new satellite sensors and improved computing power and analytical software, remote sensing is becoming an important tool for forest cover mapping, environmental monitoring, and ecological process assessments from global, regional, and landscape levels (Plummer, 2000). Recently, fine spatial resolution satellite imagery of the earth from the Ikonos, Quickbird, and now the GeoEye1 satellite have increased resolution down to less than one meter for panchromatic images and 2-4 meters for multispectral images. This has allowed for estimation of forest cover in heterogeneous landscapes (Martinez et al. 2008) and estimation of tree density, species identification and assessment of temporal changes in individual tree growth and mortality (Carleer and Wolff, 2004; Chubey et al., 2006; Clark et al., 2004).

While high spatial resolution satellite sensors can be used to assess forest structural characteristics, they only collect data on a limited number of spectral bands (blue, green, red, and near-infrared). Hyperspectral remote sensing, or imaging spectroscopy, collects data on hundreds of bands from visible to infrared wavelengths. This has expanded the potential for the study of forest canopy biochemical and physiological properties such as canopy water, leaf pigments and nitrogen content (Asner et al., 2005). These data help to improve remotely sensed predictions of forest biomass, species identity and variation inthrough a better understanding of spectral responses of forest canopies (Asner and Lobell, 2000).

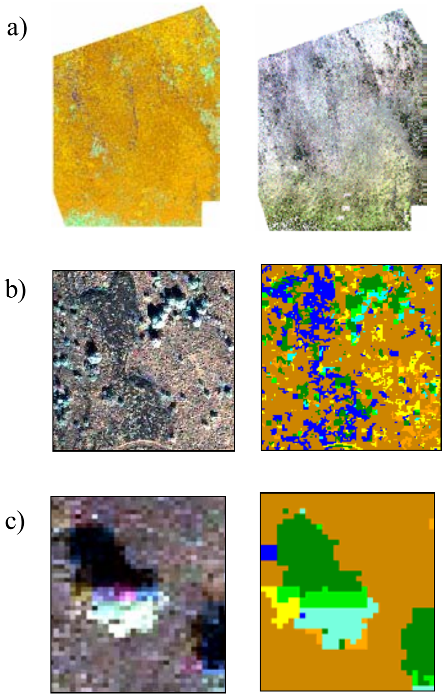
Another remote sensing technology being applied to forest studies is Lidar (light detection and ranging system). Small footprint Lidar systems have provided three-dimensional (3D) surveys of the forest canopy. This technology is becoming increasingly common in landscape architecture and forestry for detailed 3D landscape and individual-tree level estimation of height, crown area, trunk height, biomass and leaf area (Chen et al., 2007; Henning, 2005).

Combining or fusing the highly detailed vertical measurements provided by Lidar and the broad-scale mapping capabilities of passive optical sensors can provide dramatic increases in forest mapping and characterization. Asner et al. (2008a) combined airborne Lidar and hyperspectral imagery to differentiate and map native and alien tree species in Hawai‘i montane forests, including distinct understory species like strawberry guava (*Psidium cattleianum*).

The use of passive and active remote sensing technologies offers great potential to spatially map forest cover and to assess forest ecosystems structure at various scales from land-

Hyperspectral remote sensing, or imaging spectroscopy, collects data on hundreds of bands from visible to infrared wavelengths.

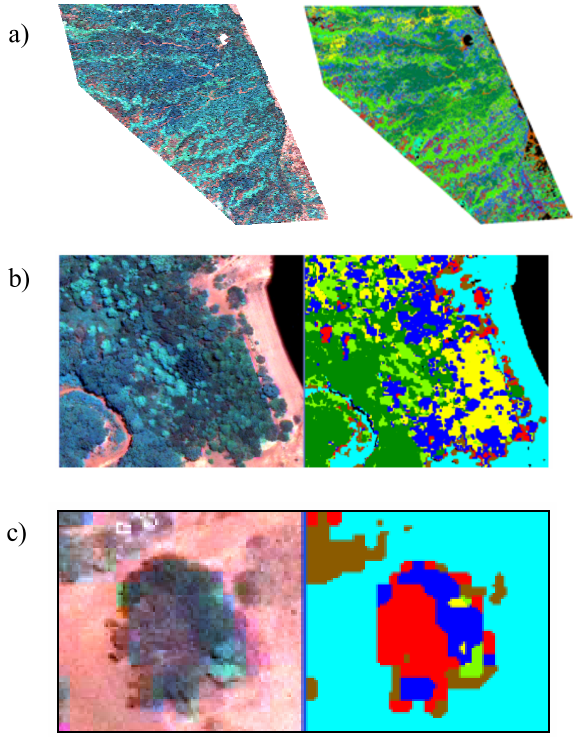
Figure 1.



