Issue 2: Forest Health: Invasive Species, Insects & Disease

Overview

The Hawaiian Islands once comprised the most isolated archipelago in the world, with a multitude of climates and varied topography conducive to forest growth. These islands provided a remarkable opportunity for establishment, population growth and evolution of the relatively few plant, insect, and vertebrate visitors that arrived early in the islands' development. One particularly successful plant species among these, the ancestor of endemic *Metrosideros polymorpha* (in the myrtle family), now known in Hawaii as *ohia lehua*, arrived on Kauai nearly 4 million years ago and evolved to form the matrix of forests found throughout roughly 80-85% of the archipelago.[1] *Acacia koa* (in the legume family), likely arrived more recently, but co-dominates in 10-15% of the forest.[2] Hawaii has many other plant species, but most are endemic to very small areas, hence Hawaii's exceptionally high number of endangered species.[3] Hawaii, like oceanic islands in general, is especially vulnerable to the establishment of invaders and subsequent impacts of invasions.[4,5] While habitat destruction by humans has been a direct factor in Hawaii's ecological losses in the past, human-facilitated biological invaders are currently the primary agents of continuing degradation.

Polynesian settlers were the first humans to land on Hawaii's shores, and with their arrival they brought plants and animals needed to survive the long voyage and settle a new land. The settlers quickly learned how to use the forest resources of Hawaii for food, clothing, medicine, and shelter. Several of the Polynesian introduced plants, such as *kukui* (*Aleurites moluccana*), naturalized in forests while the Polynesian rat (*Rattus exulans*) had an impact on the original pre-human ecosystems of Hawaii. By the time the first Europeans arrived in 1778, the native Hawaiians had developed land use practices that were sustainable and highly productive. This would change however, when wide-scale ecosystem degradation caused by non-native plants, insects, game species, and diseases were introduced by Europeans in the 18th century. As a result, over the past two centuries entire ecosystems have been replaced by invasive species in Hawaii.

Managing invasive species, along with reducing human impacts and protecting watersheds, are key elements of forest health in Hawaii today. To protect forest resources both area-based and species-based collaboration programs have been implemented. The area-based programs follow a model of identifying landowners who manage a common area often linked by watersheds or other geographic features. By working across borders the landowners can achieve effective management providing landscape-scale benefits for habitat, watersheds and perpetuating cultural traditions. Area-based invasive species management is an integral component of native forest restoration (*See Issue 1: Water Quality and Quantity for more information*).

Species-based programs recognize that introduced species often arrive at ports and become established first in urban areas. Once species are established, early detection and rapid response

programs search for, evaluate and remove new invasive species that have not yet invaded native forest areas. The highest chance of success for eradication is when the numbers of a new invader are low. Eradication also provides the greatest long-term benefit by removing the risk that the newly establishing species will cause harm.

The long history of colonization and human use in Hawaii has led to a large number of introduced species that degrade forest resources. These invasive species are very widespread and include pigs (*Sus scrofa*), albizia (*Falcataria moluccana*), rats (*Rattus* spp.) and slugs. The only way to preserve the function of important watershed areas and native species habitat is to find new tools to target these species across large areas. Research into toxicants, biological control and landscape scale management techniques is critical to slowing the harm caused by invasive species that are already widespread.

The harm caused by invasive species in Hawaii is so great that multiple federal, state, county, nonprofit and private agencies have developed separate programs to address the issue. The Hawaii State Legislature and Governor established the Hawaii Invasive Species Council (HISC) to provide enhanced statewide coordination. This body operates under the authority of state law and ensures that state agency actions related to invasive species are complementary to each other. The strategic plan is available at: http://www.hawaiiinvasivespecies.org/hisc/strategicplan.html.

The Coordinating Group on Alien Pest Species (CGAPS) which pre-dates the Hawaii Invasive Species Council, is a voluntary group including state, federal, and county agency directors and managers, nonprofit directors, and chairs and managers of island-based invasive species committees. CGAPS benefits from the knowledge and guidance of world-renowned scientists who are dedicated to protecting Hawaii from invasive species. Since its formation in 1995, CGAPS has met quarterly and has published strategic plans identifying priority invasive species needs (http://www.hawaiiinvasivespecies.org/cgaps/pdfs/cgapsvisionactionplan200912.pdf).

Field capacity to tackle invasive species as species-based projects is effectively provided by the Invasive Species Committees (ISC's) that have been established on each of Hawaii's counties; the Kauai Invasive Species Committee (KISK), the Oahu Invasive Species Committee (OISC), the Maui Invasive Species Committee (OISC), the Molokai Invasive Species Committee (MoISC) and the Big Island (Hawaii) Invasive Species Committee (BISC).[6] The ISCs have two essential components that work together; a voluntary committee of local agencies and landowners who are working on invasive species issues; and a field crew that is dedicated to invasive species detection and control. Maps 2.1 and 2.2 show where the ISC's have surveyed and/or treated incipient invasive species.

Landscape scale projects in Hawaii are carried out by the watershed partnerships who exercise area-based management to protect and restore native forest communities. Watershed partnerships are voluntary alliances of public and private landowners and other partners working collaboratively to protect forested watersheds for water recharge, biodiversity, and other ecosystem services. Much of the work carried out by watershed partnerships involves the control

of invasive species, especially feral ungulates and invasive plants. (*For more information see Issue 1: Water Quality & Quantity).*

Figure 2.1 Brought to the islands for its beautiful foliage, *miconia* is one of Hawaii's worst invasive. plant threats.

Threats

Invasive Species – Plants and Animals

The two main threats to watershed health in Hawaii and the focus of most on-the-ground management are feral ungulates and invasive plants. Animals, such as pigs, goats, sheep, mouflon, deer, and cattle, trample, browse and destroy vegetation that evolved without any protective measures from these animals. Feral ungulates also tear up the ground with their hooves, leaving the ground bare and exposed resulting in increased erosion and allowing seeds of fast growing non-native species to germinate and thrive. These animals also serve as important seed vectors for invasive plants.

Invasive plants often have negative impacts on the hydrologic processes of forested watersheds. Habitat-modifying invasive species shade out native understory species, exposing soil surface and contributing to erosion. Some alien invasive species such as miconia (*Miconia calvescens*) shown in Figure 2.1 have been shown to be significantly less effective than native trees in allowing rain to slowly infiltrate watersheds and instead create runoff.[7] The tendency for invasive species to have shallow roots also reduces the ability of the forests on steep hillsides to withstand erosion, rockfall and landslides. See Figure 2.2.

