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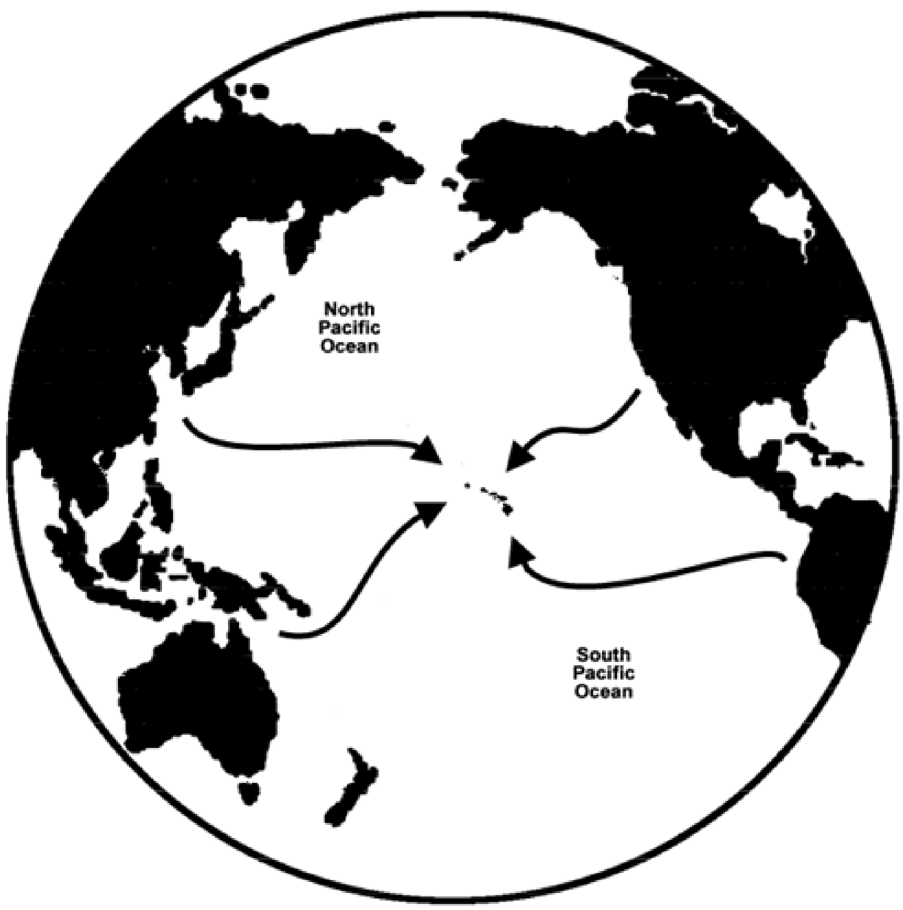
Risk and Pathway Assessment for the Introduction of Exotic Insects and Pathogens That Could Affect Hawai‘i’s Native Forests

Gregg A. DeNitto, Philip Cannon, Andris Eglitis, Jessie A. Glaeser, Helen Maffei, and Sheri Smith



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Abstract

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The unmitigated risk potential of the introduction of exotic insects and pathogens to Hawai‘i was evaluated for its impact on native plants, specifically *Acacia koa, Cibotium* spp., *Dicranopteris linearis*, *Diospyros sandwicensis*, *Dodonaea viscosa*, *Erythrina sandwicensis*, *Leptecophylla tameiameiae*, *Metrosideros polymorpha*, *Myoporum sandwicense*, *Pandanus tectorius*, *Scaevola* spp., *Sophora chrysophylla*, and *Vaccinium* spp. Assessments were made by estimating the likelihood and consequences of introduction of representative insects and pathogens of concern. Likely pathways of introduction were assessed. Twenty-four individual pest risk assessments were prepared, 12 dealing with insects and 12 with pathogens. The selected organisms were representative examples of insects and pathogens found on foliage, on the bark, in the bark, and in the roots and wood of the native hosts of interest—or closely related host species—in other parts of the world.

Among the insects and pathogens assessed, high risk potentials were assigned to the following 16 organisms or groups of organisms: apple stem borer (*Aeolesthes holosericea*), coconut rhinoceros beetle (*Oryctes rhinoceros*; during the analysis this insect was identified as present in Hawai‘i), keyhole ambrosia beetle (*Amasa truncata*), summer fruit tortrix moth (*Adoxophyes orana*), West Indian sugarcane borer weevil (*Diaprepes abbreviatus*), white wax scale (*Ceroplastes destructor*), *Acacia* gall rust pathogen (*Uromycladium tepperianum*), Armillaria root disease pathogens (*Armillaria luteobubalina*, *A. tabescens*, *A. limonea*, *A. novae-zelandiae*), *Calonectria morganii*, *Fomitiporia* spp. (*Fomitiporia australiensis*, *F. mediterranea*, *F. punctata* species complex, *F. robusta* species complex, *F. sonorae*), guava rust/eucalyptus rust pathogen (*Puccinia psidii*), *Phellinus noxious*, pink disease pathogen (*Erythricium salmonicolor*), ramorum blight/sudden oak death pathogen (*Phytophthora ramorum*), Uromyces rust pathogens (*Uromyces scaevolae*, *U. sophorae-japonicae*, *U. truncicola*), and white thread blight pathogen (*Ceratobasidium noxium*). A moderate risk potential was assigned to the following eight organisms or groups of organisms: Botany Bay diamond weevil (*Chrysolopus spectabilis*), coconut stick insect (*Graeffea crouanii*), *Erythrina* scale (*Toumeyella erythrinae*), Eugenia psyllid (*Trioza eugeniae*), lemon tree borer (*Oemona hirta*), Platypodid ambrosia beetle (*Megaplatypus mutatus*), *Aecidium* rust pathogens (*Aecidium atrocrustaceum*, *A. calosporum*, *A. carbonaceum*, *A. diospyri*, *A. mabae*, *A. melaenum*, *A. muelleri*, *A. miliare*, *A. myopori*, *A. ramosii*, *A. reyesii*, *A. rhytismoideum*, *A. royenae*, *A. ulei*, *A. yapoense*) and *Pestalotia*/*Pestalotiopsis* leaf and fruit pathogens (*Pestalotia acacia*, *P. cibotii*, *P. diospyri*, *P. dodonaea*, *P. pandani*, *P. vaccinii*, *Pestalotiopsis* sp., *P. breviseta*, *P. glandicola*, *P. palmarum*, *P. photiniae*, *P. theae*, *P. uvicola*, *P. versicolor).*

Six priority findings resulted from the analysis:

1. Inspection alone is not 100 percent effective in preventing introductions.
2. The primary sources of introductions are the mainland the United States and Asia-Pacific.
3. There is a strong need to make visitors aware that they are a significant potential source of unwanted introductions.
4. Plant materials, especially live plants, are by far the most important source of pest problems for Hawai‘i.
5. The solid wood packing material pathway needs more scrutiny. Many pests using this pathway have already become established in Hawai‘i, and many more are on the list of potentials. Because Hawai‘i Department of Forestry can only inspect wood packing material that is associated with agricultural commodities, and because wood packing material is not necessarily specified as associated with cargo, this is potentially a pathway that is being insufficiently inspected and regulated.
6. The interstate movement of certain plant materials from Hawai‘i to the mainland is restricted without treatment and certification. Similar restrictions on interstate movement into Hawai‘i are not in place. For the most part, Animal Plant and Health Inspection Service regulations do not discriminate between the mainland and islands of Hawai‘i as far as potential threats. This includes some organisms that are native or commonly found on the mainland.

Numerous other observations, both specific and general, are included in the pest risk assessment concerning detection surveys, regulations, and public education/public awareness of the dangers of introduced pests and pathogens.

Keywords: Pest risk assessment, Hawai‘i, invasive species, *Acacia koa*, *Cibotium*, *Dicranopteris linearis*, *Diospyros sandwicensis*, *Dodonaea viscosa*, *Erythrina sandwicensis*, *Leptecophylla tameiameiae*, *Metrosideros polymorpha*, *Myoporum sandwicense*, *Pandanus tectorius*, *Scaevola*, *Sophora chrysophylla*, *Vaccinium*.

Executive Summary

Background, Objectives, and Scope

Hawai‘i is unique amongst the 50 states; it was formed and developed over the millennia independently of any other land mass. This has resulted in very unique and distinct species and ecosystems on each island. Because of its geographic isolation, the state also has a rare economic situation, with almost all goods needing to be imported. Over the past decades, insects and pathogens accidently introduced into Hawai‘i threaten native forest ecosystems and urban forest trees. These introductions have increased awareness of the vulnerability of island ecosystems and the need for vigilance regarding invasive species beyond those affecting agricultural crops.

In September 2010, the Hawai‘i Division of Forestry and Wildlife (HDOFAW) requested the U.S. Department of Agriculture (USDA) Forest Service to prepare a pest risk assessment. The specific objectives of the risk assessment are to:

- Identify specific insect pest and pathogen species that could attack species of concern in Hawai‘i.
- Determine possible pathways for the introduction of insect pests and pathogens to selected native flora of Hawai‘i.
- Provide risk assessments for selected pathway/pest or pathogen combinations that are determined to be of most risk to Hawai‘i forest ecosystems.

The insect and pathogen threats identified in this assessment should represent hereto unknown threats that use similar transport pathways and occupy similar ecological niches. Our expertise did not include other types of pests, such as invasive plants, and these are not included in this assessment.

The scope of this risk assessment is limited to insect and mite pests and disease threats to 13 plant species/genera (hereafter referred to as “taxa”) identified by HDOFAW.

Species of interest identified by Hawai‘i Department of Land and Natural Resources, Division of Forestry and Wildlife, included in this pest risk assessment:

Species of interest	Family	Native name	Common English name
Acacia koa A. Gray	Fabaceae	Koa	Koa
Cibotium spp. Kaulf.	Cibotiaceae	Hāpu‘u	Hawaiian tree fern
Dicranopteris linearis (Burm. F) Underwood	Gleicheniaceae	Uluhe	False staghorn fern
Diospyros sandwicensis (A. DC.) Fosberg	Ebenaceae	Lama	Hawaiian ebony
Dodonaea viscosa (L.) Jacq.	Sapindaceae	‘A‘ali‘i	Hawaiian hopseed bush
Erythrina sandwicensis O. Deg.	Fabaceae	Wiliwili	Hawaiian coral tree

Leptecophylla tameiameiae (Cham. & Schltdl.) C.M. Weiller	Ericaceae	Pūkiawe	Hawaiian heather
Metrosideros polymorpha Gaud.	Myrtaceae	‘Ōhi‘a lehua	Ohia
Myoporum sandwicense (A. DC.) A. Gray	Scrophulariaceae	Naio	False-sandalwood
Pandanus tectorius Parkinson ex Zucc.	Pandanaceae	Hala	Hawaiian screwpine
Scaevola spp. L.	Goodeniaceae	Naupaka kuahiwi	Naupaka
Sophora chrysophylla (Salisb.) Seem.	Fabaceae	Māmane	Mamani
Vaccinium spp. L.	Ericaceae	Ōhelo	Ohelo

Risk Assessment Team

The USDA Forest Service Wood Import Pest Risk Assessment and Mitigation Evaluation Team (WIPRAMET) conducted the assessment. The team was originally chartered by the Chief of the Forest Service to provide a permanent source of technical assistance to the Animal and Plant Health Inspection Service in conducting pest risk assessments on forest trees. The team was chosen to perform this assessment because of its expertise and previous experience with similar assessments. Additional members with local knowledge of Hawai‘i and its resources were added to the WIPRAMET to supplement the original risk assessment team.

Pest Risk Assessment

The approach taken for this project followed protocols established by international plant protection organizations. The team evaluated the risk potential of the introduction of exotic insects and pathogens that could affect 13 native plant taxa.

We identified known pests on the hosts known to exist in Hawai‘i. We compiled a similar list of worldwide insects and pathogens not known to occur in Hawai‘i and recorded in association with the 13 taxa or other species of the same genera. These insects and pathogens were identified, listed, and targeted for further analysis as “agents of potential concern.”

We assessed information on commodities associated with pathways of introduction. This included a variety of data from U.S. and foreign sources. This aided in determining the likelihood of pests associated with commodities and their likelihood of introduction to Hawai‘i.

Because major emphasis was placed on pests with the potential to be transported on, in, or with a variety of commodities, these insect and pathogen agents of concern were evaluated with respect to the four principal pathways by which introduction of these insects and pathogens might occur: (1) plant material, (2) wood products, (3) hitchhikers, and (4) potting media/compost/soil.

Analysis of transport and establishment pathways also included assessment of the following:

1. Identify probable major geographic sources of potential pest introductions (based on the origin of foreign trade by all means of transportation to Hawai‘i.
2. Determine the likelihood of different pathways introducing exotic pests.
3. Evaluate pest interception records at Hawaiian ports of entry.
4. Evaluate historical information on the transport and establishment of damaging insects and pathogens in Hawai‘i or areas with similar climates and ecosystems.

Insect pests and pathogens not known to occur in Hawai‘i and associated with a likely commodity were identified to aid the team in performing more detailed risk assessments. Individual pest risk assessments (IPRAs) were then developed for the highest ranked agents: 12 dealing with insects and 12 dealing with pathogens. These 24 agents are intended to serve as examples of specific pests that presently pose a significant threat to native Hawaiian shrubs and trees. They are also representatives of general types of damaging insect and disease agents, following select pathways, specific modes of establishment, and causing damage that is unknown to presently occur in Hawai‘i, but may emerge in the future. Ranking was based on the following overall criteria: the probability of pest introduction (likely pathway to Hawai‘i), including association with a commodity; transit success; colonization success; and potential for spread; and the consequence of introduction, including economic, environmental, and sociopolitical. The individual elements were ranked and an overall risk potential was assigned to each of the 24 species.

Forest Resources of Hawai‘i

The archipelago of Hawai‘i consists of 132 islands, reefs, atolls, and shoals, over a distance of 2400 km, in the North Pacific Ocean. There are eight major islands. Hawai‘i is covered by about 707 400 ha of forest, which is 43 percent of the total land area. About 1,200 taxa of flora are native to the Hawai‘i Islands, including 1,158 that are endemic. The species chosen for this assessment include pteridophytes, woody trees and shrubs, and a monocotyledonous species. The 13 taxa are ecologically important forest species that provide habitat for native fauna and flora in Hawaiian forest ecosystems. If extirpated, it is assumed that any one of these species could have cascading deleterious effects on many other native species. It follows that improving biosecurity for these species will better protect Hawai‘i’s remaining biodiversity.

Numerous insects and pathogens have been identified on these 13 taxa, some of which are native and others introduced to Hawai‘i. For each of the 13 forest taxa, we examined the literature and consulted with other scientists and specialists to determine the insects and pathogens that occur on them in Hawai‘i. Nearly 500 insects and over 500 pathogens and saprobes were identified during this process. Although every effort was made to be complete, likely a number of species were missed.

Commodities and Pathways

Hawai‘i receives all of its commodities and visitors either by ship or aircraft. This provides many pathways and commodities to transit invasive species. Several pathways may exist for a single organism. We developed a means to identify pathways based on the location on the host plant where the pest can occur. Pathways included plant material, wood products, hitchhikers, and potting media/compost. Each of these pathways has multiple commodities in which exotic pests may find transport.

A significant source of potential pest entry is on solid wood packing material. This includes dunnage, crating, pallets, packing blocks, drums, cases, and skids. The origin of this material is not necessarily the same as that of the shipment it accompanies, as it is routinely reused and reconditioned. On September 16, 2005, the United States started enforcing the International Plant Protection Convention’s standard ISPM No. 15 to reduce the risk posed by solid wood packing material.

Airline passengers are another major source for potential pest entry. Over 70 percent of airline passengers arriving by air to Hawai‘i from 2007 to 2011 were from the mainland United States. The principal country of origin for foreign arrivals was Japan, followed by Canada. The Animal and Plant Health Inspection Service (APHIS) intercepted over 7,400 reportable pests at airports from 1984 through 2010. Many of these came in with passengers and their baggage.

Plants for horticultural use are continually arriving in Hawai‘i from foreign and domestic locations. Many of these have become invasive and are affecting native ecosystems. In addition, they may be carriers for invasive insects and pathogens. The primary and most consistent exporting countries for this material are Australia and the Netherlands.

During the period 2008 to 2010, the top countries exporting to Hawai‘i based on value of exports were Indonesia, Saudi Arabia, Vietnam, Russia, Thailand, and China. Eight of the top 10 are in the Asia-Pacific region. Using commodity value may not be the best measure to evaluate potential origins of pests but are the only data readily available.

Insects and Pathogens Posing Risk

The probability of pest introduction is determined by several related factors, including the likelihood of (1) a pest traveling with and surviving on a shipment from the place of origin, (2) a pest colonizing suitable hosts at the point of entry and during transport to processing sites, and (3) subsequent pest spread to adjacent territories. Many insects and pathogens could be introduced on various commodities into Hawai‘i from any origin in the world.

Nearly 500 insects and 400 pathogens were identified in this assessment as potentially posing risk. These were narrowed down to 12 insect species and 12 pathogens to do indepth IPRAs. The following table provides a summary of the ratings for the individual risk elements and the overall risk potential for each of the 24 species evaluated.

Summary of risk potentials for pests of concern to 13 Hawai‘i forest tax[a]

Common name (scientific name)	Likelihood of introduction				Consequences of introduction			
	Host association	Entry potential	Colonization potential	Spread potential	Economic damage	Environmental damage	Social/ political	Pest risk potential
Insects:								
Apple stem borer (*Aeolesthes holosericea*)	H[a]	H	H	H	H	H	M	H
Botany Bay diamond weevil (*Chryosolopus spectabilis*)	M	H	M	M	M	M	L	M
Coconut rhinoceros beetle (*Oryctes rhinoceros*)	H	H	H	H	M	M	M	H
Coconut stick insect (*Graeffea crouanii*)	M	M	M	L	L	L	M	M
Erythrina scale (*Toumeyella Erythrinae*)	M	H	L	M	M	M	M	M
Eugenia psyllid (*Trioza eugeniae*)	M	H	H	M	M	M	M	M
Keyhole ambrosia beetle (*Amasa truncata*)	H	H	H	H	M	L	M	H
Lemon tree borer (*Oemona hirta*)	M	M	H	M	M	M	L	M
Platypodid ambrosia beetle (*Megaplatypus mutatus*)	M	H	H	H	M	M	M	M
Summer fruit tortrix moth (*Adoxophyes orana*)	H	H	H	H	M	H	M	H
West Indian sugarcane borer weevil (*Diaprepes abbreviatus*)	H	H	H	H	H	H	M	H
White wax scale (*Ceroplastes destructor*)	H	H	H	H	H	H	M	H
Pathogens:								
Acacia gall rust (*Uromycladium tepperianum*)	H	H	H	H	M	M	M	H
Aecidium rusts (*Aecidium atrocrustaceum*, *A. calosporum*, *A. carbonaceum*, *A. diospyri*, *A. mabae*, *A. melaenum*, *A. muelleri*, *A. myopori*, *A. ramosii*, *A. reyesii*, *A. rhytismoideum*, *A. royenae*, *A. ulei*,	M	H	M	H	L	M	L	M

A. yapoense)								
Armillaria root disease (*Armillaria limonea*, *A. luteobubalina*, *A. novae-zelandiae*, *A. tabescens*)	H	H	H	H	H	H	H	H
Calonectria morganii	H	H	H	H	M	M	L	H
Fomitiporia spp. (*Fomitiporia australiensis*, *F. mediterranea*, *F. punctata*, *F. robusta*, *F. sonorae*)	H	H	H	H	M	H	H	H
Guava rust/eucalyptus rust (*Puccinia psidii*)	H	H	H	H	H	H	H	H
Pestalotia and *Pestalotiopsis* (*Pestalotia Acacia*, *P. cibotii*, *P. diospyri*, *P. dodonaea*, *P. pandani*, *vaccinii*; *Pestalotiopsis* sp., *P. breviseta*, *P. glandicola*, *P. palmarum*, *P. photiniae*, *P. theae*, *P. uvicola*, *P. versicolor*)	H	H	M	H	L	M	L	M
Phellinus noxius	H	H	H	H	M	H	H	H
Pink disease (*Erythricium salmonicolor*)	H	H	H	H	H	H	H	H
Ramorum blight /sudden oak death (*Phytophthora ramorum*)	H	H	H	H	H	M	H	H
Uromyces rusts (*Uromyces scaevolae*, *U. sophorae-japonicae*, *U. truncicola*)	M	H	M	M	L	H	L	H
White thread blight/black rot (*Ceratobasidium noxium*)	H	H	H	H	M	M	M	H

[a] H, M, and L = high, moderate, and low risk, respectively.