A dry forest ecosystem from the north Kona region in the Island of Hawai'i as viewed by the Ikonos-2 satellite. a) Natural color composite at 1-m pixel resolution (left) and its corresponding classification (right); b) Image close-up depicting differentiation among objects with similar reflectance (tree crowns from shrubs and grasses and tree shades from lava outcrops); c) Detailed close-up showing clear delineation of individual tree crowns and tree shades.

- ● Tree-crown
- ● Tree-shade
- ● Crown-shade transition
- ● Dry grass

Figure 2.



A montane forest ecosystem from the Island of Kauai as viewed by the GeoEye1 satellite. a) Natural color composite at 0.5-m pixel resolution (left) and its corresponding classification (right); b) Image close-up depicting clear differentiation among tree species; c) Detailed close-up showing classification of diseased from healthy forest

scape, stand and individual tree levels. While satellite sensors offer routine and repeated assessments at scales down to 1 meter, airborne systems combining Lidar with hyperspectral sensors has the highest potential for reliable estimations of individual-tree structure parameters such as canopy size, volume and leaf area. These imaging technologies complement to field inventories, providing detailed information in areas that are remote, inaccessible, or rapidly changing.

Hawai‘i provides unique opportunities to develop and apply these remote sensing technologies. Martinez et al. (2008) used Ikonos satellite images (1-m panchromatic, 4-m multispectral) to map tree cover in the dry forest area of Puuwaawaa Ranch on Hawai‘i Island with approximately 85% accuracy. Greg Asner’s research team has pioneered the use of airborne hyperspectral sensors combined with waveform Lidar to provide 3D images of Hawaii’s forests, including detailed biochemical data on plant canopies. Distinct structural or biochemical signatures have been used to map the distribution and spread of certain invasive species, including understory plants like Kahili ginger (*Hedychium gardnerianum*) and strawberry guava (*Psidium catleianum*) (Asner et al., 2008a; Asner et al., 2008b). The Nature Conservancy of Hawai‘i is employing an airborne imaging system with a resolution of just a few centimeters to map the distribution of Australian tree fern. The georeferenced locations can be uploaded to a handheld GPS, allowing for more efficient eradication efforts (Ambagis et al., 2009).

Remote sensing technologies are proving to be powerful research and management tools for the inventory and assessment of forests around the world and here in Hawai‘i. We are now at the point where both satellite and airborne sensing systems can provide reliable and detailed information at the individual-tree level. These technologies will become increasingly important for assessment and management of Hawaii’s forests as we continue to face the challenges of land use pressures, invasive species, and climate change.

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A Message from Dr. Travis Idol, President

The Hawaiʻi Forest Institute takes great satisfaction in publishing this fifth issue of the Hawaiʻi Forest Journal. The articles in this issue cover a broad range of forestry-related topics, including understanding the impacts of non-native species on wildland fires, innovative techniques in forest and range management, the development of improved varieties of multipurpose trees, and the application of advanced satellite remote sensing to describe and understand forest structure and function. Mahalo to all the contributing authors. The Hawaiʻi Forest Journal is supported financially by sponsors who are recognized for their contribution with grateful acknowledgment in each issue.

As Chair of the Editorial Review Committee, I want to highlight the volunteer work done by Committee members Judy Hancock, Carolyn Stewart, and Dr. J.B. Friday. We owe them a debt of gratitude for their efforts in working with the authors to ensure the high quality of the articles in this issue. Mahalo nui loa to our Journal readers from the Hawaiʻi Forest Institute Board of Directors.

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