There is also evidence that strawberry guava has higher evapotranspiration rates than ohia forest, but this has not been fully documented.[8] What has been well demonstrated for strawberry guava is that it reduces the proportion of rainfall that becomes available for ground water recharge when compared with native-dominated forests.[9]

Fifty-five birds, thirty reptiles and amphibians, and nineteen mammals are naturalized in Hawaii and have the potential to become serious pests in Hawaii's watersheds. Rats, in particular, have a significant effect on native vegetation and bird species. Black rats (*Rattus rattus*) and Polynesian rats (*Rattus exulans*) are found in abundance throughout most of Hawaii's forests. Rats consume the seeds, fruits, and flowers of numerous native plant species, including many rare ones; they also prey on native bird eggs and nestlings.[10,11] Like ungulates, rats can affect water quality by

Figure 2.2. A pure stand of *Miconia calvescens* in Tahiti illustrates what can happen if miconia is left unchecked. This landslide is attributed to miconia's shallow root system.

serving as vectors for water-borne diseases such as Leptospirosis and Cryptosporidiosis.Other non-native vertebrates that pose problems in Hawaii's watersheds include mongoose, feral cats, dogs, mice, and birds. Non-native forest birds have been observed in all vegetation types. They compete with native forest birds for food and other resources, provide vectors for avian diseases, and are vectors for the spread of many invasive plants species such as miconia. Invasive vertebrate issues are managed through partnerships with federal and state agencies with jurisdiction over harmful and injurious wildlife such as the U.S. Fish & Wildlife Service and USDA Wildlife Services.

Global and local climate change has the potential to affect Hawaii's suite of established invasive species by extending their ranges to higher elevations. One well documented example of this threat of warming is potential range expansion of mosquito species to higher elevations, resulting in increasing exposure of remnant forest bird populations to mosquito-transmitted infectious diseases.[12] Both vertical range shifts and increased disturbance from violent weather events may open opportunities for invasive species to establish in new areas. (*See Issue 5: Climate Change/Sea Level Rise for further details.*)

Insects & Disease

Another two threats, introduced insect pests and disease are a continual threat to Hawaii's forests and occur in all areas in the state; forested areas, urban areas and agricultural areas. Non-native pest introductions can devastate plant species that have no history of exposure or resistance to the pest or similar taxa, as is frequently the case in Hawaii. Of special concern are pests that could cause widespread mortality to wide ranging dominant native forest species such as koa and *ohia*. Large scale dieback of these predominant forest species would be devastating to Hawaii's remaining native ecosystems.

does not have a particularly dramatic history of plant pathogen introductions to date, but given greatly increased movement of plant material with globalization and the tendency for a few endemic plant species to have dominance and broad elevational range, prevention measures

through rigorous pathway management are urgently needed. The Hawaii Department of Agriculture has succeeded in keeping important pathogens of coffee and coconut out of Hawaii for over a century using such a strategy. Most significantly, a rust species has the potential to negatively affect the dominant tree species in Hawaii's native forests, *ohia lehua*. A strain of *Puccinia psidii* was found to be pathogenic to *Metrosideros polymorpha*, commonly known as *ohia*, as well as many other species in the Myrtaceae family. Although this genetically non-variable race of rust has demonstrated low virulence to ohia, scientists are concerned about introductions of future strains.[13] The same disease has proven to be quite virulent on rose apple (*Sygyzium jambos*), an introduced fruit tree very popular for it's rose-flavored fruit (see Figure 2.3), and also on *Eugenia koolauensis*, an endangered native Hawaiian plant with only a few populations remaining.[14]

Figure 2.3. Dieback of non-native rose apple trees (*Sygyzium jambos*) caused by *Puccinia psidii* has raised concerns for Hawaii's native ohia forests. Photo credit: Randy Bartlett

There is tremendous opportunity for the spread of pests of Myrtaceae through pathways such as establishment of commercial eucalyptus plantations. For example, *Coniothyrium zuluense*, a serious fungal leaf pathogen of Eucalyptus, believed to be derived from a pathogen on native Myrtaceae in South Africa, has already arrived in Hawaii.[15] Whether this pathogen can infect ohia is unknown, but its arrival further illustrates the need for careful management of the myrtle family pathway, not just for *P. psidii*, but for numerous forest pests.[16]

Another major pathogen is koa wilt disease, caused by *Fusarium oxysporum f.sp koae*, that threatens the health of koa. This soil born disease causes dieback and decline of in native forests by compromising the tree's vascular system.[17] Figure 2.4 shows the stain that this pathogen produces in koa. The disease has been especially virulent in lowland plantations of koa on former agriculture lands (James and others 2007) and greatly hinders the establishment of commercial plantations.

Figure 2.4 Stain on *koa* wood attributed to *Fusarium oxysporum* in a plantation.

Natural forest decline attributed to this disease has so far been limited to a couple of areas, although more work is needed to fully understand its effect and interaction with abiotic factors such as soil types and climate patterns. The full extent of the impact of koa wilt disease in natural forests is still unknown. Where outplanting of koa is used as a tool for reforestation, using disease resistant planting stock could be important to project success. In areas where a koa seedbank already exists, scarification instead of outplanting is the preferred method of regeneration.

Figure 2.5. An introduced thrips insect damaging native naio (*Myoporum sandwicensis*) was first detected in 2009 on the island of Hawaii.

Invasive insect herbivores have wrought substantial damage to certain forest species in Hawaii. Particularly notable examples include the fern weevil (*Syagrius fulvitarsus*), established about 1900, especially damaging to species of the tree fern Sadleria; the black twig borer (*Xylosandrus compactus*), established in the 1970's, and particularly damaging to *Acacia koae*[18] and numerous rare endemic dry forest trees, such as mehamehame (*Flueggea neowawrea*); the two-spotted leafhopper (*Sophonia rufofascia*), established in 1988; and the Erythrina gall wasp (*Quadrastichus erythrinae*), established in 2005.[19] A species of thrips (*Klambothrips myopori*) first detected on the Big Island in March 2009 seems to have the potential to severely damage naio (*Myoporum sandwicense*), a locally important tree in Hawaii forests.[20] (See Figure 2.6.) Climatic ranges for most of these insects are not well studied, but typically they are a problem throughout the environmental range of the host, such as with the Erythrina gall wasp which has infested all known populations of *wiliwili* to varying degrees, and has virtually eliminated other species in the genus *Erythrina* that had been very popular trees in urban areas. Figure 2.5 demonstrates the effect that this tiny wasp has on *Erythrina spp.* Black twig borer with a much wider host range is limited by elevation (found under 3000 feet) but is widely distributed in ecosystems at lower elevations.