Conclusions

A major challenge of this analysis was to determine which of the world's 400,000 fungal species and 900,000 insect species known to feed on plant/plant parts are not yet found in Hawai‘i and pose a risk to 13 native forest taxa in the Hawaiian Islands. Although this process may seem straightforward, the lists that were produced of potential pests and pathogens for each of the 13 taxa are considerable. For some species, like *Acacia koa*, this process produced lists of literally thousands of fungi and insect species that have been associated with *Acacia* species. This is, in large measure, due to the abundance of land area worldwide covered by the 700 different species of *Acacia* and the fact that thousands of forest health personnel, mycologists, entomologists, etc. have spent large portions of their careers looking at the flora and fauna that affect species in this genus. *Metrosideros polymorpha* was another key species that had a lot of fungi associated with it, no doubt because there are so many *Metrosideros* species scattered across the Pacific. By contrast, some of the other species, like *Sophora chrysophylla*, *Myoporum sandwicensis*, and *Scaevola* spp., had very short lists associated with them because their genera hold relatively small numbers of species and individuals.

We examined the lists of exotic fungal and insect species for those considered to have capacity to be effective pathogens or pests on living trees. We relied on information presented in the literature, where this was available, and also on the experience of the authors and reviewers of this document. This helped us narrow the list to the 400 insect pests and 300 pathogens shown in tables 11 and 12, respectively (app. 7). These tables represent what we consider the insect pests and pathogens with the most potential for damaging the 13 taxa should they gain entry into Hawai‘i.

We identified 12 insect pests and 12 pathogens to do indepth analyses or IPRAs. The objective was to include in the IPRAs representative examples of insects and pathogens found on seeds, roots, bark, sapwood, and heartwood that would have the greatest potential risk to forests and other tree resources of Hawai‘i. These agents were highly diverse ranging from leaf rollers and scales to root diseases, stem decay, and leaf blights.

Among the insects and pathogens assessed, high pest risk potentials were assigned to the following 16 organisms or groups of organisms: apple stem borer (*Aeolesthes holosericea*), coconut rhinoceros beetle (*Oryctes rhinoceros*; during the analysis, this insect was identified as present in Hawai‘i), keyhole ambrosia beetle (*Amasa truncata*), summer fruit tortrix moth (*Adoxophyes orana*), West Indian sugarcane borer weevil (*Diaprepes abbreviatus*), white wax scale (*Ceroplastes destructor*), *Acacia* gall rust pathogen (*Uromycladium tepperianum*), Armillaria root disease pathogens (*Armillaria luteobubalina*, *Armillaria tabescens*, *A. limonea*, *A. novae-zelandiae*), *Calonectria morganii*, *Fomitiporia* spp. (*Fomitiporia australiensis*, *F. mediterranea*, *F. punctata* species complex, *F. robusta* species complex, *F. sonorae*), guava rust/eucalyptus rust pathogen (*Puccinia psidii*), *Phellinus noxious*, pink disease pathogen (*Erythricium salmonicolor*), Ramorum blight/sudden oak death pathogen (*Phytophthora ramorum*), Uromyces rust pathogens (*Uromyces scaevolae*, *U. sophorae-japonicae*, *U. truncicola*), and white thread blight pathogen (*Ceratobasidium noxium*). A moderate pest risk potential was assigned to the following eight organisms or groups of organisms: Botany Bay diamond weevil (*Chrysolopus spectabilis*), coconut stick insect (*Graeffea crouanii*), Erythrina scale (*Toumeyella erythrinae*), Eugenia psyllid (*Trioza eugeniae*), lemon tree borer (*Oemona hirta*), Platypodid ambrosia beetle (*Megaplatypus mutatus*), Aecidium rust pathogens (*Aecidium atrocrustaceum*, *A. calosporum*, *A. carbonaceum*, *A. diospyri*, *A. mabae*, *A. melaenum*, *A. muelleri*, *A. miliare*, *A. myopori*, *A. ramosii*, *A. reyesii*, *A. rhytismoideum*, *A. royenae*, *A. ulei*, *A. yapoense*), and Pestalotia/Pestalotiopsis leaf and fruit pathogens (*Pestalotia acacia*, *P. cibotii*, *P. diospyri*, *P. dodonaea*, *P. pandani*, P. *vaccinii*, *P. glandicola*, *Pestalotiopsis* sp., *P. breviseta*, *P. glandicola*, *P. palmarum*, *P. photiniae*, *P. theae*, *P. uvicola*, *P. versicolor*).

As part of our process, we solicited input on existing and potential pests, as well as comment on a draft risk assessment, from scientists and specialists around the world. We received over 400 comments. These were extremely helpful and informative to our assessment.

Six priority findings resulted from the analysis. Some of them have been reported in other assessments (Culliney et al. [n.d]., Meissner et al. 2009) and have been adopted by us as appropriate for Hawai‘i because they are integral to invasive species transport and risk around the world. Some are more peculiar to Hawai‘i.

The six findings discussed in detail are:

1. Inspection alone is not 100 percent effective in preventing introductions. In fact, some studies have shown that port inspections, alone, have relatively low interception efficiency.
2. The primary sources of introductions are the mainland United States and Asia-Pacific.
3. There is a strong need to make visitors aware that they are an important potential source of unwanted introductions. Given what we know about plant materials as an important pathway of pest introduction, there needs to be increased efforts to persuade visitors to voluntarily stop bringing live plant material into Hawai‘i.
4. Plant materials, especially live plants, are by far the most important source of pest problems for Hawai‘i.
5. The solid wood packing material pathway needs more scrutiny. Many pests using this pathway have already become established in Hawai‘i, and many more are on the list of potentials. Because Hawai‘i’s Department of Agriculture can only inspect solid wood packing material that is associated with agricultural commodities, and because solid wood packing material is not necessarily specified as associated with cargo, it seems as if this could potentially be a pathway that is being insufficiently inspected and regulated.
6. Some pests not posing a risk to the mainland United States, or already present in the mainland, may be a potential threat to Hawai‘i. The interstate movement of certain plant materials from Hawai‘i to the mainland is restricted without treatment and certification. Similar restrictions on interstate movement into Hawai‘i are not in place. For the most part, APHIS regulations do not discriminate between the mainland and islands of Hawai‘i as far as potential threats. This includes some organisms that are native or commonly found on the mainland.

Numerous other observations, both specific and general, are included in the “Pest Risk Assessment” concerning detection surveys, regulations, and public education and awareness of the dangers of introduced pests and pathogens.

Contents

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Chapter 1: Introduction

Background

As a tourist destination, military base, and center for commerce at the "crossroads of the Pacific," Hawai'i is especially vulnerable to the introduction and establishment of exotic organisms. The likelihood is especially high because Hawai'i imports 80 percent of its consumable goods and has a climate favorable to many insects and pathogens year-round. An estimated 9,277 terrestrial arthropod species are known from Hawai'i; 3,432 (37 percent) are nonindigenous (Eldredge 2006). Some 500 species of arthropods and mollusks in Hawai'i can be classified as pests (Beardsley 1991). Of these, 98 percent have been introduced. It is estimated that 20 to 40 new terrestrial arthropod introductions occured in Hawai'i each year from 1937 through 1967 (Beardsley 1979a), with about 10 percent becoming significant pests. In recent years, the rate of new pest arthropods and mollusks establishing in Hawai'i has averaged 3.5 species annually (Beardsley 1991). In addition, over 1,100 plant parasitic and pathogenic species (nematodes, bacteria, fungi, and other micro-organisms) are known to occur in Hawai'i (Raabe et al. 1981). Most of these are nonindigenous. The islands of Hawai'i have a large number of endemic species. Because most of these endemic species have evolved in isolation—free from pressures such as grazing, predation, virulent pests, and diseases (Westbrooks 1998)—the biota lacks defenses against introduced grazers, predators, parasites, and pathogens (Simberloff 1995). Thus, like other oceanic islands, Hawai'i is particularly vulnerable to biological invasions. For example, although Hawai'i is one of the smallest U.S. states, comprising just 0.2 percent of its total land mass, more than 25 percent of the endangered species in the United States occur there (U.S. Congress OTA 1993).

Over the past decade, insects and pathogens accidently introduced into Hawai'i threaten native forest ecosystems and urban forest trees. These introductions have increased awareness of the vulnerability of island ecosystems, and the need for vigilance regarding invasives beyond those affecting agricultural crops.

For example, the two-spotted leafhopper (*Sophonia rufofascia*[1]) was discovered on O'ahu in 1987 after being detected on plants exported to California (Fukada 1996). By 1995, the insect was widespread on the six largest Hawaiian Islands, and causing major damage to uluhe (*Dicranopteris linearis*), 'ōhi'a lehua (*Metrosideros polymorpha*), and hāpu'u (*Cibotium* spp.), as well as significant damage to 'a'ali'i (*Dodonaea viscosa*) and 'ōhelo (*Vaccinium* spp.) (Conant et al. 2010). Ornamental *Erythrina* species were all but wiped out when the Erythrina gall wasp (*Quadrastichus Erythrinae*) invaded Hawai'i in 2005 and escaped into the forests, killing the native *Erythrina* species as well. *Myoporum sandwicense*, which comprises nearly half of the plant biomass in the māmane-naio forest type, is now threatened by a recently introduced myoporum thrips (*Klambothrips myopori*). Although the strain of guava rust (*Puccinia psidii*) recently found in Hawai'i is not significantly impacting native ecosystems, the threat is great that new genotypes of the rust will invade and threaten 'ōhi'a lehua, one of Hawai'i's dominant forest tree species. Koa wilt, caused by the fungal pathogen *Fusarium oxysporum* f. sp. *koae*, is of unknown origin. The wilt disease is greatly affecting survival, growth, and reforestation of koa (*Acacia koa*), a dominant canopy tree and important in native culture. As this assessment was being completed, coconut rhinoceros beetle (*Oryctes rhinoceros*) was trapped at Joint Base Pearl Harbor-Hickam on O'ahu (HDOA 2014). The source of this introduction has not been determined, but the insect has been on Guam at least 6 years. Hawai'i has a long history of implementing quarantines to protect key agricultural crops. The same level of effective quarantines is sought for native forest species.

In September 1995, the Chief of the U.S. Department of Agriculture, Forest Service (USDA FS) chartered the Wood Import Pest Risk Assessment and Mitigation Evaluation Team (WIPRAMET), made up of USDA FS employees, to provide a permanent source of technical assistance to the USDA Animal and Plant Health Inspection Service

[1] Scientific authorities for insects, pathogens, and plants mentioned in chapters 1, 2, 3, and 5 are given in appendix 2. Appendices for this report are available online at: http://www.fs.fed.us/psw/publications/documents/psw_gtr250/psw_gtr250_appendix.pdf.

(APHIS) in conducting pest risk assessments of exotic pests that may move with logs. In September 2010, the Hawai‘i Division of Forestry and Wildlife (DOFAW) made a request of the USDA FS to provide assistance in developing a pathway risk assessment for forest pests. They requested assistance in identifying high-risk pest species that are likely to become established in Hawai‘i upon arrival, as well as the pathways through which they could enter the state. This report is a response to that request. Because of the expertise within WIPRAMET, and the similarity with previous work, the request from DOFAW was assigned to this team.

Objectives

The specific objectives of this risk assessment are to:

- Identify insect pest and pathogen species that could attack species of concern in Hawai‘i.
- Determine possible pathways for the introduction of insect pests and pathogens to selected native flora of Hawai‘i.
- Provide risk assessments for selected pathway/pest or pathogen combinations that are determined to be of most risk to Hawai‘i forest ecosystems.

This information may be used to support quarantine protection, prioritize inspections, implement early detection surveys, develop rapid response plans, and educate the public. Alternatives from this assessment will be made available to regulatory personnel.

Scope of Assessment

As the native flora of Hawai‘i includes over 1,100 species (Eldredge and Evenhuis 2002), conducting risk analyses for all species is beyond the scope of this effort. For feasibility, the scope of this risk assessment is limited to insect and mite pests and disease threats to 13 plant species/genera (hereafter referred to as “taxa”) identified by DOFAW (table 1). While much attention is paid to the recovery of threatened and endangered species in Hawai‘i, the dominant forest species that provide habitat for them are vulnerable to pest outbreaks. The species chosen for this assessment include pteridophytes, woody trees and shrubs, and a monocotyledenous species, all of which make up the foundation of remaining Hawaiian ecosystems, and if extirpated, would have cascading effects on those ecosystems. Although there are other species that should arguably be included, to make the task manageable, the list was limited to these 13.

Table 1—Species of interest identified by Hawai‘i Department of Land and Natural Resources, Division of Forestry and Wildlife, included in this pest risk assessment

Species of interest	Family	Native name	Common English name
Acacia koa A. Gray	Fabaceae	Koa	Koa
Cibotium spp. Kaulf.	Cibotiaceae	Hāpu‘u	Hawaiian tree fern
Dicranopteris linearis (Burm. F) Underwood	Gleicheniaceae	Uluhe	False staghorn fern
Diospyros sandwicensis (A. DC.) Fosberg	Ebenaceae	Lama	Hawaiian ebony
Dodonaea viscosa (L.) Jacq.	Sapindaceae	‘A‘ali‘i	Hawaiian hopseed bush
Erythrina sandwicensis O. Deg.	Fabaceae	Wiliwili	Hawaiian coral tree
Leptecophylla tameiameiae (Cham. & Schltdl.) C.M. Weiller	Ericaceae	Pūkiawe	Hawaiian heather
Metrosideros polymorpha Gaud.	Myrtaceae	‘Ōhi‘a lehua	Ohia
Myoporum sandwicense (A. DC.) A. Gray	Scrophulariaceae	Naio	False-sandalwood
Pandanus tectorius Parkinson ex Zucc.	Pandanaceae	Hala	Hawaiian screwpine
Scaevola spp. L.	Goodeniaceae	Naupaka kuahiwi	Naupaka
Sophora chrysophylla (Salisb.) Seem.	Fabaceae	Māmane	Mamani
Vaccinium spp. L.	Ericaceae	Ōhelo	Ohelo

This list originated with the Natural Area Reserve System Commission, an independent group that advises the state on managing special lands that have been set aside because of their unique biological qualities. The list was reviewed by various resource managers, botanists, as well as the state forestry agency. By improving biosecurity for these species, a large portion of Hawai‘i’s remaining biodiversity will be better protected.

This risk assessment estimates the qualitative likelihood that exotic pests will be introduced into Hawai‘i as a direct result of the importation of a variety of commodities. Pests addressed in this report are phytophagous insects and plant pathogens. Major emphasis is placed on pests with the potential to be transported on, in, or with a variety of commodities. This assessment also estimates the economic and environmental impact of potentially destructive organisms if introduced into Hawai‘i. Our expertise does not include other types of pests, such as invasive plants, which are, therefore, not included in this assessment.

This risk assessment is developed without regard to available mitigation measures already in place. Once potential risks are identified, other suitable mitigation measures may be formulated, if needed, to reduce the likelihood that destructive pests will be introduced into Hawai‘i and pose a risk to the above 13 host taxa. The prescription of mitigation measures, however, is beyond the scope of this assessment and is the responsibility of APHIS and the Hawai‘i Department of Agriculture (HDOA).

Additional information became available and conditions changed as this report was in preparation. The authors attempted to keep up to date with these changes, but not all were timely in their receipt or our awareness and could not be fully incorporated.

Existing Import Regulations and Practices

The HDOA is legally mandated to protect the agricultural and natural resources of the state of Hawai‘i (Hawai‘i Revised Statutes Chapter 150A 2010). This statute provides HDOA with the authority to identify specific plants that may be detrimental or potentially harmful to agriculture, horticulture, the environment, or animal or public health, or that spread or may be likely to spread an infestation or infection of an insect, pest, or disease that is detrimental or potentially harmful to agriculture, horticulture, the environment, or animal or public health. All agricultural items, including plants, plant parts, nondomesticated animals, micro-organism cultures, microbial products, arthropods, and soil require inspection upon arrival in Hawai‘i. These items must be checked before the shipment can be released to ensure they are free of pests or will not become pests themselves. People arriving in Hawai‘i from the U.S. mainland must declare agricultural items brought into the state on the “Plants and Animals Declaration Form” and present these items for inspection to a HDOA plant quarantine inspector in the baggage claim area at airports and maritime ports.

Commodities moving domestically from the U.S. mainland are under the rules and regulations of HDOA. Shippers of these domestic commodities are required to notify HDOA of incoming shipments that require inspection. The HDOA inspects cargo based on assigned risk categories; all cargo does not receive inspection because of staffing capacity. Risk categories are determined based on the type of commodity, records of past interceptions, and specific pests potentially associated with the commodity.

General guidelines for the importation of plants from the U.S. mainland to Hawai‘i are as follows:

- All plants require inspection upon entry into the state (however, because of limited staffing, this is not always achieved).
- Plants must be apparently free of insects and diseases.
- Plants do not need to be bare-rooted, but the growing media cannot contain soil.
- Parcels brought into the state by mail or cargo must be clearly labeled with the words “Plant Materials” or “Agricultural Commodities.”
- Shipments must be accompanied by an invoice or packing manifest, listing the contents and quantities of the commodities imported.

The USDA regulates the introduction of plants and plant products into the United States from foreign origin under the authority of the Plant Protection Act of 2000

(Plant Protection Act 2000). The Department of Homeland Security, Bureau of Customs and Border Protection (CBP) is authorized to inspect foreign travelers and nonpropagative agricultural commodities for potential harmful pests. Officers and specialists within CBP inspect arrivals by air and sea using procedures similar to the HDOA's. The USDA APHIS Plant Protection and Quarantine (PPQ) performs the inspection of propagative plant materials.

Previous Hawai‘i Pest Risk Assessments

In 2007, APHIS conducted a pathway risk assessment for Hawai‘i (Culliney et al., n.d.), focusing on invasive species that threaten the state's economy and environment. That assessment reviewed risks associated with airline passengers, cargo, hitchhikers, wood packaging material, and the military. It listed imminent pest threats to Hawai‘i agriculture. Although never finalized, the draft assessment provides a foundation to build upon for analyzing the invasive pest threat to native forest species. This current assessment relied heavily on the draft 2008 APHIS assessment for background information and for data on Hawai‘i and its trade.

In addition to the APHIS assessment (Culliney et al., n.d.), HDOA prepared a pest risk assessment for the Kahului Airport in 2002 (HDOA 2002). That assessment was based on inspection "blitzes" conducted during 2000 and 2001, where HDOA inspectors and detector dogs examined checked and carry-on baggage, aircraft cabins and cargo holds, and 100 percent of all agricultural products shipped by air cargo. They found an average of one new invertebrate or plant pathogen per day arriving in agricultural cargo through a port that receives only 2 percent of Hawai‘i's incoming goods. Although primarily focused on inspection of agricultural products, that 2002 assessment does provide critical information regarding entry pathways, interception rates, and commodities entering the state, some of which may be relevant to the current investigation.

To address the invasive species problem in Hawai‘i, the origins of alien species, and the means or "pathways" by which they are introduced into the state, must be examined. To date, no pathway analysis has been conducted to assess and quantify the risks posed by invasive insect and pathogen species to Hawai‘i's native forest systems. Such an assessment is essential to provide a sound basis for science-based decisionmaking. Unfortunately, we did not have access to sufficient data to properly do a quantitative analysis.

Pest Risk Assessment Process Overview

A team of USDA FS and DOFAW specialists were responsible for producing this assessment. They received input and assistance from HDOA and U.S. Geological Survey personnel. The risk assessment complies with general standards set by the international plant protection organizations—for example, North American Plant Protection Organization (RSPM 2012), and the International Plant Protection Convention (IPPC) of the Food and Agriculture Organization of the United Nations (IPPC 2007), as well as U.S. government regulations (7 CFR 319.40-11) (APHIS 1998). These standards are the same as have been used for the most recent pest risk assessments prepared by the USDA FS for APHIS (Kliejunas et al. 2001, 2003; Tkacz et al. 1998).

The general process followed can be found in appendix 4.

Outreach

To gather information pertinent to the pest risk assessment, WIPRAMET contacted scientists and specialists in the fields of forestry, forest entomology, forest pathology, and plant quarantine around the world, but especially in the Pacific (app. 1). A preliminary list of potential organisms of concern was compiled for the 13 hosts of concern and sent to individuals for review (app. 1). Suggested revisions to the list were incorporated into the final list prepared by WIPRAMET. A draft of the assessment was also sent to scientists and specialists. Over 400 comments were returned, evaluated, and incorporated into the final assessment where the team felt appropriate.

Chapter 2: Forest Resources of Hawai‘i

Introduction

The archipelago of Hawai‘i consists of 132 islands, reefs, atolls, and shoals, over a distance of 2400 km, in the North Pacific Ocean. There are eight major islands, comprising more than 99 percent of the total land area, and supporting almost all of the human population there and forest cover (Loope 1998) (fig. 1). The largest of these islands is Hawai‘i. The other seven islands are Kaho‘olawe, Maui, Lāna‘i, Moloka‘i, O‘ahu, Kaua‘i, and Ni‘ihau. All of the land area is volcanic in origin. The main islands range in age from 600,000 years (Hawai‘i) to about 5.5 million years (Ni‘ihau).

The climate of Hawai‘i is varied, with significant changes of rainfall, solar radiation, temperature, humidity, and wind over short distances (Schnell 1998). Mean monthly temperature only varies about 5 °C at sea level over a year. The mountainous topography influences these temperatures because of increased cloudiness in windward locations and decreasing temperature with elevation. The rate of temperature decrease with elevation is fairly constant. Below about 1250 m, temperature drops 6.5 ˚C per 1000 m. Above this elevation, the temperature decreases 4 °C per 1000 m (Schnell 1998).

Hawai‘i is covered by about 707 400 ha of forest, which is 43 percent of the total land area (Smith et al. 2001). About 1,200 taxa of flora are native to the Hawai‘i Islands, including 1,158 that are endemic (Loope 1998). Over one-fourth of these are considered at some risk of becoming extinct. In total, 319 species of plants are listed by the U.S. Fish and Wildlife Service as endangered (USFWS 2012). The Web database maintained by the Smithsonian National Museum of Natural History (2012) includes over 2,400 taxa of flowering plants on the islands, about half of which are not native.

Hawai‘i Department of Land and Natural Resources (DLNR) identifies four native and five introduced forest cover types: (1) ‘ōhi‘a/hāpu‘u; (2) koa/‘ōhi‘a, (3) māmane/naio, (4) a mixture of species comprising the native dry land forest, (5) eucalyptus (*Eucalyptus* spp.), (6) mixed introduced hardwoods, (7) guava (*Psidium cattleianum*), (8) kiawe/*Leucaena*, and (9) mixed-conifer plantations

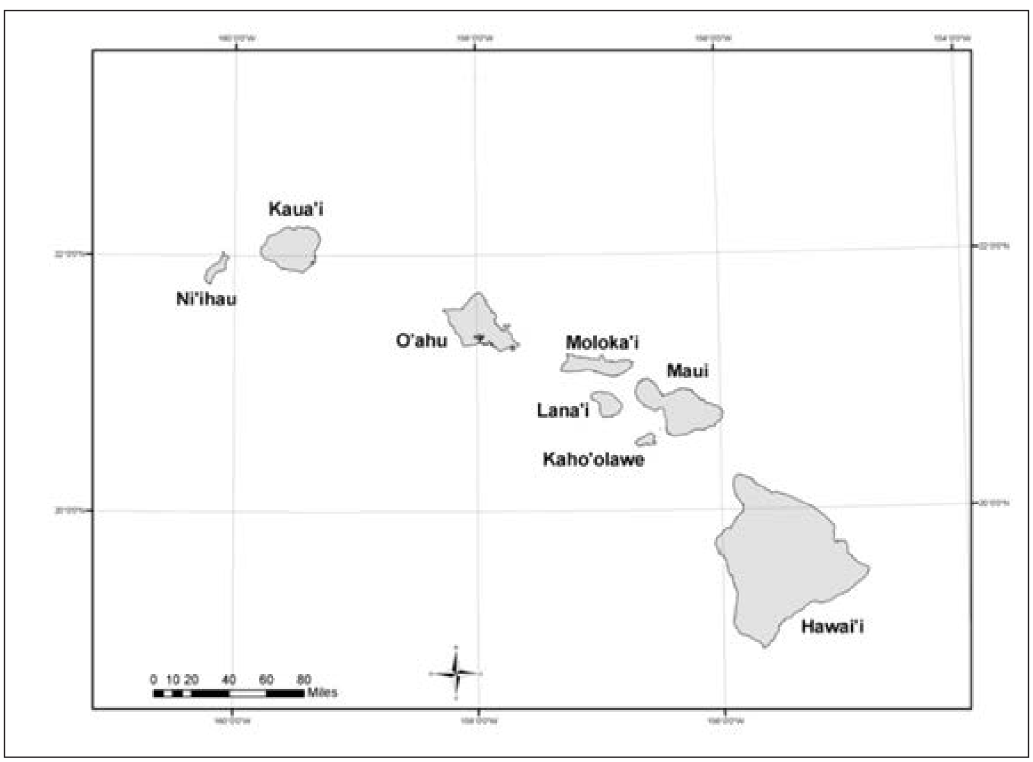

Figure 1—The major islands of the Hawaiian Archipelago.

(DLNR 2001). These communities were first identified and mapped by Little and Skolmen (1989) (fig. 2).

Hawai‘i recently completed an assessment of the state's forest resources to meet requirements of the 2008 Farm Bill (Cannarella 2010). In that document, the state‘s forest resources, the benefits they provide, and the threats that they face were identified. Consult that document for more details on forests, their benefits and threats.

Description of Taxa Analyzed

While much attention is paid to the recovery of threatened and endangered species in Hawai‘i, the dominant forest species that provide habitat for them are vulnerable to pest outbreaks. Recent incursions have spurred resource managers to seek improvements of the biosecurity system to prevent an ecosystem instability or collapse that would occur if such important species were eliminated from the landscape. The species chosen for this assessment include pteridophytes, woody trees and shrubs, and a monocotyledonous species, all of which make up the foundation of remaining Hawai‘i ecosystems, and if extirpated, would have cascading effects on them.

Although there are other species that could arguably be included, the list was limited to 13 species/genera to make the task manageable. This list originated with the Natural Area Reserve System Commission, an independent group that advises the state on managing special lands that have been set aside because of their unique biological qualities. The list was reviewed by various resource managers, botanists, and the state forestry agency (Hawai‘i Department of Forestry and Wildlife [DOFAW]). By improving biosecurity for these species, a large portion of Hawai‘i's remaining biodiversity will be better protected.

Because of the broad distribution of these 13 species/genera across the islands and their importance to native ecosystems, we refer to them on the whole as taxa. What follows is more detailed information on each of the 13 species/species groups analyzed in this report, including geographic distribution, ecology, uses, and known pests in Hawai‘i.

1. *Acacia koa* Gray; Fabaceae (Bean family)

Common name—koa

Distribution in Hawai‘i—Hawai‘i, Kaua‘i, Lāna‘i, Maui, Moloka‘i, and O‘ahu. The potential range has been identified across most of each of these islands except at the highest elevations and along much of the coast (Grünwald et al. 2012).

Distribution worldwide—The species is endemic to the Hawai‘i Islands. The genus *Acacia* previously contained roughly 1,300 species, about 960 of them native to Australia, with the remainder spread around the tropical to warm-temperate regions of both hemispheres, including Europe, Africa, southern Asia, and the Americas. In 2005, the genus was divided into five separate genera; instead of the name *Acacia* being retained for the majority of the Australian species and a few in tropical Asia, Madagascar, and the Pacific Islands. Koa's closest relatives may be *Acacia* species on Rénuion and Mauritius in the Indian Ocean, or *A. melanoxylon* in Australia.

Ecology—Koa is a large, nitrogen-fixing, shade-intolerant tree, typically attaining a height of 15 to 25 m and a spread of 6 to 12 m. Height and spread are greater in deep volcanic ash. The tree is capable of reaching 6 to 9 m in height in 5 years on a good site. The species grows at elevations of 100 to 2300 m on acidic to neutral soils, and requires 850 to 5000 mm of annual rainfall. Koa and ‘ōhi‘a lehua dominate the canopy of mixed mesic forests. Koa is second in abundance to ‘ōhi‘a lehua in native Hawai‘i forests, and frequently grows co-dominantly with it. Koa provides important habitat to native birds and invertebrates, and is regenerated for restoration, both by scarifying areas where a seed bank persists, and by outplanting seedlings (Baker et al. 2009).

Human uses—Ancient Hawaiians used koa for voyaging canoes and surf boards. The resurgence in Hawaiian culture, and specifically traditional navigation, has created an interest in growing koa for canoe building; however, few canoe-sized trees exist today. Koa wood is valuable for high-quality wood carvings and furniture making,

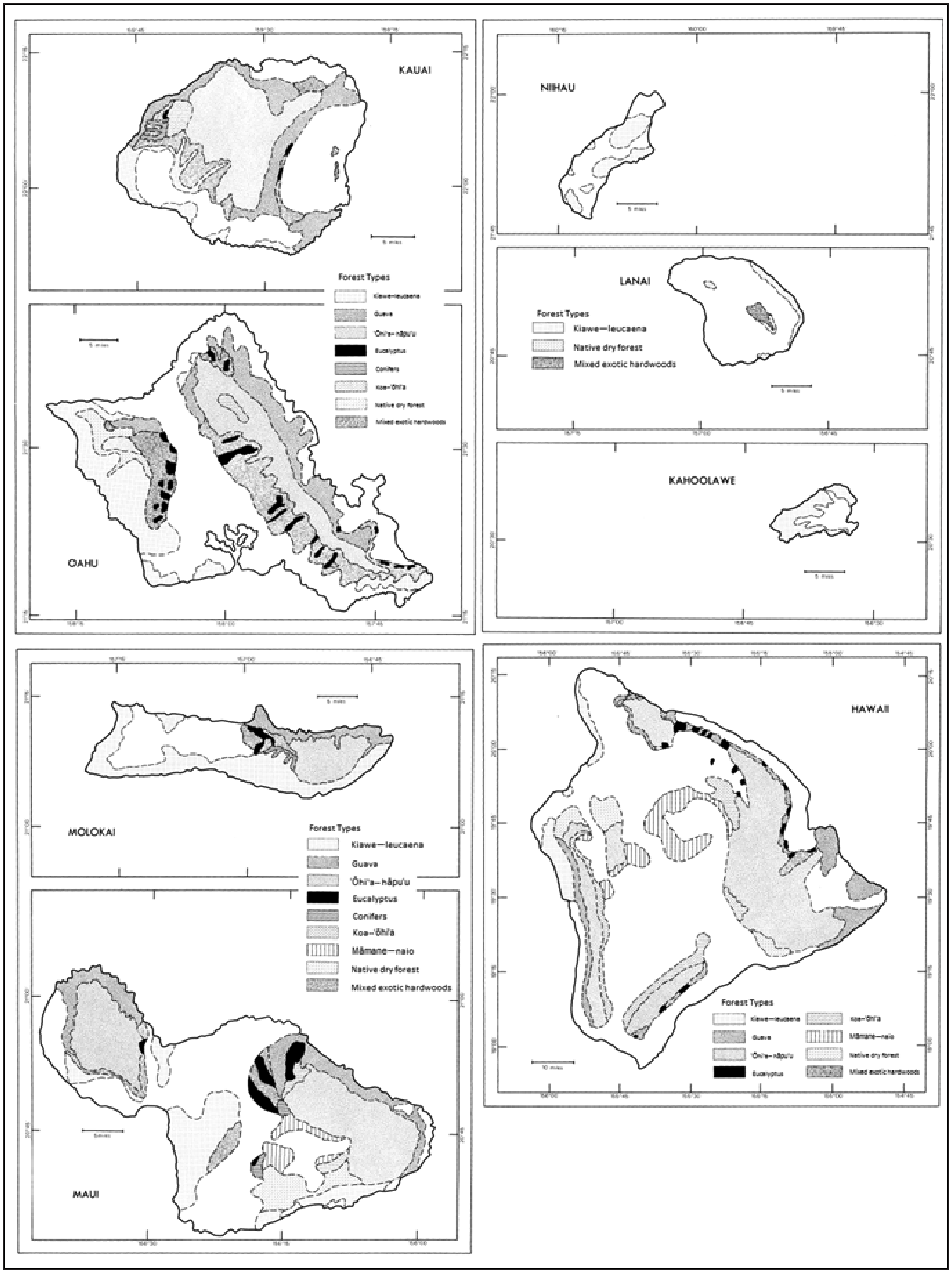

Figure 2—Generalized forest types mapped on the eight major islands of Hawaiʻi (Little and Skolmen 1989).

especially if the piece being worked has strongly expressed curly grain. There are several small koa mills, mainly on the island of Hawai‘i.

Because of the high value of koa wood, and the general acceptance of this tree as an important part of Hawaiian culture, there is considerable interest in growing koa in plantations. Although the species produces large amounts of seed that germinate easily, and grows quickly on some sites, it has problems as a plantation tree. It does not stand up well in competition, especially from itself, so mortality rates tend to be high (greater than 60 percent)

2. *Cibotium* spp. Kaulf.; Cibotiaceae (Dicksoniaceae) (Tree fern family)

Common names—hāpu‘u, tree fern

Distribution in Hawai‘i—four species are endemic to the Hawai‘i Islands—

C. chamissoi; Hawai‘i, Lāna‘i, Maui, Moloka‘i, O‘ahu. The potential range of *C. chamissoi* is primarily coastal and mid elevations (Grünwald et al. 2012).

C. glaucum; Hawai‘i, Kaua‘i, Lāna‘i, Maui, Moloka‘i, O‘ahu. The potential range of *C. glaucum* is primarily coastal and mid elevations (Grünwald et al. 2012).

C. menziesii; Hawai‘i, Kaua‘i, Lāna‘i, Maui Moloka‘i, O‘ahu. The potential range of *C. menziesii* is primarily coastal and lower elevations (Grünwald et al. 2012).

C. nealiae; Kaua‘i. The potential range of *C. nealiae* is primarily coastal and mid elevations (Grünwald et al. 2012).

Distribution worldwide—The genus *Cibotium* is endemic to northeast India, southern China, Taiwan, Malaysia, Indonesia, New Guinea, the Ryukyu Islands (Japan), the islands of the Pacific (including Hawai‘i), El Salvador, Guatemala, Honduras, and southern Mexico (Chiapas, Oaxaca, and Veracruz).

Ecology—The genus consists of 11 species of large tree ferns (plus a naturally occuring hybrid, *Cibotium* x *heleniae* [*C. chamissoi* x *C. menziesii*]). Some species have tall trunks and may reach a height of 8 m with a crown of spreading fronds up to 6 m in length. Others have a prostrate habit.

Cibotium chamissoi (Chamisso’s manfern) is a large, upright tree fern found in mesic to wet forests from 150 to 1200 m on all major islands except Kaua‘i. It is common on O‘ahu and uncommon and scattered on Moloka‘i, Maui, Lāna‘i, and Hawai‘i (Palmer 2003).

Cibotium glaucum (Hāpu‘u pulu) is a large tree fern with leathery fronds. Although the trunk usually does not surpass 3.7 m in height, the arching fronds can reach a great length. It is abundant in mesic to wet forests, from 300 to 1700 m on all major islands. This species is usually found at higher elevations than the other Hawai‘i species (Palmer 2003). Hapu‘u pulu is one of the most commonly used of Hawai‘i’s native tree ferns in landscape plantings and is an excellent understory plant to help control erosion. The species can occasionally be found for sale in California.

Cibotium menziesii (Hāpu‘u ‘i‘i) can grow up to 11 m tall, but is typically 2.1 to 7.6 m in height with a diameter of nearly 0.91 m, making it Hawai‘i’s largest tree fern. *Cibotium menziesii* is locally abundant on the windward portions of the main Hawai‘i Islands. It is found in rainforests, occasionally in mesic forests, at elevations of 305 to 1830 m, and can grow on the ground or on trees as an epiphyte.

Cibotium nealiae (Neal’s manfern) is a 1-m-tall dwarf variety, restricted to the island of Kaua‘i between 135 and 1300 m. It is never seen in the horticultural trade.