The absence of social insects in Hawaii throughout its evolutionary history has had enormous implications for Hawaiian flora and fauna.[21] Over time, unfortunately, accidental introductions of social insects has greatly altered Hawaiian ecosystems. Today, Hawaii is home to over 40 known species of ants. Without ants present for protection, piercing and sucking insects (such as scales and aphids) were unable to successfully colonize the Hawaiian islands and were therefore absent. These insect pests are now established and in tandem with the introduced ants are

common pests of many native Hawaiian plants.

Climate change is also expected to exacerbate pest impacts on Hawaii's forests. Warming temperatures at higher elevations where most remaining native forests exist could make them more vulnerable to pest damage by increasing the climatic range of certain pests that are still limited to lower elevation, non-native forests. Increased drought could also increase susceptibility to existing pests. (*See Issue 5:Climate Change/ Sea Level Rise for additional information*.)

Figure 2.6. Damage to leaves by the erythrina gall wasp--responsible for the death of thousands of endemic and introduced trees in the genus *Erythrina* trees throughout the state. Photo credit: Ron Heu

Trends

Invasive Species

The numbers of invasive species establishing in Hawaii is increasing over time. While there are shifts from accidental introductions to new pathways such as internet mail order for some taxa, new species continue to be detected each year. Island wide plant surveys continue to find new island records as well as new species in cultivation. Through the Invasive Species Committees, there is more capacity to respond to new invasive species and at least a dozen species have been eradicated island wide preventing harm to the environment and economy of the state.[22]

Insects & Disease

Introductions of insects and disease is a continuing problem in part because Hawaii is so heavily dependent on imports. Approximately 20 insect species establish in Hawaii each year, about half from foreign countries and half from the U.S. mainland. The loss of 30% of existing Hawaii Department of Agriculture (HDOA) inspectors in 2009 reduced state quarantine capacity. Additionally, loss of HDOA monitoring and biocontrol positions in 2009 seriously compromised detection and assessment of new pests. (*See Issue 9: Multi-Multi-State Issues for additional information).*

Outreach & Education

Public awareness surveys show that public knowledge of invasive species in Hawaii has improved in past years and the percentage of people who view invasive species as a serious

problem is rising (see Figure 2.7). Ongoing efforts to convey to the public the threat and costs of invasive species such as snakes, red imported fire ants, invasive seaweeds, and miconia, appear to be working. Special efforts are now underway to increase public understanding of the important role of biological control in managing invasive species in Hawaii.

Although public awareness is quite high for the concept of invasive species in general and certain species in specific (see http://www.hawaiiinvasivespecies.org/cgaps/whitepapersreports.html for a full report on recent surveys), much more can be done to engage the public in understanding, preventing, detecting and controlling invasive species in Hawaii.

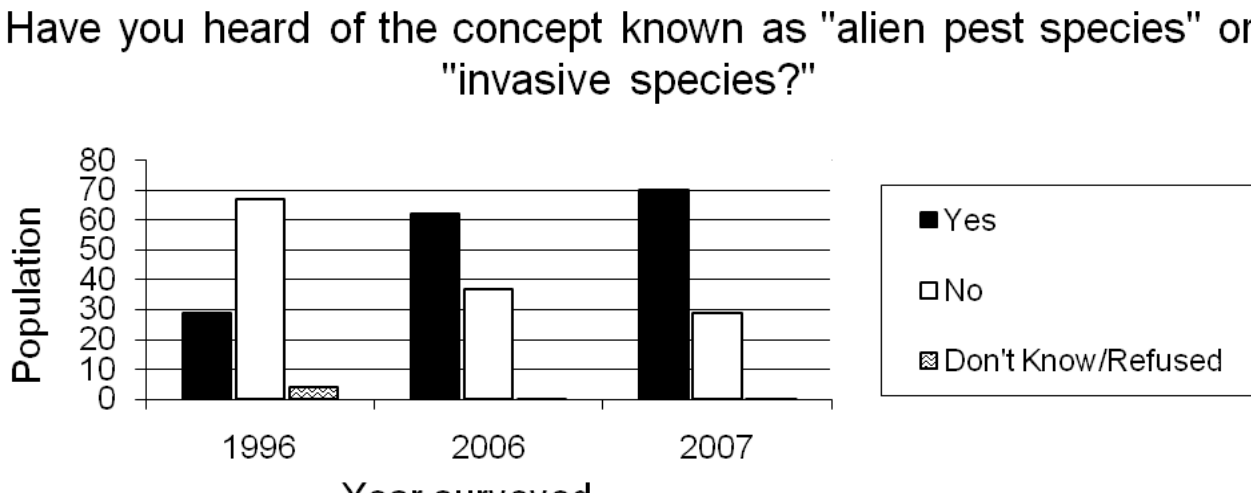


Figure 2.7. Results of a survey to assess public awareness of invasive species.

Present Conditions

Invasive Species

In response to the complaint that "you cannot conserve what you do not know," the Hawaii Biological Survey embarked on a study of the numbers of species known to occur in Hawaii. This group, sponsored by Bishop Museum, scoured the published literature and compiled the names of all the plants and animals that reported to occur in Hawaii. The result of those efforts was the first tabulation of the numbers of species in Hawaii by Eldredge & Miller.[23] It provided a detailed table by kingdom, phylum, and class of the numbers of species that were known from the Hawaiian Islands. Each year subsequent to that study, supplements were published in the annual Records of the Hawaii Biological Survey summarizing in an abridged format the changes in the constituent fauna and flora of the islands (Miller & Eldredge, 1996, 2000; Eldredge & Evenhuis, 2002).[24,25,26,27,28,29]

The list of species identified in Hawaii is expected to continue growing. Approximately 10,000 alien plant species are or have been cultivated in the islands. Of these, it is expected that at least 10% will naturalize leading to additional species that could pose a threat to native species