The three large *Cibotium* species, locally important as ecosystem dominants, are also important for biodiversity preservation in Hawai`i, as their trunks serve as substrates for epiphytic growth of many other ferns and flowering plant species. In forest areas where feral pig damage is moderate, allowing hāpu‘u to persist, many native herbaceous species survive pig rooting by growing epiphytically on the fern, out of reach of pigs, and can recolonize the forest floor if pigs are controlled.

Human uses—The starchy core is an important food source for feral pigs (Anderson 1994). Parts of *C. menziesii* have been used in traditional medicine to treat a variety of illnesses and ailments. The fibers are used in handcrafted pillows that are sold as souvenirs on the islands. The trunk was hollowed out by native Hawaiians and used as a planter for uhi (*Dioscorea alata*); this practice continues today.

3. *Dicranopteris linearis* (Burm. F.) Underwood; Gleicheniaceae (Forked fern family)

A form of *D. linearis*, *D. linearis* (Burm.) Underw. forma *emarginata*, is endemic to Hawai‘i.

Common names—uluhe, old world forked fern, false staghorn fern

Distribution in Hawai‘i—Indigenous to Hawai‘i, Kaua‘i, Lāna‘i, Maui, Moloka‘i, and O‘ahu. The potential range of *D. linearis* has been identified on all of the major islands from the coast to mid elevations, including near Hilo and Līhu‘e (Grünwald et al. 2012).

Distribution worldwide—The genus *Dicranopteris* contains about 22 species of terrestrial ferns. *Dicranopteris linearis* is pantropical, widely distributed throughout wetter parts of the Old World tropics and subtropics, including all of Polynesia.

Ecology—Uluhe is a very common terrestrial fern in mesic to wet forests, often covering steep slopes, near sea level to above 2000 m, on all major islands. It is intolerant of drought, shade, and frost and is an early invader on disturbed sites. It is an important soil-binding pioneer species that volunteers after a landslide or other erosion (Follett et al. 2003). Uluhe forms dense thickets, often more than 3 m deep, over large areas of wet Hawai‘i rainforests. Rhizomes, which aid in its spread, can climb other vegetation up to several meters.

After establishment, this fern can persist for an extended period but is eventually shaded out by overstory trees. It plays a large role in structuring plant communities in many habitats of Hawai‘i. In typical succession on new lava or cinder surfaces, uluhe mats eventually give way in succession to *Metrosideros* forest (Follett et al. 2003, Mueller-Dombois 2000).

Human uses—*Dicranopteris linearis* has numerous uses around the world. It has been used medicinally for asthma, women’s sterility, and as an antihelmintic (Perumal 2010). Hawaiians drank an infusion brewed from the fronds as a laxative (Palmer 2003). The aqueous extract from *D. linearis* fronds was shown to have antinociceptive, anti-inflammatory, and antipyretic properties in experimental animals (Zakaria et al. 2008). It has been used for erosion control and for building materials. Fiber from the plant is used in the production of various domestic and personal items. It can be formed into ropes for lashing posts. It is also used for the construction of leis.

4. *Diospyros sandwicensis* (A. DC.) Fosberg; Ebenaceae (Ebony family)

Common names—lama, ēlama

Distribution in Hawai‘i—Hawai‘i, Kaua‘i, Lāna‘i, Maui, Moloka‘i, O‘ahu. The range of this species is primarily coastal and low elevations. It can grow near Hilo, Honolulu, Kawaihae, and Kona (Grünwald et al. 2012).

Distribution worldwide—The species is endemic to Hawai‘i.

Ecology—*Diospyros* is a genus of about 450 to 500 species of deciduous and evergreen trees. The majority are native to the tropics, with only a few species extending into temperate regions. They are commonly known as ebony or persimmon trees. *Diospyros sandwicensis* is a small, slow-growing tree generally not more than 15 m tall and 3 m wide. It occurs, sometimes as a dominant plant, in dry to moist forests and occasionally in wet forests. Lama was once a primary component of Hawai‘i dry forests, but habitat degradation owing to wildfire and grazing by cattle and goats have drastically reduced the extent of dry forests and the abundance of lama. It grows at elevations ranging from almost sea level to 1220 m (Wagner et al. 1990). Currently, the Hawai‘i species is treated as endemic, but the closeness to other Pacific species should be recognized.

Human uses—Lama is considered sacred in Hawaiian culture. It is not a primary medicinal plant but can be found as a secondary ingredient in many remedies. The berries are edible.

5. *Dodonaea viscosa* (L.) Jacq.; Sapindaceae (Soapberry family)

Common names—‘a‘ali ‘i, ‘a‘ali‘i ku makani, ‘a‘ali‘ ku ma kua, kumakani, hopbush.

Distribution in Hawai‘i—Hawai‘i, Kaho‘olawe, Kaua‘i, Lāna‘i, Maui, Moloka‘i, Ni‘ihau, and O‘ahu. This species can be found almost anywhere on all of the islands except the highest elevations of the island of Hawai‘i (Grünwald et al. 2012).

Distribution worldwide—The species is indigenous and widespread throughout the tropics and subtropics, particularly in the Southern Hemisphere, including Australia, New Zealand, Southeast Asia, Pacific Islands, India, Africa, Southern United States, Mexico, Caribbean, Central and South America. It has been introduced to Israel. The evolutionary origin of the genus is Australia; 59 of the 61 species of *Dodonaea* are restricted to Australia. In Australia, *D. viscosa* has seven subspecies that are geographically distinct.

Ecology—The species is found in almost every habitat from near sea level to 2347 m. Tree-sized plants are mostly in the upper elevation forests of Hawai‘i and Maui, but are also observed occasionally in the Wai‘anae and Ko‘olau Ranges on O‘ahu. It is often found in open locations, such as ridges, and is an early colonizer of lava fields and pastures.

Human uses—*Dodonaea viscosa* is used extensively in dry forest restoration in Hawai‘i. The flowers of *D. vicosa* are unspectacular, but its winged fruits can become red and purple as they mature, making it an attractive garden plant in the tropics and subtropics. One cultivated variety develops purple leaves when grown in direct light and is a popular ornamental. Fruits and seeds were traditionally used for dye. The dense, hard, and durable wood is used for specialty products, lumber, and fuel wood by native cultures. The plants have medicinal properties that have been used by native populations throughout the world.

6. *Erythrina sandwicensis* O. Deg.; Fabaceae (Bean family)

Common names—wiliwili, Hawaiian erythrina, Hawaiian coral tree

Distribution in Hawai‘i—Hawai‘i, Kaho‘olawe, Kaua‘i, Lāna‘i, Maui, Moloka‘i, Ni‘ihau, and O‘ahu. This species principally occupies coastal and very low elevations. It may be found near Kawaihae, Kona, Honolulu, and Kahului (Grünwald et al. 2012).

Distribution worldwide—The wiliwili tree is endemic to Hawai‘i. About 115 species of *Erythrina* have been described, with centers of distribution in South and Central America, and Africa. Two native *Erythrina* exist on the U.S. mainland—*E. herbacea* and *E. flabelliformis*. *Erythrina herbacea* (redcardinal) is widespread throughout the Southeastern United States, and *E. flabelliformis* (coralbean) is found in arid environments in Arizona and New Mexico. The Neotropics are a center of endemism for *Erythrina*; 24 species are native to Mexico.

Ecology—*Erythrina sandwicensis* is a small deciduous tree characterized by short spines, leaves with three broadly triangular leaflets, and showy orange, yellow, salmon, greenish or whitish flowers when leafless. Trees are 4.5 to 9 m tall, with a short, stout, crooked or gnarled trunk 0.3 to 0.9 m in diameter, stiff spreading branches, and broad thin crown becoming wider than high. Wiliwili was once an abundant endemic tree in the now much-reduced dry forests at low elevations of 152 to 610 m on the lee side of the Hawai‘i Islands. It is locally common in dry forests up to 600 m on leeward slopes of all main islands (Wagner 1990). At present, native dry forests have been largely replaced by kiawe (*Prosopis pallida*), but wiliwili may still be seen in the dry gullies on the leeward side of all islands (Little and Skolmen 1989). Wiliwili is used as a restoration species in dry forests, especially following the success of a biological control release to control the Erythrina gall wasp.

Human uses—*Erythrina* spp. are important to native cultures and are keystone species in many tropical and subtropical ecosystems. The bright reddish-orange seeds are used in leis. On Moloka‘i, trees produce an especially treasured yellow seed. Coral trees are cultivated for their showy flowers, and countless numbers exist as high-value ornamentals. Some *Erythrina* spp. are used widely in the tropics and subtropics as street and park trees, especially in drier areas.

7. *Leptecophylla tameiameiae* (Cham. & Schltdl.) C.M. Weiller; Ericaceae (Heath family)

Common name—pūkiawe

Distribution in Hawai‘i—Hawai‘i, Kaua‘i, Lāna‘i, Maui, Moloka‘i, and O‘ahu. *Leptecophylla tameiameiae* occurs over much of the islands except for the driest sites (Grünwald et al. 2012).

Distribution worldwide—Indigenous to Hawai‘i and Marquesas Islands (Nuku Hiva)

Ecology—Now in the Ericaceae, pūkiawe was formerly known as *Styphelia tameiameiae* and placed in the Family Epacridaceae (Wagner et al. 1990). Pūkiawe, or Hawaiian heather, is a common indigenous shrub that is often the principal vegetation component in mixed mesic forests, wet forests, bogs, and alpine shrublands. It occurs, from 15 to 3200 m elevation, on all the main Hawai‘i Islands except Ni‘ihau and Kaho‘olawe. Pūkiawe is an exceedingly variable species, both morphologically and ecologically. The largest wild specimens of pūkiawe, generally in wet forest situations, grow to 3 m in height and have a spread of about 2 m. The species is found in areas where the annual precipitation ranges from 12 to 250 cm or more.

Human uses—The entire pūkiawe plant was highly esteemed by early Hawaiians. Second-stage kapa beaters, called kua kala, were made from several native woods including pūkiawe. The leaves were used medicinally for cold or headaches. The new leaves (liko) and berries were used by lei makers, and the boiled and mashed berries were used as a dye for coloring kapa cloth.

8. *Metrosideros polymorpha* Gaud.; Myrtaceae (Myrtle family)

Common names—‘ōhi‘a lehua, ‘ōhi‘a

Distribution in Hawai‘i—Hawai‘i, Kaua‘i, Lāna‘i, Maui, Moloka‘i, and O‘ahu. *Metrosideros polymorpha* occurs over much of the islands except for the driest sites (Grünwald et al. 2012).

Distribution worldwide—*Metrosideros polymorpha* is endemic to the Hawai‘i Islands.The genus *Metrosideros* has about 50 species of trees, shrubs, and vines; native to the islands of the Pacific Ocean, from the Philippines to New Zealand, and including the Bonin Islands, Polynesia, and Melanesia, with an anomalous outlier in South Africa.

Ecology—‘Ōhi‘a lehua is the most common of Hawai‘i trees, and makes up about 80 percent of the remaining native Hawai‘i forest (Friday and Herbert 2006). The species exhibits tremendous morphological variation and occurs over a wide range of habitats. The tree typically reaches 20 to 24 m in height. It grows over a wide elevation range, from sea level to 2500 m, and over a wide range of precipitation, from 40 to 1000 cm. The largest components of ‘ōhi‘a are in lowland and montane wet and mesic forests, dry forests, subalpine shrublands, and new lava flows. Past land use practices have resulted in the reduction of ‘ōhi‘a’s range. It tends to be slow growing and shade intolerant. It does not regenerate in its own shade or under other tree canopy, but regenerates rapidly and prolifically from wind-blown seeds after site disturbance. The species is a critical food source to endemic nectivorous and insectivorous birds (Berger 1981, Smith et al. 1995) and critical specific habitat to endemic *Achatinella* and *Partulina* tree snail species (Hadfield and Miller 1989, Hadfield and Mountain 1980).

Human uses—There are many ancient and modern uses for the flowers, leaves, and wood of ‘ōhi‘a lehua. Ōhi‘a lehua is an important landscape tree and provides shade and wind protection. The flowers provide nectar for honey production. The wood is very hard and dense. The most common uses of the wood include wood strip flooring, decking, decorative posts, and round wood construction.

9. *Myoporum sandwicense* (A. DC.) A. Gray; Scrophulariaceae (Figwort family)

Common names—naio, false sandalwood

Distribution in Hawai‘i—Indigenous to Hawai‘i (endemic to Hawai‘i and Mangaia, a small island in the Cook Islands). In Hawai‘i, naio is found on Hawai‘i, Kaua‘i, Lāna‘i, Maui, Moloka‘i, Ni‘ihau, and O‘ahu. This species can be found almost anywhere on all of the islands except the highest elevations of the island of Hawai‘i (Grünwald et al. 2012).

Distribution worldwide—*Myoporum* is a genus of flowering plants in the Scrophulariaceae (formerly placed in Myoporaceae). There are about 32 species in the genus, which is found from Mauritius, across Australasia to the Pacific Islands, and north to China. *Myoporum* spp. are widely planted as ornamentals.

Ecology—Naio is common in dry upland forest and shrublands and near sea level. It is uncommon in many areas it formerly occupied because of site disturbance. On Hawai‘i and Maui, trees, some large, occur in mesic and dry forests, whereas on the other islands it is mostly a shrub. Along with mamane (*Sophora chrysophylla*), naio is an integral part of palila (an endangered honeycreeper) habitat on Mauna Kea. Naio is planted as an ornamental shrub.

Human uses—Timber of this species was among those preferred for frames of Hawaiian homes. It was also used for fishing torches because of its good burning characteristics. Naio is considered good firewood by most upland ranchers. The lumber cut from large trees in recent years has been used for flooring, furniture, and craftwood items.

10. *Pandanus tectorius* Parkinson ex Zucc.; Pandanaceae (Screwpine family)

Common names—hala, pū hala

Distribution in Hawai‘i—Hawai‘i, Kaua‘i, Lāna‘i, Maui, Moloka‘i, Ni‘ihau, and O‘ahu. This species principally occupies coastal and very low elevations. It may be found near Hilo, Kawaihae, Kona, Honolulu, and Kahului (Grünwald et al. 2012).

Distribution worldwide—The genus *Pandanus* contains about 600 species of palm-like monocots native to the Old World tropics and subtropics. *Pandanus tectorius* naturally occurs in strandline and near coastal forests in Southeast Asia, including the Philippines and Indonesia, extending eastward through Papua New Guinea and northern Australia, and throughout the Pacific islands, including Melanesia (Solomon Islands, Vanuatu, New Caledonia, and Fiji), Micronesia (Palau, Northern Marianas, Guam, Federated States of Micronesia, Marshall Islands, Kiribati, Tuvalu, and Nauru), and Polynesia (Wallis and Futuna, Tokelau, Samoa, American Samoa, Tonga, Niue, Cook Islands, French Polynesia, and Hawai‘i).

Ecology—Hala is common to abundant in many Hawai‘i coastal ecosystems. Hala was generally believed to have been first introduced to Hawai‘i by the Polynesians (Abbot 1992), but in 1993, was proved to be native to the Hawai‘i Islands when a rockslide uncovered a 1-million year-old fossilized impression on a Kaua‘i beach (TenBruggencate 1993). Polynesians undoubtedly brought selected cultivars with them, increasing the variation of this species in Hawai‘i (Staples and Herbst 2005).

Pandanus tectorius grows in maritime (usually less than 20 m above sea level), tropical, humid and subhumid climates. *Pandanus* mainly occurs in localities with 1500 to 4000 mm annual rainfall, and with no or a short dry season (i.e., no or a few months receiving less than 40 mm on average). In its native habitats, temperatures are warm to hot throughout the year and show little variation, both seasonally and diurnally. It is adapted to an extraordinarily wide range of light to heavy-textured soil types, including brackish/saline soils, light-colored, infertile coralline atoll sands, alkaline sands, thin soils over limestone, and peaty swamps. In Hawai‘i, it is an important component of the few remaining intact lowland wet forests on the islands of Hawai‘i and Kaua‘i.

Human uses—Hala is an extremely important cultural plant species for native Hawaiians, who traditionally used it for cordage, thatching, healing, decoration, and other uses (Abbot 1992, Thompson et al. 2006). The plant is prominent in Pacific culture and tradition, including local medicine. Hundreds of cultivated varieties, collectively recognized in the Pacific, but specific to numerous independent cultural traditions, are known by their local names and characteristics of fruits, branches, and leaves. All parts are used, from the nutritious fruits of edible varieties, to the poles and branches used in construction, to the leaves for weaving and garlands.

11. *Scaevola* sp. L.; Goodeniaceae (Goodenia family)

Common name—naupaka

Distribution in Hawaiʻi—The species of *Scaevola* and their distribution in the Hawaiʻi Islands are listed in table 2:

Distribution worldwide—Goodeniaceae consists of more than 130 tropical species, with the center of diversity being Australia and Polynesia, including Hawaiʻi. *Scaevola taccada* is the only Hawaiʻi species that is found outside of the Hawaiʻi Islands. It is widely distributed throughout the tropical and subtropical Pacific and Indian Oceans. It is an introduced species in Florida and certain Caribbean islands, including the Cayman Islands and the Bahamas. Many species of *Scaevola,* and all other genera of the Goodeniaceae, are limited to Australia where they are herbaceous and have little commercial value.

Ecology—The Hawaiʻi Islands are home to nine endemic *Scaevola* species, most of which are short shrubs. The mountain naupaka, *S. gaudichaudiana*, is a small tree that grows up to 4.9 m tall and 7.6 cm in diameter. Beach

Table 2—*Scaevola* spp. and their distribution in the Hawaiʻi Islands

Botanical name	Common name/ Hawaiʻi name	Hawaiʻi distribution (when known)
Scaevola chamissoniana Gaudich. endemic	Naupaka kuahiwi	Hawaiʻi, Lānaʻi, Maui, Molokaʻi
Scaevola coriacea Nutt. endemic	Dwarf naupaka	Maui, Molokaʻi (Mokuhoʻoniki Islet); historically on five additional islands. Endangered species.
Scaevola gaudichaudiana Cham. endemic	Mountain naupaka, Naupaka kuahiwi	Kauaʻi, Oʻahu
Scaevola gaudichaudii Hook. & Arn. endemic	Ridgetop naupaka; Naupaka kuahiwi	Hawaiʻi, Kauaʻi, Lānaʻi, Maui, Molokaʻi, Oʻahu
Scaevola glabra Hook. & Arn. endemic	ʻOhe naupaka	Kauaʻi, Oʻahu
Scaevola kilaueae O. Deg. endemic	Huahekili uka, Papa'ahekili; Naupaka kuahiw'i	Hawaiʻi (Ocean View Estates, Kaʻu District; Kilauea). Rare.
Scaevola mollis Hook. & Arn. endemic	Naupaka, Naupaka kuahiwi	Kauaʻi, Molokaʻi (rare), Oʻahu
Scaevola procera Hillebr. endemic	Forest naupaka, Naupaka kuahiwi	Kauaʻi, Molokaʻi
Scaevola taccada (Gaertn.) Roxb. indigenous	Beach naupaka, Naupaka kahakai, Aupaka, Huahekili	Kure atoll, Midway atoll, Pearl and Hermes atoll, Lisianski Island, Laysan Island, French Frigate Shoals, Hawaiʻi

naupaka, *S. sericea* (= *S. taccada*), is a densely branched, woody shrub that can grow more than 3 m tall. Hybridization occurs among some of the nine species.