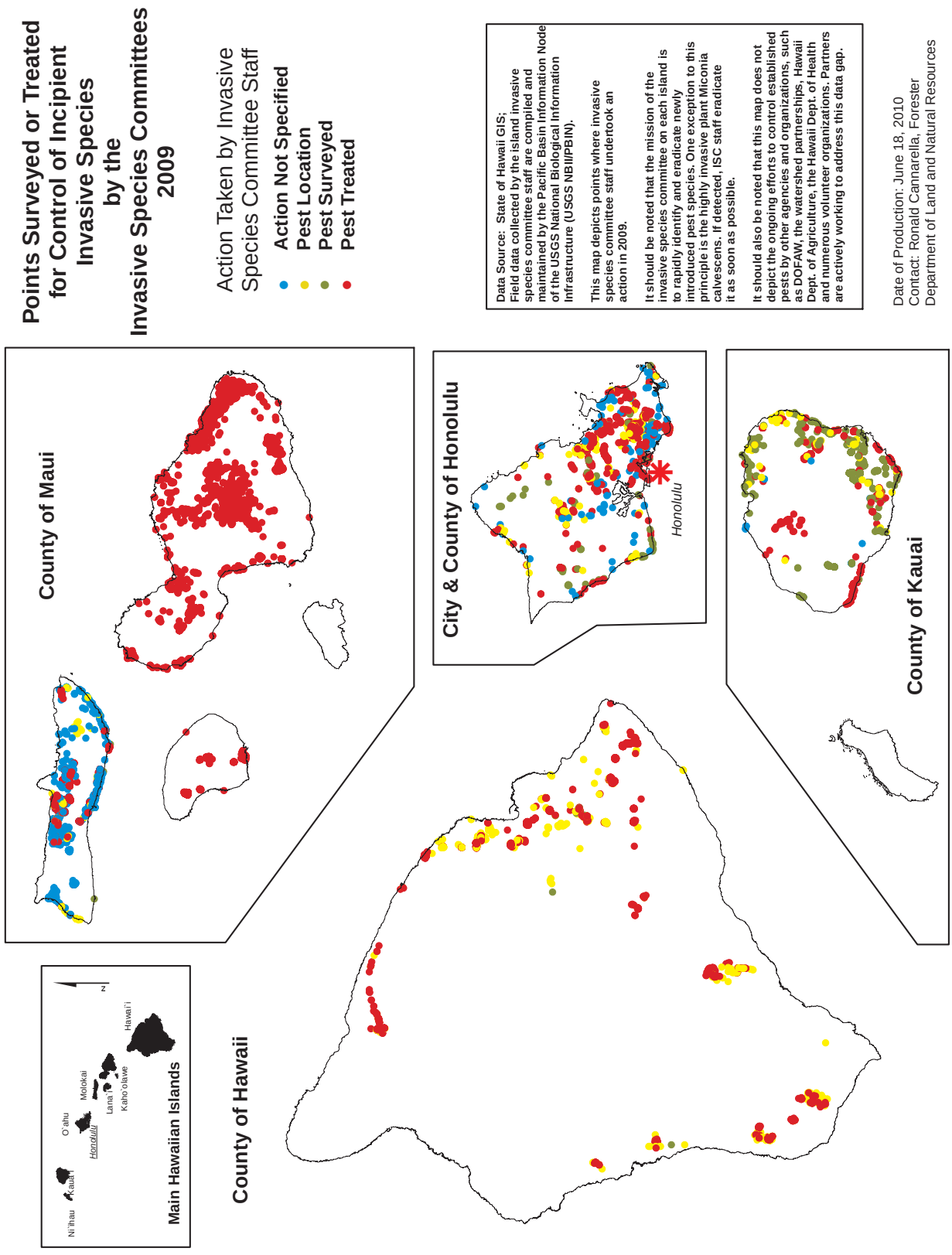
survival, changes to the watershed, interfere with agriculture or decrease our quality of life. Building capacity to identify and address these species is a high priority and the following three areas are the focus of our partnership work with the U.S. Forest Service:

Prevention: It is well established that prevention is this most cost-effective tool for invasive species management. The agencies responsible for Hawaii's biosecurity are the Hawaii Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS), and The Department of Homeland Security U.S. Customs and Border Protection (DHS CBP). Working with these agencies DOFAW attempts to prevent new species from being introduced to the state as well as between islands. This includes invasive plants, insects, and diseases as well as any other organisms that could harm Hawaii's environment. Risk assessments for pathways and specific pests are an important tool for prevention.