Human uses—Species of *Scaevola* are abundantly planted in Hawai‘i as landscape trees and shrubs, with different species being suited for different habitats—from arid wastelands to wet areas. The flowers of *Scaevola* are valued owing to traditional folklore tales, and flowers and seeds are used in lei making. Fabric dyes can be made from fruits.

12. *Sophora chrysophylla* (Salisb.) Seem.; Fabaceae (Bean family)

Common names—māmane, māmani

Distribution in Hawai‘i—Hawai‘i, Kaua‘i, Lāna‘i (extinct?), Maui, Moloka‘i, and O‘ahu; it is rare on Kaua‘i, Moloka‘i, and O‘ahu but common at higher elevations on Maui and Hawai‘i. It primarily may be found at lower to mid elevations on the islands (Grünwald 2012).

Distribution worldwide—The species is endemic to Hawai‘i. *Sophora* is a genus of about 45 species of small trees and shrubs. The species are native to Southern Asia, Australasia, the islands of the Pacific Ocean, western South America, and southeast Europe. One species, *S. tomentosa* (necklace pod), has a native distribution in coastal areas of subtropical and tropical climates around the world—Americas, Africa, Australia, Japan, and other Pacific islands.

Ecology—Māmane is a large shrub or medium-sized tree up to 15 m tall. This species is one of the most widely distributed trees in Hawai‘i and is a dominant species in subalpine forest types on east Maui and Hawai‘i. It is common mainly in dry mountain forests at 1219 to 2438 m elevation, ranging down almost to 30 m and up to 2896 m at the treeline on the highest mountains of the island of Hawai‘i (Mauna Kea, Mauna Loa, and Hualalai). It reaches its best development as a tree on the higher slopes of Mauna Kea and Mauna Loa. Elsewhere, except for portions of Haleakala on Maui, it grows predominantly as a shrub.

Māmane is essential for the endangered palila bird, a Hawai‘i honeycreeper that feeds almost exclusively on the plants' immature seeds when these are in season and nests in māmane branches. Caterpillars of *Cydia* moths eat the māmane's seeds, and, in turn, are eaten by the palila.

Human uses—The flowers were used as an astringent. The hard, durable wood was used by the native Hawaiians for house-building material, digging sticks, sled runners, tools, firewood, and fence posts. The wood was also used in religious rituals to ward off evil.

13. *Vaccinium calycinum* Sm., V. *dentatum* Sm., V. *reticulatum* Sm.; Ericaceae (Heath family)

Common names—‘ōhelo, tree ohelo

Distribution in Hawai‘i—Endemic to Hawai‘i. The potential ranges of *V. calycinum* and *V. dentatum* are mainly at low elevations. *Vaccinium reticulatum* extends elevationally to near the highest points of the island of Hawai‘i (Grünwald et al. 2012).

Vaccinium calycinum—Hawai‘i, Kaua‘i, Lāna‘i, Maui, Moloka‘i, O‘ahu

Vaccinium dentatum—Hawai‘i, Kaua‘i, Lāna‘i, Maui, Moloka‘i, O‘ahu

Vaccinium reticulatum—Hawai‘i, Kaua‘i, Maui, Moloka‘i, O‘ahu

Ecology—About 450 species of *Vaccinium* are found in north temperate, tropical, and subtropical regions around the world. Numerous species are grown for fruit production and as ornamentals. *Vaccinium calycinum* is a woody shrub or small tree that is slow growing and long lived. It ranges from 500 to 1800 m elevation in wet forests and bogs in its natural habitat. *Vaccinium dentatum* is a small, sprawling shrub. *Vaccinium reticulatum* is a small shrub that is long lived and grows on disturbed sites from 640 to 3700 m elevation. It is rare on Kaua‘i, O‘ahu, and Moloka‘i but common on Maui and Hawai‘i. The berries provide an important food source for the endangered nēnē or Hawaiian goose (*Branta sandvicensis*), Hawai‘i's state bird.

Human uses—The early Hawaiians believed that the ‘ōhelo was sacred to Pele, the goddess of fire. Various parts of ‘ōhelo have been used for their medicinal properties. The flowers and fruit were (and are to this day) used in lei making. The berries produced are similar to other *Vaccinium* species and are edible. They are used to make jams, jellies, and pie filling. Research on production of ornamental ‘ōhelo has been done to provide an agricultural source of berries and lessen the impact of extensive berry harvesting on native populations.

Known Insect and Disease Pests in Hawai‘i

Numerous insects and pathogens have been identified on these 13 taxa, some of which are native and others introduced to Hawai‘i. These are of obvious interest in our analysis because of their presence already in the state. We did an extensive literature search and consulted with local forest health specialists to identify known insects and pathogens. The known insects and pathogens are listed in tables 5-1 and 5-2 (app. 5)[1], including the species they attack, whether they are native or introduced, the part of the plant on which they are found, and which islands they inhabit.

Previous Interceptions of Quarantine Organisms

A search of the APHIS Pest-ID database was made for pests identified at Hawai‘i ports of entry from 1984 to 2010 (APHIS 2007a). This does not include military ports of entry. The search included insects and pathogens on all plant hosts and other means of entry. Over 10,000 items were reported at least once transporting a pest (table 6-1, app. 6). More than 9,800 pests were intercepted on these commodities during this period (table 6-2, app. 6). The majority of the pests were insects and often not identified to species. The severity of the infestation is not reported. A difficulty in interpreting these data is that foreign shipments undergo inspection at the first port of U.S. entry. If a shipment first makes entry at a U.S. mainland port then is shipped to Hawai‘i, the port of entry for the interception is the mainland port, not the final destination port. Any associated pest is then recorded associated with the commodity at the mainland port and not with any Hawai‘i port. Much of the international trade destined for Hawai‘i occurs through U.S. mainland ports and is, therefore, not included in this pest data.

Most of the interceptions were in Honolulu, either at the airport or seaport. A very small number were intercepted at the Kailua and Kahului airports and harbors. Most of the pests were intercepted in baggage at the Honolulu International Airport. The second largest source of interceptions was with cargo. *Citrus* sp. and *Alyxia* sp. had the largest number of interceptions of all commodities. Most of these were either fruit and leaves of *Citrus* and leaves of *Alyxia*. This is most likely because of the volume of these materials imported. Figure 3 identifies the commodities with more than 100 interceptions each. Several of this assessment's species of concern had related host species with interceptions reported, including *Acacia, Diospyros, Erythrina, Pandanus,* and *Vaccinium.* The imported commodity for *Acacia* was cut flowers and seed. The two interceptions on *Erythrina* were on plants. Interceptions on the remaining three species concerned fruit. Most intercepted pests came from countries in the Asia-Pacific region. The largest source was the Phillipines (1,540), followed by Japan (1,032), and Thailand (1,002). The majority of these interceptions were insects (7,580), followed by pathogens (1,637), mites (76), and nematodes (4). This supports the idea that most inspections more readily find and identify easily visible pests.

[1] Appendices for this report are available online at: http://www.fs.fed.us/psw/publications/documents/psw_gtr250/ psw_gtr250_appendix.pdf.

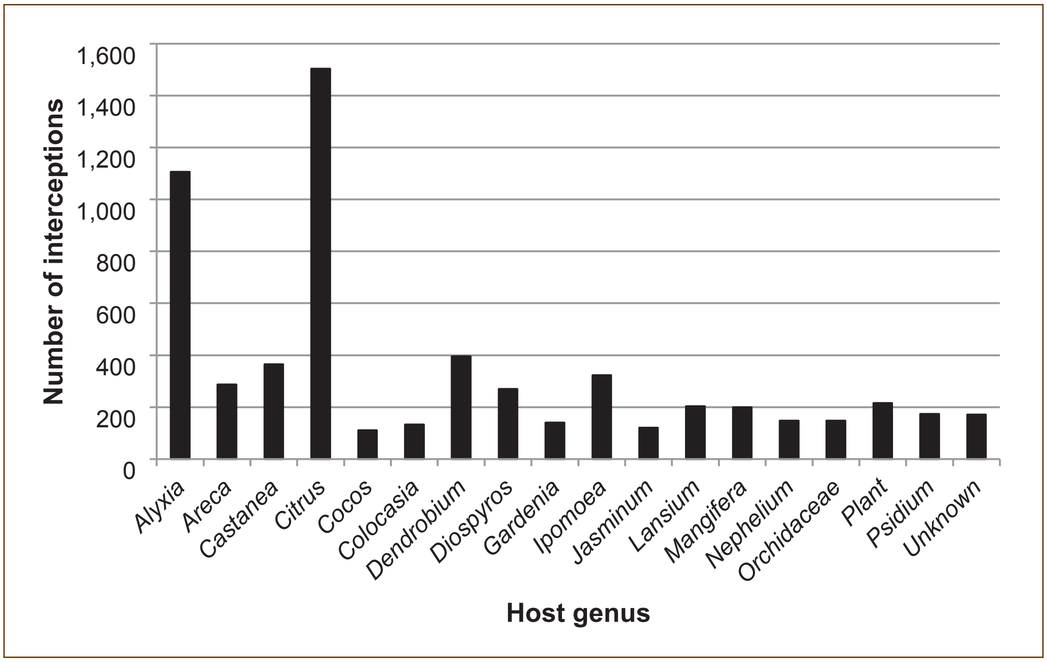

Figure 3—Number of pest interceptions on commodities arriving in Hawai‘i, 1984–2010.

In addition to surveying the APHIS database, HDOA performed a risk assessment for Kahului Airport in 2000 to 2001 (HDOA 2002). Intensive inspections of baggage, aircraft, and air cargo from the continental United States and foreign areas were done. During this time period, nearly 2,200 insects were intercepted in all ports across the state. Over 1,400 insects were intercepted in air cargo at Kahului Airport. The family Aphididae was the most commonly recovered, although most of these were species already established in Hawai‘i. Most of the insects that were intercepted that were not established in Hawai‘i included members of Aphididae, Lygaeidae, Staphylinidae, Gracillariidae, Chrysomelidae, and Cicadellidae. A total of 156 plant pathogenic organisms were intercepted during these same inspections. The most common interceptions were avocado scab disease (caused by the fungus *Sphaceloma perseae*) and *Cercosporidium sequoiae*, cause of needle blight of Leyland cypress and related conifers, neither of which was established in Hawai‘i.

A previous pathway risk analysis for Hawai‘i by APHIS listed intercepted pests on agricultural commodities between 2004 and 2006. The data source was the Agricultural Quarantine Activity System (Culliney et al., n.d.). An unidentified pest on *Erythrina* was reported in an air shipment of cut flowers from South Africa, and on plant material from South Africa at a port inspection station. An unidentified pest on *Pandanus* was discovered in 129 air shipments of cut flowers and several shipments of plant material from Thailand. Unidentified pests were intercepted on *Scaevola* plant material from Micronesia. No interceptions were reported on any of the other hosts being evaluated in this assessment (Culliney et al., n.d.).

Chapter 3: Pathways and Commodities for Pest Entry

Pathways

The principal pathways considered for this assessment follow. Other pathways are likely, but we believe the ones listed are sufficiently inclusive to cover other, unidentified pathways.

- Plant material
    - Seeds for sowing and consumption
    - Nursery stock
    - Cut flowers
    - Fruits and vegetables
    - Living plant material
    - Christmas trees
    - Cut foliage
    - Dried plant material
    - Tissue culture
- Wood products
    - Unmanufactured wood products
    - Manufactured wood products
    - Jewelry and handcrafts
    - Pallets, crating, dunnage
- Hitchhikers
    - Privately owned vehicles
    - Maritime ship superstructures
    - Aircraft
    - Containers
- Potting media/compost/soil

Several pathways may exist for a single organism. We developed a means to identify pathways based on the location on the host plant where the pest can occur. Table 3 identifies likely relationships between the parts of the host that are affected and probable commodity pathways. This simplified and streamlined the analysis, as many of the pathways for specific organisms are difficult to predict.

Significant Pathways for Potential Pest Entry

Wood Packing Material

A significant source of potential pest entry is on solid wood packaging material (SWPM). This includes dunnage, crating, pallets, packing blocks, drums, cases, and skids. The origin of this material is not necessarily the same as that of the shipment it accompanies, as it is routinely reused and reconditioned. It is also not reported on shipping manifests, so it cannot be tracked and quantified. On September 16, 2005, the United States started enforcing the International Plant Protection Convention's standard ISPM No.15, "Guidelines for Regulating Wood Packaging Material in International Trade" (IPPC 2009). The standard requires fumigation or heat treatment for all wood packaging material entering the United States.

Table 3—Location of pest on host and potential pathways of pest entry

Location of pest on host	Pathway
Seeds	Seeds for sowing
Seeds	Hitchhikers
Roots	Nursery stock
Roots	Live plant material
Roots	Potting media
Foliage/other	Nursery stock
Foliage/other	Cut flowers
Foliage/other	Cut foliage
Foliage/other	Live plant material
Foliage/other	Propagative plant cuttings
Foliage/other	Fruit
Foliage/other	Christmas trees
Foliage/other	Hitchhikers
Foliage/other	Decorative dried plant material
Foliage/other	Jewelry and handicrafts
Bark/cambium	Nursery stock
Bark/cambium	Cut flowers
Bark/cambium	Live plant material
Bark/cambium	Propagative plant cuttings
Bark/cambium	Christmas trees
Bark/cambium	Hitchhikers
Bark/cambium	Unmanufactured wood products
Bark/cambium	Wood packing material
Bark/cambium	Manufactured wood products
Bark/cambium	Decorative dried plant material
Bark/cambium	Jewelry and handicrafts
Sapwood	Christmas trees
Sapwood	Unmanufactured wood products
Sapwood	Wood packing material
Sapwood	Manufactured wood products
Heartwood	Unmanufactured wood products
Heartwood	Wood packing material
Heartwood	Manufactured wood products

Culliney et al. (n.d.) estimated that between 3 and 11 percent (95 percent binomial confidence interval) of all shipments with SWPM arriving at the port of Honolulu are infested with live pests based on an evaluation of Agricultural Quarantine Inspection Monitoring (AQIM) data records for the period between October 2005 and April 2007 (APHIS 2011a).

Airline Passengers

Airline passengers are another major source for potential pest entry. The total number of visitors arriving by air in Hawai‘i from 2007 to 2011 was over 34 million (fig. 4). Over 70 percent were from the mainland United States. The principal country of origin for foreign arrivals was Japan, followed by Canada (fig. 5) (HDBDET 2013). From 1984 through 2010, The U.S. Department of Agriculture Animal and Plant Health Inspection Service (APHIS) intercepted over 9,800 reportable pests of foreign origin at Hawai‘i ports of entry. Almost 7,400 of these interceptions were associated with airports (APHIS 2007a).

Live Plant Material

Annual imports—

Plants for horticultural use are continually arriving in Hawai‘i from foreign and domestic locations. Many of these have become invasive and are affecting native ecosystems. In addition, they may be carriers for invasive insects and pathogens. Figure 6 provides information on recent foreign imports of live plant material into Hawai‘i. The majority consists of live trees, shrubs, and plants without soil attached to roots. The quantity imported has remained stable during the past 5 years. The primary and most consistent exporting countries for this material are Australia and the Netherlands (U.S. Department of Commerce Census Bureau 2013). Data on interstate movement of live plant material from the continental United States were not available for comparison.

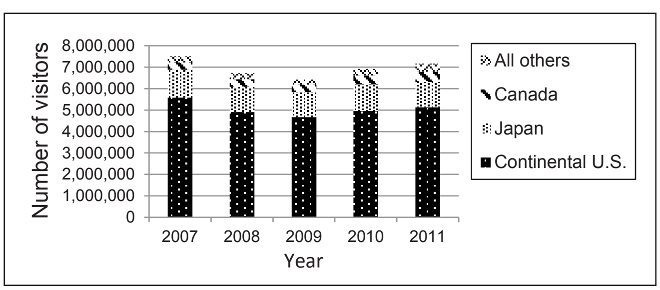

Figure 4—Number of airline passenger arrivals to Hawai‘i by air from 2007 to 2011. Source: Hawai‘i Department of Business, Economic Development and Tourism 2011.

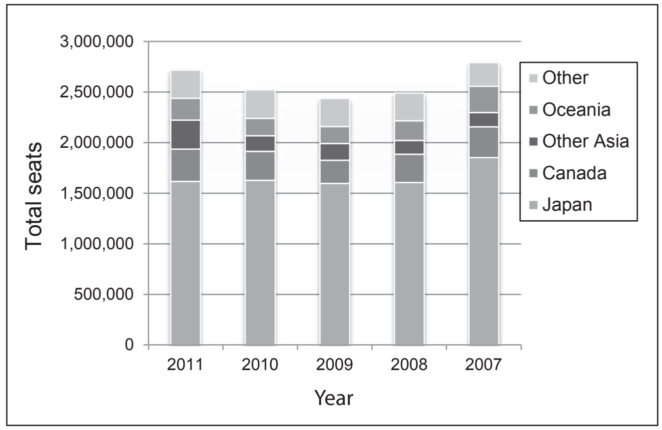

Figure 5—Total passenger seats to Hawai‘i by international air travel, 2007 to 2011 . Source: Hawai‘i Department of Business, Economic Development and Tourism 2013.

Restrictions on importation of plants and plant parts—The importation of plants and plant parts is regulated by APHIS and Hawai‘i Department of Agriculture (HDOA), depending on the place of origin. APHIS has a plant inspection station at the Honolulu International Airport where plants and seeds are inspected for plant pests and diseases. Plants known to be invasive, or known to carry unwanted insects or pathogens, may be restricted entry or require quarantine prior to release. However, these restrictions are established based on known issues and do not cover unknown or unexpected insects and pathogens. Current regulations (7 CFR part 319.37) prohibit or restrict the importation of certain plants and plant products into the United States (APHIS 2013a). Those allowed entry must be accompanied by a phytosanitary certificate of inspection issued by the national plant protection service of the exporting country.