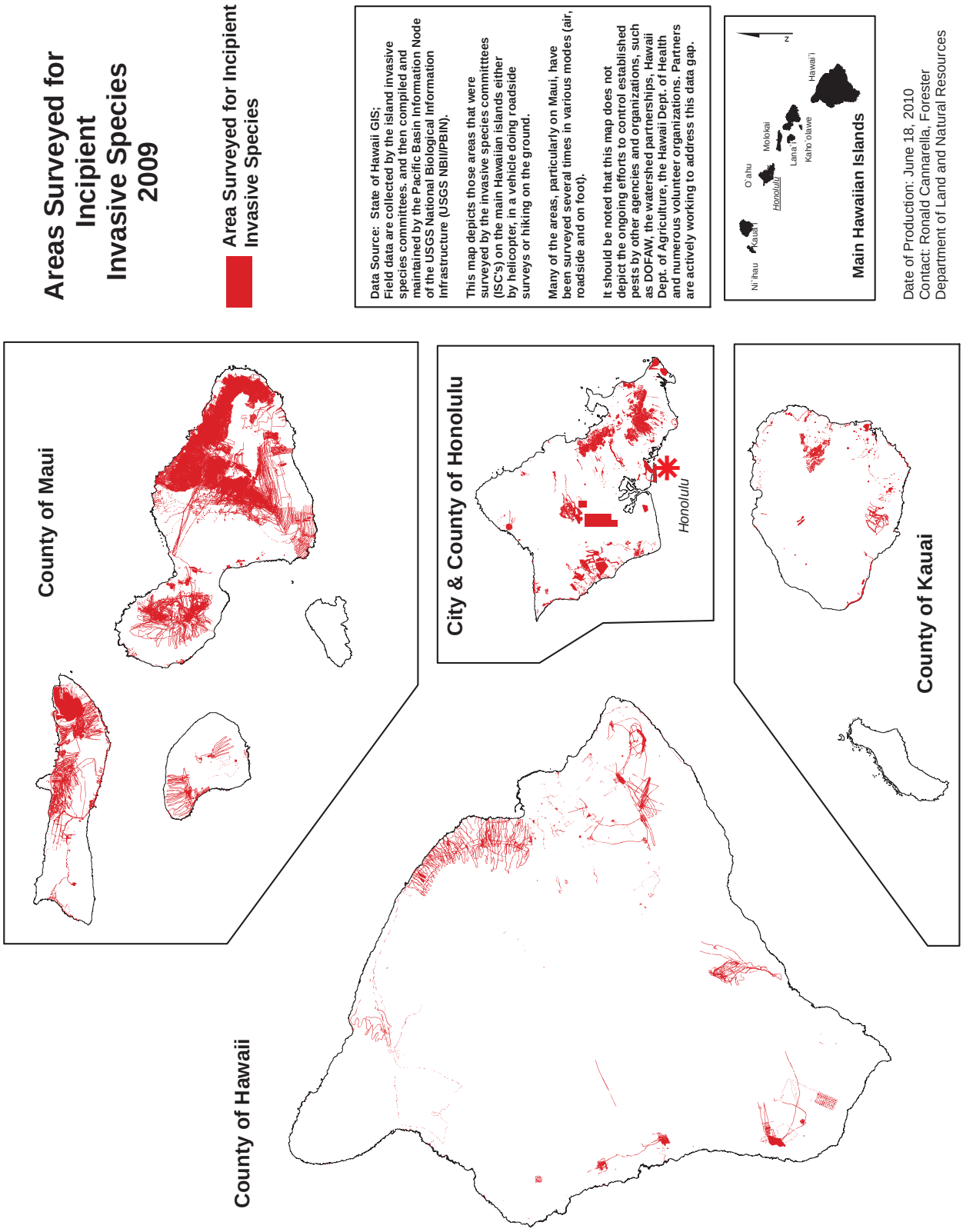
Hawaii-Pacific Weed Risk Assessment: The Hawaii-Pacific Weed Risk Assessment (HP-WRA) is used as a diagnostic tool to help predict a plant's likelihood to become a weed. The HP-WRA was developed in Australia and New Zealand and modified for use in Hawaii and other Pacific islands by Professor Curt Daehler of the University of Hawaii. The HP-WRA screens plant species and assigns a score based on propensity to become weedy. A high scoring plant poses a high risk of becoming an invasive pest. The assessment is based on 49 questions that address several plant characteristics, such as number of seeds produced and habitat preferences to determine if a species is likely to become invasive. Although the HP-WRA was developed as a tool to prevent new invasions, it is also used to evaluate the threat of newly established plants. Use of the HP-WRA for directing biosecurity regulations is being pursued.

Early Detection. Several limited-term projects have been completed that focused on identifying the locations and extent of populations of plants known to have been planted in Hawaii and considered (*use link to Weed Risk Assessment process below*) to pose a threat to native ecosystems (http://www.botany.hawaii.edu/faculty/daehler/WRA/default2.htm). These surveys covered specific areas at high risk for introduction of vascular plants, creating a framework of agencies and data collection to ensure that these high-risk areas are monitored on a periodic basis and are tied to an effective rapid response capability.

Early detection projects for new invasive plant species that may have been introduced via arboreta, nurseries or residential plantings have been initiated on Oahu, the Big Island, Kauai, Lanai, Maui, and Molokai. Maps 2.1 and 2.2 show areas surveyed and/or treated by the Invasive Species Committees on those islands. Continued support is needed to complete or expand these surveys across the islands. A new survey is scheduled for Kauai this year. The Oahu Early Detection project employs two botanists based at the Bishop Museum who assist with identifying new plants found in early detection surveys statewide; these botanists will carry out the survey on Kauai.



Map 2.1 Points surveyed or treated by the island invasive species committee staff.



Map 2.2 Areas surveyed for incipient invasive species.

Support is also needed to evaluate and prioritize rapid response targets following the identification of targets through these surveys. Detecting species when they are limited to a few individuals or cover less than ten acres greatly increases the likelihood of a successful eradication effort as supported by studies on invasive trees in the Galapagos. A process has been developed in Hawaii for evaluating species detected in early detection surveys (see above), and candidates will be evaluated on an ongoing basis.

Early detection efforts for insects and disease are also being developed in collaboration with U.S. Forest Service, Hawaii Department of Agriculture, USDA APHIS, and the University of Hawaii. While only now getting off the ground, it is hoped that this program will be as successful in finding new introductions as the plant early detection program has been. Efforts will focus on areas where introductions are likely to occur such as harbors and airports, new developments, and urban forests.

A significant improvement to the process of picking new invasive species targets has been the standardization of the evaluation process. Initially, the "Eradicate this weed or not?" decision tree created by the New Zealand Department of Conservation was used on Oahu and in a modified form on Maui. This decision tree has been modified to use the Hawaii-Pacific Weed Risk Assessment screening system to evaluate species as to their risk of becoming serious forest pests along with other factors relating to their ecology, distribution and known control techniques. This standardized process ensures that limited resources are used to control the species that pose the greatest risk and have the best possibility for island-wide eradication.

Rapid Response: Hawaii is unique in its extreme isolation from other terrestrial biodiversity centers. Even once an invasive species becomes established in the state, individual islands may remain free of pest species through intra-state quarantine practices and constant monitoring followed by effective control. Eradication, even island-specific eradication, is the most cost-effective, long-term protection for native ecosystems. While several of the highest priority plant species are fairly widespread, new targets will be prioritized by the level of the threat they pose to native forest ecosystems and the feasibility of eradication.

Insects & Disease

Insect and disease pests damage all forest ecosystems in the state. Non-native insects and diseases are a primary threat in Hawaii. While current efforts focus on invasive pests such as the erythrina gall wasp (biological control), black twig borer (development/refinement of lures for local control), guava rust (trying to get regulation/capacity in place to prevent arrival/ establishment of new strains), and naio thrips (assessment and exploration of biocontrol options), preventing new pests from entering Hawaii by strengthening quarantine agencies is key to protecting Hawaii's forests.

Other pests such as koa wilt disease (*Fusarium oxysporum*) and the koa moth (*Scotorythra paludicola*), which is native to Hawaii, occur periodically causing defoliation or mortality.

Figure 2.8. Ohia seedling infested by *Puccinia psidii*. In nurseries where conditions are conducive to outbreaks the disease must be managed with fungicides.

Efforts to isolate genetic resistance in koa to *F. oxysporum* have been successful and continue to be developed. Abiotic stressors such as vog (volcanic fumes) and drought also impact forests in Hawaii and may interact with pest damage stress.

Biological Control

As a part of an integrated pest management strategy, biological control is often the most effective, permanent, and best use of limited funds to control pest species, especially when a pest is widely established. With current regulatory reviews and approvals, it is also the best environmental solution to controlling pest problems in Hawaii. Long-term suppression of ecosystem altering pests or pests that threaten key native species is often unachievable with any other tool. The Hawaii Department of Agriculture, the U.S. Forest Service, the University of Hawaii and the Agricultural Research Service all maintain some capacity for biological control research and collaborate with scientists in other states and countries to efficiently pool resources. Their efforts are coordinated through a statewide biological control working group.

However, current statewide capacity to develop biological control is severely limited. Facilities are outdated, cramped, and inadequate for comprehensive non-target testing of multiple candidates. State budget shortfalls jeopardize HDOA's biological control program, and staff is frequently tasked with non-biological control duties. Funding for exploratory trips is rarely available. In order to adequately address invasive species issues in Hawaii, a substantial increase in resources for biological control is required. This needs to be accompanied by public outreach efforts so that the public has a better understanding of biological control as a necessary tool in invasive species management.

Restoration

Restoration is an integral part of invasive species management. Without revegetating treated areas with desirable plants, invasives are likely to return. Native forest restoration in Hawaii normally follows a two-pronged effort of fencing out harmful ungulate species and suppressing invasive plants. Outplanting native plants or scarification which can release the seedbank in areas

previously covered by koa forests, can also be used to suppress invasive plants. Creating forest canopy can suppress invasive grasses which promote fire and prevent native species from reestablishing. Restoration efforts need to be site-specific based on the climate and other physical factors. Invasive species management needs to take into consideration how treatment will affect future plant and animal communities.

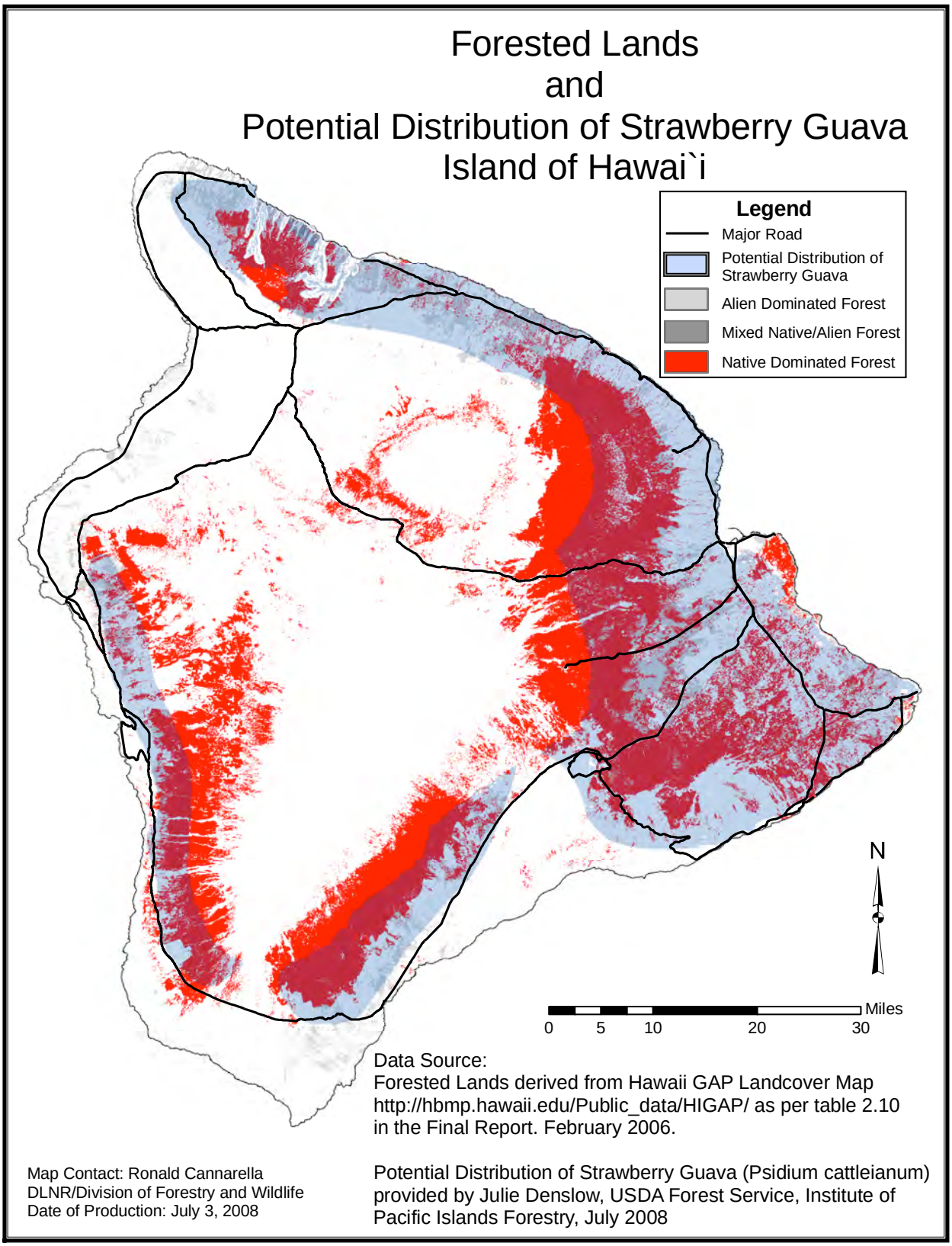
Figure 2.9. The Septoria leaf-spot fungus has brought the weedy vine banana poka (*Passiflora tarminiana*) under control in many areas.