Plants and plant parts in the following genera and families related to species covered by this risk assessment are either prohibited from importation into the United States (7 CFR 319.37-2), require specific treatment prior to importation (7 CFR 319.37-6), or have a postentry quarantine requirement (7 CFR 319.37-7). Although they

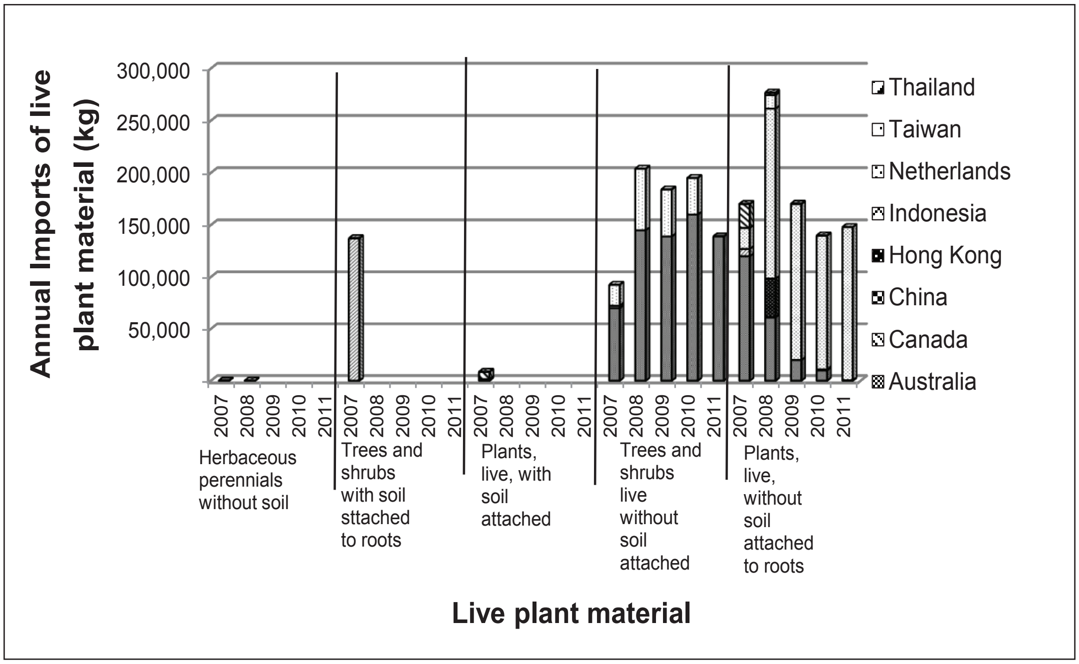

Figure 6—Annual import of live plant material from foreign countries to Hawai‘i, 2007 to 2011.

are not the species of interest in this pest risk assessment, their close relationship indicates the potential for harboring insects and pathogens that could attack the 13 taxa. Any species not listed must have a phytosanitary certificate and be inspected at the port of entry, but is then released if no pests are identified.

Species, genus, or family of plants with restrictions on importation of plants or plant parts into the United States from foreign countries—

- Prohibited from importation
    - *Acacia* from Australia and Oceania
    - *Eucalyptus* spp. from Europe, Sri Lanka, and Uruguay
    - Herbaceous species in Fabaceae (=Leguminosae) from all countries except Canada
    - *Vaccinium* spp. from Canada not meeting the conditions for importation in §319.37–5(t)
- Specific treatment required
    - *Lathyrus* (Fabaceae) from all countries except North and Central America
    - *Lens* (Fabaceae) from all countries except North and Central America
    - *Vicia* (Fabaceae) from all countries except North and Central America
- Restricted postentry quarantine
    - *Acacia* spp. from all countries except Australia, Canada, and Oceania
    - *Blighia sapida* (Sapindaceae) from all countries except Canada, Cote d’Ivoire, and Nigeria
    - *Eucalyptus* spp. (Myrtaceae) from all countries except Canada, Europe, Sri Lanka, and Uruguay
    - Fruit and nut articles and other propagules of:
        - *Ceratonia* (Fabaceae)
        - *Diospyros* (Ebenaceae)
        - *Euphoria* (Sapindaceae)
        - *Eugenia* (Myrtaceae)
        - *Feijoa* (Myrtaceae)
        - *Litchi* (Sapindaceae)
        - *Melicoccus* (Sapindaceae)
        - *Nephelium* (Sapindaceae)
        - *Psidium* (Myrtaceae)
        - *Rhodomyrtus* (Myrtaceae)
        - *Syzygium* (Myrtaceae)
        - *Vaccinium* (Ericaceae)

In 2011, APHIS established new regulations (7 CFR 319.37-2a) on importation of plants for planting (APHIS 2011c). In addition to the existing categories of prohibited and restricted plants, a third category called Not Authorized Pending Pest Risk Analysis (NAPPRA) was established. This category identifies plants for which scientific evidence indicates they are quarantine pests or hosts of quarantine pests and pose a risk to the United States. The current NAPPRA list contains 107 genera of hosts of quarantine pests that are not allowed entry into the United States from certain countries. Plants on this list are prohibited entry pending pest risk analysis. Three genera, *Acacia*, *Sophora*, and *Vaccinium,* which are part of this analysis, are included in this list. In addition, the following genera are in the same families of some of the 13 species being assessed in this pest risk assessment and are in the NAPPRA list: *Albizia* (Fabaceae), *Cajanus* (Fabaceae), *Cercis* (Fabaceae), *Litchi* (Sapindaceae), *Maackia* (Fabaceae), *Psidium* (Myrtaceae), *Rhododendron* (Ericaceae), *Robinia* (Fabaceae). Although these are not the same species as those being analyzed, some pests do occur on multiple species, often of the same family.

Commodities Entering Hawai‘i

Hawai‘i receives all of its commodities and visitors either by ship or aircraft. Six principal maritime ports (Honolulu, Hilo, Barbers Point, Kahului, Kawaihae, and Nawiliwili) receive most of the foreign and continental U.S. shipments. Excluding interisland service, Hawai‘i has five principal commercial airports (Hilo, Honolulu, Kahului, Kona, Lihue); most overseas visitors arrive through the Honolulu International Airport. In addition to these commercial ports of entry, military ports, both air and sea, are significant places for commodity imports.

Maritime cargo—

In 2010, maritime ports in Hawai‘i received 8 million metric tons of cargo on over 600 vessels from foreign points of origin. They also received 8 million metric tons on more than 7,000 vessels from domestic sources, which include mainland United States, Alaska, Puerto Rico and the Virgin Islands, Guam, American Samoa, Wake Island, and the United States Trust Territories (U.S. Army Corps of Engineers 2010). This includes military cargo shipped as ordinary commercial cargo but does not include what is shipped on Department of Defense vessels. A breakdown by harbor illustrates the volume of cargo arriving by ship at each port in 2010 (table 4).

The arrival of cargo on commercial maritime vessels was about equally split between domestic and foreign sources in 2010 when considering the quantity of goods (table 4). The number of vessels was considerably higher from domestic ports. However, this is somewhat misleading as the majority of foreign cargo is not shipped directly

Table 4—Foreign and domestic commercial traffic arriving at Hawai‘i maritime ports in 2010[a]

Harbor	Number of vessels inbound[b]		Total vessels inbound	Cargo (short tons)[c]		Total cargo (short tons)
	Foreign	Domestic		Foreign	Domestic	
Barbers Point, O‘ahu	127	772	899	7,336,838	307,614	7,644,452
Hilo, Hawai‘i	64	673	737	26,322	833,309	859,631
Honolulu, O‘ahu	398	3,010	3,408	836,902	5,010,833	5,847,735
Kahului, Maui	19	968	987	94,218	1,243,508	1,337,726
Kawaihae, Hawai‘i	1	643	644	28,175	604,613	632,788
Nawiliwili, Kaua‘i	37	542	579	10,475	586,135	596,610
Total	646	6,608	7,254	8,332,930	8,586,012	16,918,942

[a] Data source: U.S. Army Corps of Engineers 2010. http://www.navigationdatacenter.us/index.htm.

[b] Inbound self-propelled and non-self-propelled vessels, which includes dry cargo, tanker, and tow or tug vessels ranging in draft.

[c] Cargo includes agricultural and nonagricultural freight. Short ton = 2,000 lbs. (907.18474 kg).

to Hawai‘i, but arrives at the U.S. mainland and is then shipped as domestic cargo. This results in different phytosanitary inspections upon arrival in Hawai‘i. All foreign imports are cleared by the U.S. Department of Homeland Security, Bureau of Customs and Border Protection (CBP), whereas domestic shipments (including shipments of foreign origin arriving from the U.S. mainland) are cleared by HDOA at the port of arrival (Culliney et al., n.d.).

Much of this cargo is nonagricultural and would only carry insects and pathogens as hitchhikers or in material used for packing, crating, and dunnage. Data on categories of commodities of direct interest to our analysis are not available, but volumes of some likely commodities of interest are reported. Honolulu Harbor received all of the forest product type commodities from foreign sources in 2010. This included fuel wood (28 short tons), rough wood (218 short tons), lumber, (2,652 short tons), and forest products not classified elsewhere (576 short tons) (U.S. Army Corps of Engineers 2010). Even there, the quantity is a small proportion of the total maritime cargo received. Most of this was identified as lumber. Regardless of form, this material needs to meet APHIS importation requirements (7 CFR 319.40), which restrict certain types of lumber from importation and require mitigation measures (kiln dried, heat treated, or fumigated) for the remainder (APHIS 2013b).

During the past several decades, the amount of foreign imports into Hawai‘i has been on a general increase, but the recent economic downturn has seen this trend reversed. There was stabilization in maritime importation in 2010 (fig. 7), and this foreign importation will likely continue and increase as economic conditions improve.

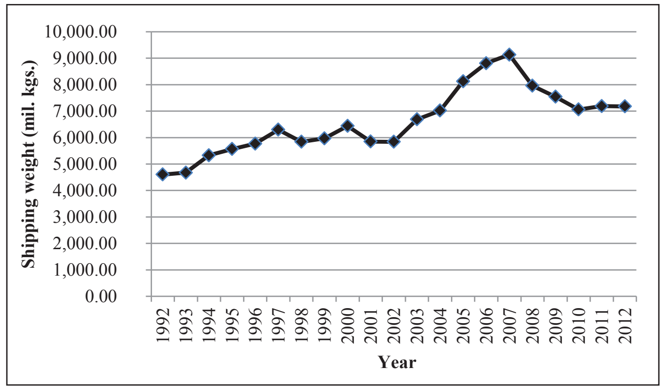

Figure 7—Foreign cargo arriving in Hawai‘i via maritime vessels between 1992 and 2012. Source: Hawai‘i Department of Business, Economic Development and Tourism 2010, 2012.

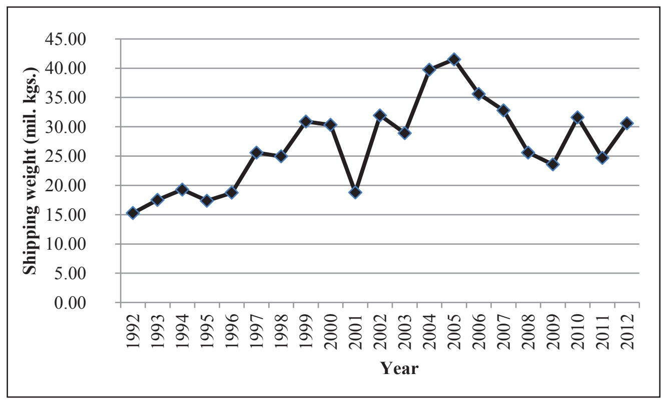

Figure 8—Foreign cargo arriving in Hawai‘i via aircraft between 1992 and 2012. Source: Hawai‘i Department of Business, Economic Development and Tourism 2010 and 2012.

Air cargo—

Hawai‘i is a resort destination and receives most visitors by air. Preliminary estimates for 2011 indicate over 7,284,000 visitor arrivals to Hawai‘i, with about 98 percent arriving by air (USDOT BTS 2011). Table 5 displays data for 2011 on air traffic into Hawai‘i. Most foreign passengers and cargo arrive through Honolulu International Airport.

Foreign cargo arriving by air has had a similar trend as foreign cargo arriving by sea. As with maritime importation of foreign goods, there was stabilization in air importation in 2010 (fig. 8), and this foreign air importation is expected to continue to increase as economic conditions improve.

Inspection of international arrivals is the responsibility of the U.S. Customs and Border Patrol (CBP). Officers with CBP meet arriving foreign transports and inspect a percentage of passengers, crew, luggage, and cargo to prevent entry of agricultural pests and diseases. Domestic travelers, including those from the U.S. mainland, are the responsibility of HDOA for inspection. Interception data from HDOA quarantine inspections of passenger carry-on baggage identified over 300 pest interceptions between 1995 and 2006 in domestic travelers (HDOA 2007). Currently, HDOA does not have a program in place to routinely inspect passenger carry-on baggage.

Table 5—Number of aircraft, passengers, cargo, and mail arriving at Hawai‘i airports from January through August 2011[a]

	Number of aircraft		Number of passengers		Cargo (short tons)		Mail (short tons)	
Airport	Foreign origin	Domestic origin	Foreign origin	Domestic origin[b]	Foreign origin	Domestic origin[b]	Foreign origin	Domestic origin
Hilo	0	4,692	1	12,643	0	70	0	0
Honolulu	5,882	42,113	1,296,599	414,778	56,494,828	14,185,243	277,002	2,207,421
Kahului	592	19,127	102,416	937,175	7,114	10,261,229	0	196
Kona	53	11,431	8,178	354,401	32,234	9,563,835	0	80,703
Lihue	35	8,806	4,758	306,900	0	657,765	0	2,797
Total	7,042	86,169	1,411,952	2,025,897	56,534,176	34,668,142	277,002	2,291,117

[a] Data Source: U.S. Department of Transportation, Bureau of Transportation Statistics 2011. www.transtats.bts.gov.
[b] Interisland traffic excluded.

Potential Origins of Pests

The above information on potential pathways provides an idea of the quantity of importation, but not the origin. The origin of foreign trade by all means of transportation to Hawai‘i is tracked by the U.S. Department of Commerce Census Bureau. During the period 2008 to 2010, the top countries exporting to Hawai‘i based on value of exports have been identified. The top 14 are shown in figure 9. The cumulative 3-year total is valued at over $14.7 billion from these countries (USDC CB 2013). Eight of the top 10 are in the Asia-Pacific region. Using commodity value may not be the best measure to evaluate potential origins of pests but are the only data readily available. Measures of volume or shipments could provide a better measure, but were not available to the authors.

In 2010, over 8.3 million tons of cargo arrived at Hawai‘i ports on marine vessels from foreign sources (U.S. Army Corps of Engineers 2010). About 95 percent of that arrived from 11 countries, primarily in Asia or the Pacific. This includes Australia, China, Indonesia, Japan, Russia, South Korea, Thailand, and Vietnam (fig. 10).

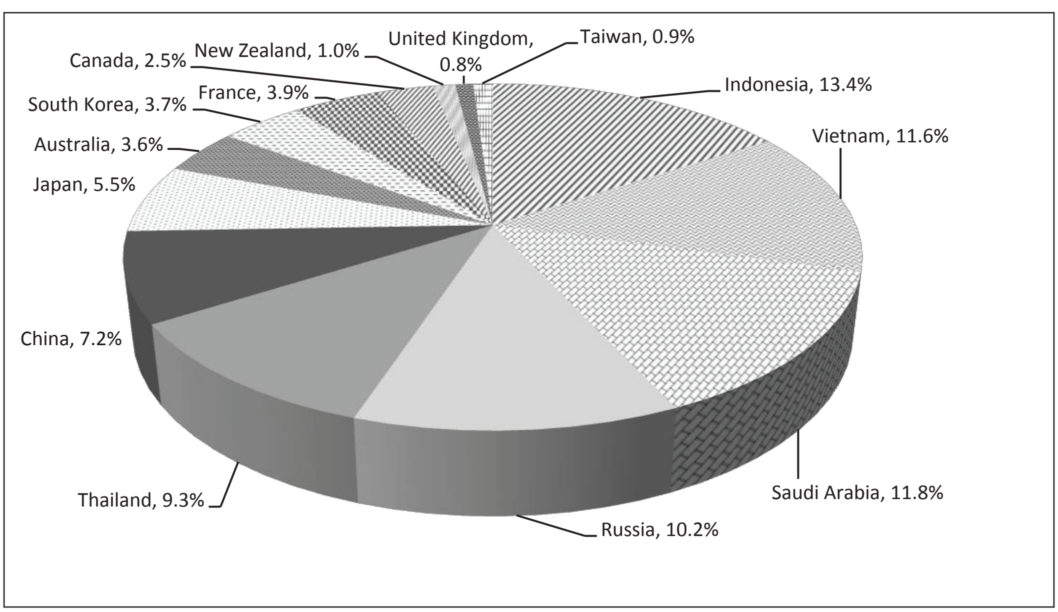

Figure 9—Top countries exporting to Hawai‘i based on 3-year average, 2008 to 2010, dollar value. Source: USDC CB 2013.

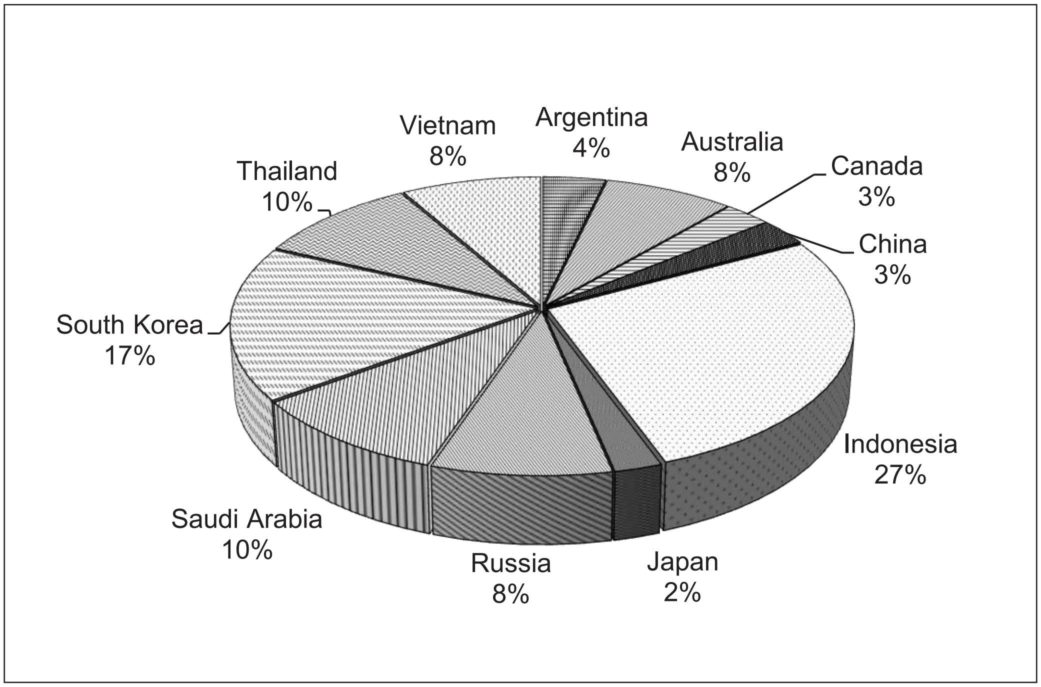

Figure 10—Origin of foreign freight arriving by sea to Hawai‘i in 2010. Source: U.S Army Corps of Engineers 2010.

The Bureau of Transportation Statistics collects data on movement of trade by aircraft in the United States. In 2010, Japan was the major exporter by air to Hawai‘i, with about 75 percent of the total cargo. Almost all of the remaining 25 percent arrived from sources in the Pacific and Asia (fig. 11). A total of over 50,200 tons arrived by air from foreign sources in 2010 (USDOT RITA 2010). In addition to foreign sources, a considerable amount of freight arrives by air from the U. S. mainland. In 2011, over 239,300 tons of freight was shipped by air to Hawai‘i from the continental United States and its territories (USDOT BTS 2011). The majority of the domestic freight arrived through the Honolulu International Airport (fig. 12). Of this, 1,830 tons were shipped from Guam, American Samoa, and Saipan. Material from these three territories may present particular concern because of their similar environment to Hawai‘i and the increased potential of exotic pests to find habitable conditions in Hawai‘i.

Known Pests at Potential Origins

A principal means of determining potential pests for introduction is the evaluation of the host plant and its pests in other geographic areas. Of the 13 host taxa in this assessment, nine are endemic to the Hawai‘i Islands. Exposure to foreign pests only occurs where these plants have been introduced to foreign environments. Most of these have not been planted in other locations and have not been exposed to potential insect pests and pathogens. To better assess what pest organisms might be a threat, we went beyond the species level and looked at the genus and family to provide a list of potential pests around the world. In some cases this was a daunting task. For example, *Diospyros* and *Vaccinium* are genera with members that produce agricultural commodities. Because of the economic value of these crop plants, extensive lists of pests have been identified and evaluated. These crops have also been planted in many areas around the world. The list of insects and pathogens for these species is considerably longer and more complete than those lists of species with more limited host distribution.

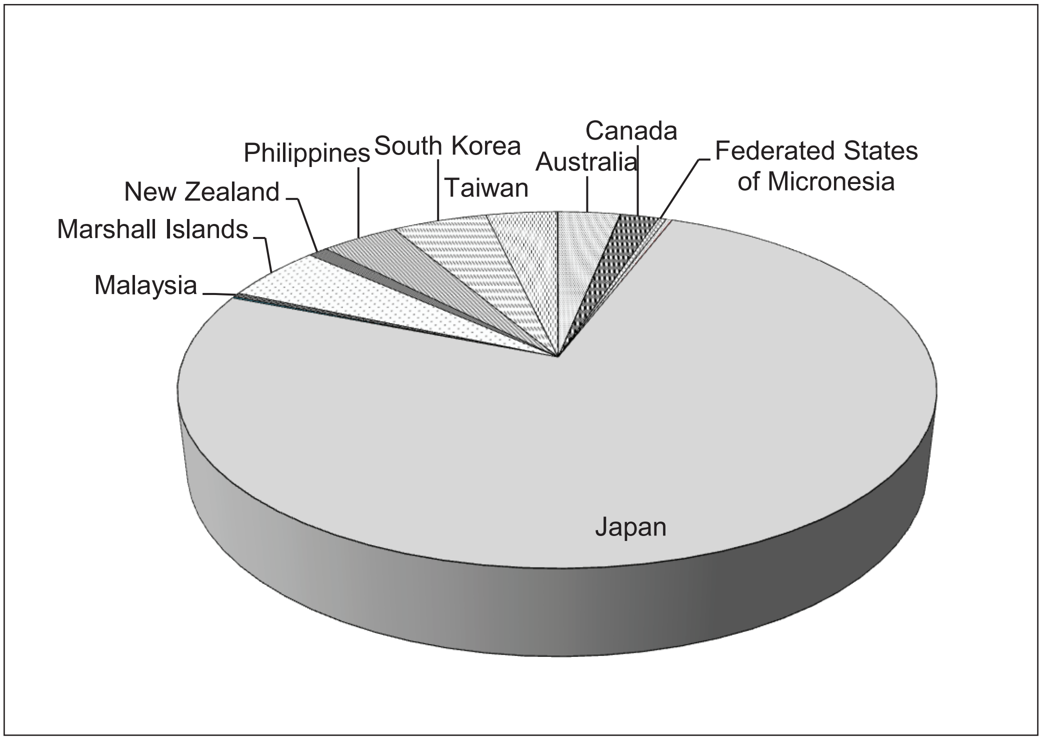

Figure 11—Origin of foreign freight arriving by air to Hawai‘i in 2010. Source: USDT BTS 2011.

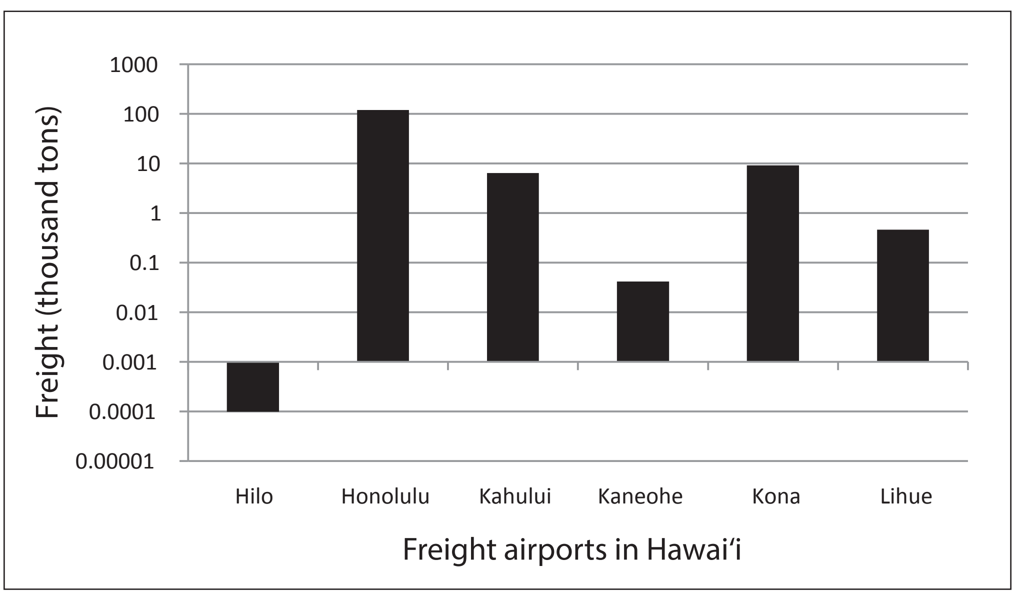

Figure 12—Destination of air freight arriving in Hawai‘i from the continental United States and its territories, 2011. Source: USDT BTS 2011.

Chapter 4: Insects and Pathogens Posing Risk

Introduction

The probability of pest introduction is determined by several related factors, including the likelihood of a pest traveling with and surviving on a shipment from the place of origin, a pest colonizing suitable hosts at the point of entry and during transport to processing sites, and subsequent pest spread to adjacent territories. Many insects and pathogens could be introduced on various commodities into Hawai‘i from any origin in the world. Because it would be impractical to analyze the risk of all of them, some form of selection was necessary. Selection was based on the likelihood of the pest being on or in a commodity, and on potential risk the pest poses to resources in Hawai‘i. The pest risk assessment team compiled and assessed pertinent data using the methodology outlined in “Pest Risk Assessment Process” in appendix 4,[1] and as used in previous pest risk assessments (Kliejunas et al. 2001, 2003; Tkacz et al. 1998; USDA FS 1991, 1992, 1993).

Analysis Process

The general analysis process used is explained in appendix 4. For this risk assessment, information was collected from an array of sources on the organisms associated with or considered a risk to any of the 13 taxa identified as hosts of concern in Hawai‘i. Lists of insects and pathogens that have been reported to inhabit these species or closely related species outside of Hawai‘i were compiled from the literature, information provided by Hawaiian entomologists and plant pathologists, information received from reviewers of a preliminary list prepared by the team, and information described in appendix 4. These organisms were catalogued in one of the categories of quarantine pests defined in the log import regulations. The team broadened some of the categories to include a broader definition of genetic variation (table 6). The part of the plant the organisms affect was also noted: seeds, roots, on foliage or bark, in or under the bark, in sapwood, or in heartwood. From these lists, organisms were selected for further analysis. Organisms were selected from each of the plant parts affected. Organisms were selected based on the amount of damage they may cause in Hawai‘i, the availability of information available on the organism, and the pathway the organism represents. For each organism selected, a thorough individual pest risk assessment (IPRA) was developed as described in appendix 4.

Potential Insects and Pathogens of Concern

The species of insects and pathogens associated with the 13 taxa in Hawai‘i and identified as potential pests of concern are presented in appendix 7 (tables 7-1 and 7-2). The organisms listed are not meant to be all-definitive or

[1] Appendices for this report are available online at: http://www.fs.fed.us/psw/publications/documents/psw_gtr250/ psw_gtr250_appendix.pdf.

Table 6—Pest categories and descriptions

Category	Description
1	Nonindigenous plant pest not present in Hawai‘i
2	Nonindigenous plant pest present in Hawai‘i and capable of further dissemination in Hawai‘i
2a	Native plant pest of limited distribution in Hawai‘i, but capable of further dissemination in Hawai‘i
3	Nonindigenous plant pest present in Hawai‘i that has reached probable limits of its ecological range but differs genetically from the plant pest in Hawai‘i in a way that demonstrates a potential for greater damage potential in Hawai‘i
4	Native species of Hawai‘i that has reached probable limits of its ecological range, but differs genetically from the plant pest in Hawai‘i in a way that demonstrates a potential for greater damage potential
4a	Native pest organisms that may differ in their capacity for causing damage, based on genetic variation exhibited by the species
5	Nonindigenous or native plant pest that may be able to vector another plant pest that meets one of the above criteria

all-inclusive lists but are a result of literature searches and information provided by colleagues. For an organism to be listed in table 7-1 or in table 7-1, it must have been identified with one of the 13 Hawai‘i host species or a closely related species, either in the literature or by communication amougst other entomologists or plant pathologists. That host is listed in the tables, as are any additional hosts known to harbor the insect or pathogen. Bold type is used in the tables to highlight the insects or pathogens treated in IPRAS. The tables represent a list of potential pests of concern, and do not represent, or judge, quarantine status of any of the organisms listed.

Individual Pest Risk Assessments

Twenty-four IPRAS were prepared, 12 dealing with insects and 12 with pathogens. The objective was to include in the IPRAS representative examples of insects and pathogens found on seeds, roots, bark, sapwood, and heartwood that would have the greatest potential risk to forests and other tree resources of Hawai‘i. The team recognized that these might not be the only organisms associated with these hosts in Hawai‘i. They, however, are representative of the diversity of insects and pathogens that might inhabit the hosts of concern. By necessity, the IPRAS focus on those insects and pathogens for which biological information is available. The assessments of risks associated with known organisms that inhabit a variety of niches can be used by the Animal Protection and Health Inspection Service (APHIS) and Hawai‘i Department of Agriculture (HDOA) to identify effective mitigation measures to eliminate both the known organisms and any similar heretofore unrecognized organisms that inhabit the same niches. A summary table (table 11) of the IPRA results can be found in chapter 5.

Insect IPRAs

Apple Stem Borer

Assessor: Andris Eglitis

Scientific name of pest: *Aeolesthes holosericea* (Fabricius) (Coleoptera: Cerambycidae)

Scientific names of hosts: *Acacia nilotica, A. arabica, Aegle marmelos, Alnus nitida, Anogeissus latifolia, Bauhinia acuminata, Bauhinia retusa, B. variegata, Bombax malabaricum, Bridalia retusa, Butea frondosa, Careya arborea, Cedrela toona, Chloroxylon swietenia, Cynometra ramiflora, Duabanga sonneratioides, Eucalyptus robusta, Excaecaria agallocha, Ficus bengalensis, Grewia oppositifolia, Hardwickia binata, Juglans regia, Kydia calycina, Lannea grandis, Largerstraemia parviflora, Mallotus philippinensis, Malus domestica, Mangifera indica, Miliusa velutina, Morus alba, Myristica andamanica, Ougenia dalbergioides, Pentacme suavis, Pinus longifolia, Prunus armeniaca, P. avium, P. communis, P. domestica, P. persica, Psidium guajava, Pterocarpus marsupium, Pyrus baccata, P. communis, Quercus incana, Shorea robusta, Tamarix articulata, Tectona grandis, Terminalia balerica, T. myriocarpa, T. tomentosa, Sapium sebiferum, Shorea assamica, Soymida febrifuga (*Rahman and Khan 1942).

Distribution: India

Summary of natural history and basic biology of the pest: The apple stem borer, also known as the cherry stem borer, is widely distributed throughout forested areas in India (Rahman and Kahn 1942, Tara et al. 2008). The insect has a very wide host range that includes many important fruit trees such as apple (*Malus* sp.), and several *Prunus* species, including cherry, apricot, plum, and peach (Rahman and Kahn 1942). The apple stem borer is considered to be one of the most destructive borers of apple plantations in India (Tara et al. 2008). Larval feeding progressively weakens trees, initially causing branch dieback, and eventually tree death (Gupta and Tara 2013). As many as 70 larvae may be found within infested branches (Tara et al. 2008). Rahman and Kahn (1942) reported that a single larva could kill a young apple tree. Infested trees are easily recognized because of the continuous sap flow from the openings of larval feeding galleries and from the frass plugs on the trunk and branches (Gupta and Tara 2013).

Adult beetles are large and stout, measuring from 38 to 45 mm in length and 10 to 13 mm wide (Gupta and Tara 2013). Males are distinctly smaller than females and have antennae considerably longer than their body. The insects are dark brown or reddish brown and covered by dense golden brown pubescence, giving them a silky appearance (Gupta and Tara 2013).

In the field, adult beetles begin emerging from infested material in March or April (spring) and emergence continues well into the summer or fall, depending on the area and the affected host (Gupta and Tara 2013). For oviposition, females select crevices or injured areas on the bark, where eggs are laid singly or in groups of two to five. The egg-laying period can occur between May and October (spring and fall) (Rahman and Kahn 1942). Under laboratory conditions, each female is capable of producing 45 to 80 eggs (Gupta and Tara 2013). The eggs hatch within 2 weeks and young larvae immediately begin feeding on the phloem and cambium. As the larvae grow, the later instars move into the heartwood where they create branched galleries. These “sub-tunnels” are open to the exterior of the tree, allowing the insects to expel their excreta as they feed (Gupta and Tara 2013). The gallery openings are typically plugged with frass and oozing sap (Gupta and Tara 2013). Gupta and Tara (2013) reported that the period of larval development is extremely variable on fruit trees, ranging from 9 to 32 months. Mature larvae widen the main feeding tunnel to form a pupal chamber that is located near the outer surface of the infested tree (Gupta and Tara 2013). Pupation takes place between September and October (fall), and the insects spend the winter in the pupal stage (Gupta and Tara 2013). The entire life cycle can range from 2 to 3 years (Rahman and Kahn 1942).

Specific information relating to risk elements (elements defined in table 7):

A. Likelihood of introduction (untreated wood pathway)

1. Pest with host-commodity at origin potential: **High** (VC) (Applicable rating criteria, from app. 4: c, e, f, g, h)

The insect has a broad host range and is widely distributed throughout India. All of the life stages of wood-boring beetles are well-protected beneath the bark or in the wood of host material, and survival during shipment of at least a few individuals would be expected. Cerambycids are very adept at finding freshly cut or otherwise suitable host material and once inside their host, are not easily dislodged.

2. Entry potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d)

Life stages of the wood borer would be well-protected within untreated raw wood and could be difficult to detect in packing material made of that wood. Wood-boring insects have been highly successful in gaining entry into new environments via the solid wood packing material pathway.

3. Colonization potential: **High** (RC) (Applicable rating criteria, from app. 4: b, d, e)

Hawai‘i occupies the same latitudinal band as parts of India. Within India, the apple stem borer ranges in elevation from 1067 to 2438 m and has nearly 40 host plants (Rahman and Kahn 1942). *Aeolesthes holosericea* has a high reproductive potential, with each female capable of laying up to 80 eggs (Gupta and Tara 2013).

4. Spread potential: **High** (RC) (Applicable rating criteria, from app. 4: a, c, d, e, f, g)

The apple stem borer has a very broad host range including plant genera that occur in Hawai‘i (e.g., *Acacia*, *Bauhinia*, *Eucalyptus*, *Mangifera*, *Morus*, *Psidium*, *Pterocarpus*, *Prunus*, *Pyrus*, *Tectona*, *Terminalia*). As evidenced by introductions of cerambycids in other parts of the world, infestations often go undetected for many years. Typically, the lengthy period of time between detection of infestations and response means that eradication is not possible.

B. Consequences of introduction

5. Economic damage potential: **High** (RC) (Applicable rating criteria, from app. 4: a, b, c, d)

The apple stem borer infests a wide variety of fruit trees and is capable of weakening and killing many of its hosts through repeated infestation (Gupta and Tara 203).

6. Environmental damage potential: **High** (RC) (Applicable rating criteria, from app. 4: d, e)

This insect is being evaluated because it has hosts in the genus *Acacia*, which could include the Hawai‘i species *A. koa*. Given its wide host range, cryptic nature, and ability to attack economically important plants, the apple stem borer might affect species with limited ranges and could require aggressive controls once established.

7. Social and political considerations: **Moderate** (RU) (Applicable rating criteria, from app. 4: a)

Public concerns could be likely if another economically important pest were introduced into Hawai‘i.

C. Pest risk potential:

High (Likelihood of introduction = **high**; Consequences of introduction = **high**)

Selected bibliography:

Gupta, R.; Tara, J.S. 2013. First record on the biology of *Aeolesthes holosericea* Fabricius, 1787 (Coleoptera: Cerambycidae), an important pest on apple plantations (*Malus domestica* Borkh.) in India. Munis Entomology and Zoology. 8(1): 243–251.

Rahman, K.A.; Khan, A.W. 1942. Bionomics and control of *Aeolesthes holosericea* F. (Coleoptera: Cerambycidae). Proceedings of the Indian Academy of Sciences, Sec. B. 15: 181–185.

Tara, J.S.; Gupta, R.; Chhetry, M. 2008. A study on *Aeolesthes holosericea* Fabricius, an important pest of apple plantations (*Malus domestica* Borkh.) in Jammu region. The Asian Journal of Animal Science. 3(2): 222–224.

Reviewers' comments: None received.

Botany Bay Diamond Weevil

Assessor: Andris Eglitis

Scientific name of pest: *Chrysolopus spectabilis* Fabricius (Coleoptera: Curculionidae)

Scientific names of hosts: *Acacia decurrens*, *A. mearnsii*; nearly 30 other *Acacia* spp.

Distribution: Australia (Queensland, New South Wales, Victoria, South Australia)

Summary of natural history and basic biology of the pest: Hawkeswood (1991) summarized the biology of the Botany Bay weevil as described by several Australian authors and added his personal observations. The adult weevil feeds on at least 28 species of *Acacia* (wattles), 10 of which have bipinnately compound leaves, and 18 of which are phyllodinous species. The bipinnate host species occur in the more heavily timbered habitats such as the dry sclerophyll forests, and the phyllodinous *Acacia* species are in the coastal heathland and open woodland habitats (southeastern Queensland and northern New South Wales, Australia) (Hawkeswood 1991). The wattles preferred by *C. spectabilis* are usually thick-stemmed, large, shrubby species with mucilaginous bark (Hawkeswood 1991).