Part of restoration also involves the genetic preservation of species threatened by a pest or disease. For example, a statewide effort was made to collect wiliwili seed from as many populations as possible when the gall wasp was introduced, and it became apparent that the species could become endangered. As the gall wasp population has become suppressed by the introduced biocontrol agent, restoration efforts will utilize this seedbank for reestablishing wiliwili in forests. Similarly, collections of koa that are screened for koa wilt resistance can be used to establish koa forests where they have been long extirpated by animal grazing.

Priority Issues and Areas for Forest Health

Management of invasive species in Hawaii involves working in diverse areas. Many species are initially detected in urban areas through the efforts of the island invasive species committees around harbors and ports, along roadways, and in people's yards. If eradication is not initially possible they can quickly spread to adjacent forested watersheds. Much of Hawaii's low elevation forests, and where control of incipient populations frequently occurs, are predominantly made up of non-native species. The focus of the ISC's early detection and rapid response actions shown in Maps 2.1 and 2.2 fall into two broad categories; roadside surveys in urban areas, and aerial surveys of priority upland forest areas where native ecosystems remain largely intact, primarily at higher elevations (*see Issue 6: Conservation of Native Biodiversity*). The aerial surveys conducted by the ISC's put a high priority on locating and eradicating miconia before it begins to produce seeds. Maintenance of these priority forest areas requires ongoing monitoring and control of invasive species (*see Issue1: Water Quality and Quantity*).

Therefore, priority landscapes for invasive species include high-risk areas such as ports and new developments in urban areas, as well as high-value areas such as predominantly native forests identified to have important hydrological or biodiversity values in other Issue sections in this document. This does not preclude working in any area that becomes infested with a high-priority species utilizing a species-led strategy as described above.



Map 2.3. The map shows how one invasive plant, strawberry guava, threatens remaining native forests on the island of Hawaii. It is already widely established in the lower elevation mixed and alien dominated forest types.

Currently many long-established insect pests and disease damage native Hawaiian forest trees, but little work has been done on describing their environmental range or mapping their risk. This is in part due to the extreme variation and heterogeneity in Hawaiian ecosystems. Therefore maps are not included for most of these pests, nor are specific priority landscapes given because the pests range and sometimes that of the host is neither well known nor mapped. Map 2.3 shows the potential distribution for one of our well-established and highly invasive forest species, strawberry guava (*Psidium cattleianum*) for which a biocontrol agent has been identified and will soon be released in hopes of controlling the spread of this species.

Priority areas from highest to lowest are those with intact native ecosystems (*see Map 6.4 in Issue 6: Conservation of Native Biodiversity*), valued native species outside of intact ecosystems (such as wiliwili), urban areas, commercial forests, and non-native forested watershed. In reality, most pests heavily overlap these various areas.

Data Gaps & Opportunities

Currently few maps exist for the statewide distribution of widespread invasive species because of the lack of the data and the technology to acquire it. Monitoring of forest health conditions occurs throughout the state on all land ownerships; private and public. These programs use ground surveys, transect monitoring, helicopter surveys, road surveys, photo points, and remote sensing for gathering data. The watershed partnerships have extensive data on invasive plant management for their internal use, but the data is not standardized throughout the state to communicate statewide species-specific information in the same manner as the data from the invasive species committees. Progress has been made in developing remote sensing tools for monitoring the presence of invasive plants and in determining plant mortality and damage from insects and disease in Hawaii's forests. Since many of the most habitat-modifying invasive plants live in the understory, the technology to "see beneath the canopy" is in its infancy, but proof-of-concept research has proven that it can be done using a combination of LiDAR and multi-spectral imaging. Research and development of these new technologies must be supported if they are to become practical tools for resource managers.

The diverse and well-established urban forests in Hawaii are an extraordinary resource for local communities (*See Issue 4: Urban & Community Forestry*). However, these forests link ports with the native forests and could provide a bridge for the spread of introduced pests and pathogens into native forests. Establishing closer links between forest health, agriculture staff, and urban forest professionals will lead to the detection of these pests and diseases and analyze their impact. It will also promote the development of appropriate control measures and inform arborists and other interested parties on how to recognize and contend with these pests and pathogens.

A thorough risk assessment of pathways and pests that threaten Hawaii's native forests is required to provide important information for managers and quarantine agencies. A similar risk assessment that focuses on agriculture commodities has been made and an inspection 'blitz' at

the Kahului airport on the island of Maui several years ago pointed to several high-risk pathways and commodities. A forest pest risk assessment would build on these previous efforts and contribute greatly to the protection of Hawaii's native forests.

For invasive species monitoring, another data need is for close coordination between shippers and federal and local quarantine agencies. Creating the capacity for electronic, advance manifests for all incoming cargo will assist inspectors in targeting their inspections to the highest risk products.

There is also a gap of information to support candidates for HDOA's restricted and prohibited plant lists, the expansion of which could help protect forests from damaging pests. Most insects and plant pathogens arrive on imported plants—the more diverse the imported flora the higher the risk. Information on what plants are entering the state is very limited. Information on plant pests that are entering the state would be used to compile the necessary risk assessments to 'list' plants by the state agriculture agency. This information could also be used to get high risk species on USDA APHIS's "Not Approved Pending Risk Assessment" (NAPRA) list for plants for planting.

Strategies for Issue 2: Forest Health: Invasive Species, Insects & Disease

Although Hawaii is one of the most isolated island chains in the world, it is the center for travel and transport of goods to the Pacific and far west. As such, many non-native and invasive species and have been brought to these islands that threatened those that are native or endemic to Hawaii. Management of invasive species in the Pacific involves working in diverse landscapes from mauka to makai. Many species are initially detected in urban areas, around harbors and ports, along roadways, and in people's yards, but there are many more that go undetected. Where total eradication is not possible, invasive species can quickly spread to adjacent areas and eventually impact entire watersheds and/or ecological hydraulic functions. Much of Hawaii's low elevation forests are fractured into patches that are dominated by non-native incipient populations; whereas upland priority forested areas are more intact and encompass more native species. Maintenance & protection of these priority forests and suppression of encroaching lowland non-native species are equally important.

Forest Health: Suppression of Invasive Species							
Long Term Strategy	**Priority Landscape Areas**	**Secondary Issues Addressed**	**Program Areas that Contribute**	**Key Stakeholders**	**Resources Available & Partners**	**Measures of Success**	**Supports National Objectives**
1) Prevent harm from new invasive species by improving biosecurity policies.	Ports and harbors, urban areas, targeted upland areas, wildland urban interface.	Improved protection of T&E spp., improved hydraulic functions, coral reef protection.	HISC, HDOA, USDA APHIS, DHS CBP, Invasive Species Program (Wildlife), Forest Health, UCF, WPP, HTA, DOD, EQIP, FSCG,	Private landowners, NPS, TNC, HI Counties, public, DOD, HAWP, USFWS	Cargo fees, conveyance tax, state general funds, HDOA, CGAPS, HISC, FHP, PBIN, LICH, TNC, SPC, SPREP, HCA, USDA APHIS CAPS, USGS-BRD	Interceptions of forest weeds and pests by quarantine officials; Risk assessments.	1.2 2.2 3.1 3.4 3.5
2) Establish early detection networks & support island-wide eradication and containment of incipient species.	Ports, urban areas, wildland urban interface, degraded ecosystems.	Same as above	Same as above	Same as above	Same as above	Species eradicated; New state or island records; Acres surveyed/ treated for incipient invasive species.	1.2 2.2 3.1 3.4 3.5
3) Restore areas where invasive plants, insects, and disease have harmed forests.	Intact native forests; threatened ecosystems; watershed partnership lands.	Same as above	Watershed Partnerships, NARS, Wildlife, FRS, FHP, Stewardship,	Public, private landowners, TNC, DOD, HAWP, USFWS	State general, Natural Area Reserve Fund, FHP, USFWS, Stewardship	Acres forest restored.	1.2 2.2 3.1 3.4 3.5
4) Develop new tools to increase effectiveness of invasive plant, insect, and disease management, including biological control.	Intact native forests; threatened ecosystems; watershed partnership lands; commercial plantations.	Share new knowledge with the rest of the Pacific & Caribbean, T&E spp. Protection.	Invasive Species Program (Wildlife), Forest Health, Special Tech. Development Program, FSCG, NRCS	UH, USFWS, USDA APHIS WS, NWRC, HDOA, TNC, HARC, WPP, USGS-BRD	HISC, STDP IPIF, PSWRS, HDOA staff and facility, UH scientists, CGPS	Increased capacity to suppress invasive species, insects, and disease, improved Best Management Practices.	1.2 2.2 3.1 3.4 3.5

Strategies for Issue 2: Forest Health: Invasive Species, Insects & Disease

Forest Health: Outreach & Education

Long Term Strategy	Priority Landscape Area(s)	Secondary Issues Addressed	Program Areas that Contribute	Key Stakeholders	Resources Available & Implementing Partners	Measures of Success	Supports National Objectives
1) Increase public support and involvement in invasive species prevention and control.	Statewide	Increased funding, improved coral reef health.	Conservation Education, HISC, Invasive Species Program (Wildlife), FSCG, Forest Health, WPP, UCF, HCA	Public at large, agricultural & horticultural industries, urban forest users & workers, land management agencies	HISC, State special funds, CGAPS, LICH, AAA, DOFAW staff	More effective invasive spp. control messages to the public; combined funding.	1.2 2.2 3.1 3.4 3.5 3.6
2) Monitor invasive plants and damage or mortality caused by forest pests for trends to inform management activities.	Native and non-native forests; urban forests.	Utilize a variety of new technologies already available.	HISC, Invasive Species Program (Wildlife), Forest Health Protection, Forest Health Monitoring, UCF, WPP competitive grants	Public, agricultural industry, horticultural industry, urban forest users and workers, land management agencies	Conveyance Tax, state funds, HISC, CGAPS, Forest Health Monitoring Lab facilities	More informed decision making; appropriate funding levels for the profundity of problems we have.	1.2 2.2 3.1 3.4 3.5 3.6
3) Work with other programs ensuring integrative approaches to management of invasive species.	Statewide		Forest Health, UCF, FSP, Wildfire Conservation Education, FSCG	UCF, FSP Council, HAWP, HISC	DOFAW and US Forest Service personnel, CGAPS	Improvement in sharing resources.	1.2 2.2 3.1 3.4 3.5 3.6

Acronyms Used:

1. CZM – Coastal Zone Management
2. OHA – Office of Hawaiian Affairs
3. C&C – City & County of Government of Hawaii
4. AAA – Aloha Arborists Association
5. NARF – Natural Area Reserve Fund
6. Friends – Friends of Urban Forests
7. FRS – Forest Reserve System
8. DOFAW – EE – Environmental Educational
9. HARC – Hawaii Agriculture Research Center
10. LLCF - Legacy Land Conservation Program
11. FLP – Forest Legacy Program – Forest Service
12. FSCG - Forest Service Competitive Grants
13. DAR - Division of Aquatic Resources
14. Na Ala Hele – State Na Ala Hele Trails & Access Program
15. HISC – Hawaii Invasive Species Council
16. FSP – Forest Stewardship Program
17. CGAPS – Committee Group on Alien Pest Species
18. HCA – Hawaii Conservation Alliance
19. IPIF – Institute of Pacific Island Forestry
20. UCF – Urban & Community Forestry (Kaulunani)
21. NOAA – National Oceanographic and Atmospheric Administration
22. USGS – US Geological Service
23. YCC – Youth Conservation Corps

Strategies for Issue 2: Forest Health: Invasive Species, Insects & Disease

24. STDP - Special Technology Development Program
25. PSWRS – Pacific Southwest Research Station
26. HFIA – Hawaii Forest Industry Association
27. SPC – The Secretariat of the Pacific Community
28. SPREP – South Pacific Regional Environmental Program
29. FAO UN – Food and Agriculture Organization of the United Nation
30. SOPAC – Secretariat of the Pacific Applied Geoscience Commission
31. HFIA - Hawaii Forest Industry Association
32. SAF - Society of American Foresters
33. LICH – Landscape Industry Council of Hawaii
34. PBIN – Pacific Biodiversity Information Node

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Internet Resources

Hawaii's Invasive Species Partnerships – reports and strategic plans
http://www.hawaiiinvasivespecies.org/
Statewide Partnerships annual report for 2009:
http://www.hawaiiinvasivespecies.org/cgaps/whitepapersreports.html

Control of Rats:
http://removeratsrestorehawaii.org/
Kahalui Airport Risk Assessment:
http://hawaii.gov/hdoa/pi/pq/KARA
Hawaii Pacific Weed Risk Assessment
http://www.botany.hawaii.edu/faculty/daehler/wra/default2.htm

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