Adults are typically observed on their hosts during the summer (November, December, January), when they feed and mate on stems, branches, and foliage. Hunt et al. (1996) described damage caused by this insect in young plantations of *Acacia mearnsii* in southeastern Australia. The weevils removed the leading shoots from saplings and hindered the development of a single stem in the affected hosts. For egg-laying purposes, the female weevil typically attacks the main stem just above the ground line, where she gnaws the bark into small roughened spots and deposits an egg under each spot (Hawkeswood 1991). Some trees may have as many as 20 eggs laid in this fashion (Hawkeswood 1991). After the eggs hatch, the small larvae bore down into the main roots, which are eventually completely hollowed out. Host trees can sometimes be killed by this larval feeding (Hawkeswood 1991). The life cycle is believed to be completed in 1 year (Hawkeswood 1991). The adult weevils are bronze-black to black with three bright green bands on the pronotum of those emerging early, and metallic blue on weevils that emerge later in the season (Hawkeswood 1991). The elytra are irregularly mottled with metallic green to blue and covered with dense scales on the underside of the body.

Hawkeswood (1991) points out that even though *C. spectabilis* is considered one of the most distinctive and common weevils in Australia, there is relatively little known about larval food plants and biology of the insect. Only six larval hosts have been recorded, although all of them are also adult hosts and Hawkeswood (1991) speculated that further research would probably expand the list of larval hosts, perhaps to include most of the *Acacia* species utilized by the adults.

Specific information relating to risk elements:

A. Likelihood of introduction (wood or plant material pathway)

1. Pest with host-commodity at origin potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: c, e, g, h)

The larval stage could be harbored within stems of *Acacia,* if infested wood were to be transported. Hawkeswood (1991) describes adult behavior, noting that sometimes the weevils firmly grasp the foliage of their hosts and can be very difficult to dislodge.

2. Entry potential: **High** (MU) (Applicable rating criteria, from app. 4: b, c, d)

Although *C. spectabilis* has not often been intercepted, other curculionids with similar habits are commonly found during port inspections. Criterion "d" would only apply to larvae within the wood; adults on foliage would likely be conspicuous.

3. Colonization potential: **Moderate** (MU) (Applicable rating criteria, from app. 4: b)

Chrysolopus spectabilis occurs in Queensland, Australia, which is at latitudes similar to those of the Hawai'i Islands. *Acacia koa* is a potential host in Hawai'i and occurs between the latitudes of 19 and 22 degrees N. *Acacia koa* belongs in the *Acacia* subgroup that includes phyllodinous and bipinnate species, which are the only *Acacia* hosts for the Botany Bay diamond weevil.

4. Spread potential: **Moderate** (MU) (Applicable rating criteria, from app. 4: d, e)

If *A. koa* proves to be an acceptable host for *C. spectabilis*, then criterion "d" would apply. Infestations would not likely be detected in the short term.

B. Consequences of introduction

5. Economic damage potential: **Moderate** (MU) (Applicable rating criteria, from app. 4: a, b, e)

Hunt et al. (1996) reported that the Botany Bay weevil was capable of affecting the growth patterns of young trees by killing the leaders through adult feeding. In addition, Hawkeswood (1991) observed that larval feeding could kill host trees.

6. Environmental damage potential: **Moderate** (MU) (Applicable rating criteria, from app. 4: e)

The chemical controls necessary to eradicate this weevil could have negative environmental effects.

7. Social and political considerations: **Low** (MU) (Applicable rating criteria, from app. 4: none of the rating criteria apply)

C. Pest risk potential:

Moderate (Likelihood of introduction = **moderate**; Consequences of introduction = **moderate**)

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Reviewers' comments: None received.

Coconut Rhinoceros Beetle

Assessor: Sheri Smith

Scientific name of pest: *Oryctes rhinoceros* Linnaeus (Coleoptera: Scarabaeidae)

Scientific names of hosts: *Cocos nucifera, Elaeis guineensis, Areca catechu, Phoenix dactylifera, Wodyetia bifurcata,* ***Pandanus tectorius****, Colocasia esculenta, Ananas comosus, Musa* spp., *Saccharum* spp., *Corypha* spp; a variety of other ornamental palms

Distribution: Pakistan, India, Maldive Islands, Hainan, Taiwan, Hong Kong, Thailand, Vietnam, Malay Peninsula, islands of Java, Sumatra, Bali, Lombok, Kalimantan, Celebes, Ceram and Amboina in Indonesia, Philippine Islands, Sri Lanka, Upolu, Western Samoa, American Samoa, Tonga, Palau Islands, New Britain, West Irian, New Ireland, Pak Island and Manus Island (New Guinea), Fiji, Cocos (Keeling) Islands, Mauritius, Reunion, and Guam.

2014 update: One adult coconut rhinoceros beetle (CRB) was found in baggage claim at the Honolulu Airport on O‘ahu in November 2013; an additional adult beetle was detected in a trap in the same vicinity in December 2013. Breeding sites (piles of green waste) were subsequently found on the Joint Base Pearl Harbor-Hickam military facility. It is not known exactly how the beetles arrived in Hawai‘i. As of June 2014, 423 adults, 531 larvae, and 16 pupae have been found in the established buffer zone (HDOA 2014).

Summary of natural history and basic biology of the pest: Coconut rhinoceros beetle is a major pest of coconut palm in its Asian homeland, and on the south and western Pacific Islands it has invaded. Adult beetles attack several species of endemic and ornamental palms and *Pandanus*, banana, taro, and pineapple. The CRB likely entered Malaysia about 1895 and worked its way throughout the coconut growing areas of lower Burma over the following 15 years (McKenna and Shroff 1911). In the early part of the 20^{th} century, the major economic activity for most Pacific Islands was production of copra from coconuts in natural and managed plantations. The CRB is believed to have entered the Pacific concealed in rubber seedling potted plants from Ceylon in 1909 (Catley 1969). The insect established rapidly in Samoa and subsequently spread to Tonga and to multiple other locations by the mid-1960s. The CRB was first reported from Fiji in 1953, and despite intensive attempts to implement quarantine procedures, had spread through most of the Fiji Island group by 1971 (Bedford 1976). Initial outbreaks of CRB have been devestating; when it invaded Palau in 1942, coconut palms were completely eradicated from some islands, and overall tree mortality was about 50 percent (Gressitt 1953). Since its invasion of Guam in 2007, CRB has spread to most parts of the island (Aubrey Moore, entomologist, University of Guam, personal communication). Typhoons produced an abundance of dead coconut material suitable for breeding sites, and larval food and coconut palms killed by adult feeding are adding to the supply of larval food, further facilitating population growth. In addition, CRB seems to be free of control by natural enemies on Guam. Over 6,000 beetles have been trapped and over 11,000 larvae found. Sixty dead or dying coconut palms have been felled and destroyed. An aggressive eradication program was implemented on Guam but has failed and is now transitioning to a management program. The most likely method of CRB introduction onto Guam was as a hitchhiker with construction material from the Philippines (Berringer 2007). Floating logs can also contain larvae and serve as transporters to new or already infested locations.

Adults are the injurious stage of the insect. They feed and aggregate in the crowns of palm trees. They are generally night-time fliers, and when they alight on a host, they enter the axil and bore into unfurled tissue at the meristem to feed on sap. Each feeding visit can cause petiole or leaflet injury to three to four fronds (Hinckley 1966). Male beetles produce an aggregation pheromone, attractive to both sexes, which results in patchy distribution of beetles within stands of palms. Beetle presence is evident through notching, fanning, and breaking of emergent palm fronds. V-shaped cuts in the fronds and holes through the midrib are visible when the leaves grow out and unfold. If the growing tip is injured, the palm will have severe loss of leaf tissue and decreased nut set. High feeding pressure results in mortality of the growing tip, leaving a dead standing stump. Feeding wounds may also serve as an infection pathway for pathogens or other pests. The effects of adult boring may be more severe on younger palms where spears are narrower.

Almost any log or heap of material soft enough for burrowing, yet firm enough to provide compacted frass, may be utilized for oviposition. Large numbers of CRB larvae may develop in the tops of dead standing coconut palms, coconut stumps, and in logs on the ground. High numbers of palms injured or killed in typhoons have served to initiate outbreaks in many locations. Gressitt (1953), Cumber (1957), and Paine (1967) all emphasized the correlation between abundance of larval food and damage by adults to palms. Based on recent information from Guam, CRB is able to complete the entire life cycle in the crowns of palms, negating the need for down material (Aubrey Moore, entomologist, University of Guam, personal communication), which would likely increase the establishment potential in Hawai‘i. The CRB is most likely to be of economic importance whenever and wherever suitable breeding sites are numerous. On Guam and in other locations, the beetle is also known to breed in compost piles and shredded palm material. Decaying *Pandanus* trunks have served as breeding sites on Palau (Gressitt 1953), and other breeding sites such as cattle dung, decaying cocoa pod shells, and decaying matter of other host species have been noted.

Hinckley (1973) described the life cycle of *O. rhinoceros* from Western Samoa, which agreed closely with the description made by Gressitt (1953) from Palau. Under favorable conditions, one generation, egg to egg, can be as short as 20 weeks. The female beetle makes a serpentine burrow, laying eggs one by one and compressing the chewed material behind her. Clutch size averages about 27 eggs but can be as many as 62, with more being laid by larger females. About 11 days are required for development in the egg stage. It is not known how many clutches are laid by each female but numerous (e.g., five) may be possible. Gressitt (1953) estimated between three or four, totaling 90 to 120 eggs per female. First instar larvae feed on the burrow frass and develop rapidly under favorable conditions. About 3 weeks each are spent as first and second instars, and 5 to 9 weeks as third instars. The late third instar burrows into a firm portion of material prior to pupation, creates a pupal chamber and goes through a nonfeeding stage lasting about 1 week (Gressitt 1953). High mortality rates of larval instars are common, particularly in the first and third instar. Teneral adults are found in chambers after about 3 weeks. After the teneral period, the adult beetle chews out of the pupal chamber and emerges.

Adult feeding visits are multiple, and burrowing depths into host crowns vary greatly. Deep burrows on young palms are often fatal, either by destruction of the growing tip or from secondary infections by pathogens. The normal interval between feedings is probably more than 10 days and less than 20 days. Dispersal, mating, and oviposition occur within 2 weeks of emergence, and adults can survive up to 12 more weeks. A female beetle can lay viable eggs for several months after one mating. The lifespan of individuals reaching maturity is 4 to 9 months (Bedford 1980).

Specific information relating to risk elements:

A. Likelihood of introduction (hitchhiker)

1. Pest with host-commodity at origin potential:

Plant material/pots/detritus—**High** (MC) (Applicable risk criteria from app. 4: b, c, d, e, f, g)

Hitchhiker in shipping containers/military equipment—**High** (RC) (Applicable risk criteria from app. 4: b, c, d, e, f, g)

A number of risk criteria apply for this element when movement of plants, detritus, and shipping containers/military equipment are considered. The CRB is widely distributed in the Western and Southern Pacific and Asia. Building populations on Guam are also of great concern, particularly now that eradication has failed and adult beetles are likely to be numerous, increasing the likelihood of accidental transport to other islands in Micronesia, Hawai‘i, and beyond. Guam has more than 13 million coconut palms (Donnegan et al. 2004), so host supply is readily available for continued population increase. The most likely method of introduction onto Guam was by adult beetle(s) hitchhiking in a shipping container from Asia. There is evidence that Guam and other Micronesian islands have been the source of several major insect pests invading Hawai‘i. Oriental fruit fly is a prime example (Swezey 1942). Accidental transport of other scarab beetles from Guam to Hawai‘i is well documented (Moore 2007).

2. Entry potential:

Plant material/pots/detritus: **High** (MC) (Applicable risk criteria from app. 4: b, c, d)

Hitchhiker in shipping containers/military equipment: **high** (VC) (Applicable risk criteria from app. 4: a, b, c, d)

The adult stage is most likely to be transported as a hitchhiker in shipping containers or with military equipment. Five adult beetles were detected in maritime shipments, originating in Indonesia, at the Kahului seaport on Maui during two different time periods in 2003, confirming that previous entries have occurred. Dependent upon the amount of plant material transported from CRB-infested locations to Hawai‘i, this could also be a mode of entry for adults, but less likely than in containers. The most likely method of introduction onto Guam was by adult beetle(s) hitchhiking in a shipping container from Asia. Invasion of CRB into Palau in 1942 has been linked to transport of military equipment/supplies. Adult survival during transport would be higher than for other life stages, but it seems plausible that other life stages could be transported as well. Adults can live for several months, and several days can lapse between sap feeding visits.

3. Colonization potential: **High** (VC) (Applicable risk criteria, from app. 4: a, b, c, d, e)

The CRB has already invaded and successfully colonized several western and southern Pacific Islands with similar climates and hosts as those that exist in Hawai‘i. Proximity of hosts to ports of entry would greatly increase the likelihood of successful colonization. As has occurred with other invasive insects in Hawai‘i, nonnative ornamental plantings served as initial hosts to facilitate colonization, and then populations expanded into more distant native hosts; this could easily be the case with CRB as well, with numerous ornamental palms available in proximity to ports of entry. In addition to palms, *Pandanus tectorius*, pineapple, and other hosts exist on several Hawai‘i islands. *Pandanus tectorius* is thought to be much more common in some parts of Honolulu and on other islands today, and fan palms could also serve as hosts. Any type of outbreak can expand and become self-perpetuating if attacks by adult beetles become frequent enough to kill mature palms. Given that females lay an average of 90 eggs, CRB generation time is 4 months, and a one to one sex ratio. Gressitt (1953) estimated that a single gravid female could theoretically produce a progeny, assuming no mortality, of 16,995,293,890 by the end of 2 years.

4. Spread potential: **High** (VC) (Applicable risk criteria, from app. 4: a, b, c, d, e, f)

Based on laboratory data from tethered adult CRBs, flight duration after feeding was between 2 and 3 hours, and distances travelled were between 2 to 4 km; so ability to disperse is high (Hinckley 1973). However, it may be somewhat lessened by potentially poor fitness of beetles upon arrival. The organism does have high reproductive potential but is also susceptible to high levels of mortality in the larval stages. Based on beetle distribution and numbers found initially on Guam in 2007, we estimate that it was present there 1 to 2 years (three to six generations) before detection, which could potentially be the case as well in Hawai‘i. A single CRB was caught in a seaport warehouse on Saipan, 241 km to the north of Guam, in September 2006. Infestations can be contained, suppressed, and eradicated by removing larval breeding sites and mass trapping adults. The CRB was exterminated from the 36 km^2 of Niuatoputapu Island, between Samoa and Tonga, using these methods (Gressitt 1953). However, mass trapping coupled with sanitation during 1971 through 1974 failed to eradicate CRB on two islands in Fiji, and eradication has failed recently on Guam.

B. Consequences of introduction

5. Economic damage potential: **Moderate** (RC) (Applicable risk criteria, from app. 4: b, c, d)

The CRB killed over 50 percent of the coconut palms on Palau after it was introduced in 1942 (Gressitt 1953). In 1968, CRB caused over $1 million in damage to palms in South Pacific countries (Bedford 1980). The damage and losses to resort, park, and residential and ornamental plants in Hawai‘i will affect the aesthetic appeal of important properties and tourist areas. Some losses in recreational use and revenue owing to diminished scenic appeal are likely. Costs associated with hazard tree removal, tree replacement, and regulatory actions are expected to increase. Current cost of replacing a mature ornamental palm on Guam is $1,000. A permanent infestation could lead to interstate and international quarantine restrictions, affecting Hawai‘i, its trade partners, and other U.S. states.

6. Environmental damage potential: **Moderate** (MC) (Applicable risk criteria, from app. 4: d)

Outbreaks of CRB can expand and become self-perpetuating if attacks by the adult beetles become frequent enough to kill mature palms and other hosts. Based on CRB's invasiveness, injury to native host plants is expected to be substantial if populations are left untended. Movement of wood, debris, or infested host plants would likely increase the rate of spread into native forests. Extensive mortality of cultivated and wild hosts should be expected. The consequent changes in composition and age structure of palms and *P. tectorius* could have long-term ecological effects.

7. Social and political considerations: **Moderate** (MC) (Applicable risk criteria, from app. 4: a, b, c)

The successful introduction of CRB would likely result in public concerns regarding the aesthetics of damaged palms in urban plantings. In addition, *P. tectorius* is prominent in Pacific culture and tradition, including local medicine. All parts are used, from the nutritious fruits of edible varieties, to the poles and branches in construction, to the leaves for weaving and garlands.

A permanent infestation could lead to interstate and international quarantine restrictions, affecting Hawai'i, its trade partners, and other U.S. states.

C. Pest risk potential (plant material/pots/detritus): **High** (Likelihood of introduction = **high**; Consequences of introduction = **moderate**)

(Hitchhiker in shipping containers/military equipment): **High** (Likelihood of introduction = **high**; Consequences of introduction = **moderate**)

Selected bibliography:

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Swezey, O.H. 1942. Insects of Guam-1. Bull. 172. Honolulu: Bernice P. Bishop Museum. 1-218.

Reviewers' comments: The economic rating of **moderate**; that seems underestimated. An overhaul of the landscaping in Waikīkī, and other tourist areas seems significant as well as the removal of the iconic swaying palms when 50 percent are gone. Hawai'i imports substantial amounts of taro from the Pacific. It is important if commercial trade in taro corms are likely to harbor CRB. More information on where we would expect to find CRB in taro, the signs for inspectors and field extension agents would be helpful. Hawai'i is active in preserving taro varieties as an important cultural crop.

Response to comments: The economic damage potential rating of **moderate** is an estimate based on the rating criteria determined to be appropriate by the author of this assessment. There is no disagreement that economic losses could be quite high with the loss of high numbers of ornamental palms. The CRB is likely to arrive as an adult and as a hitchhiker "at large," not correlated with any particular commodity. The adults are attracted to bright lights and like to hide out in dark places during the day, so they are likely to enter the hold of a ship or aircraft at a loading dock.

2014 update—Coconut rhinoceros beetle was not established in Hawai'i when this pest risk assessment effort was initiated, although five adult beetles had been detected in 2003 at the Kahului seaport on Maui. Coconut rhinoceros beetle was included as a pest for further evaluation in the risk assessment process primarily owing to the building CRB populations on Guam where eradication has failed and adult beetles are numerous, increasing the likelihood of accidental transport to other islands.

Since the 2013 CRB detection on O'ahu, a joint effort between the U.S. Department of Agriculture, the University of Hawai'i at Manoa, the U.S. Navy, the Hawai'i Department of Agriculture, USDA Forest Service, and other partners have mobilized surveying, trapping and control efforts in the area where the beetles were initially found. An Incident Command System has been established to help manage the various agencies and activities needed to efficiently respond to this pest (for more information see emergencyhttp://hdoa.hawaii.gov/pi/main/crb/). Breeding sites have been located at several locations on the Joint Base Pearl Harbor-Hickam military facility. As of June 2014, 423 adults, 531 larvae, and 16 pupae have been found within the established buffer zone. Based on the high number of all life stages found at the base compost sites and in traps, CRB has likely been on O'ahu for at least 2 to 3 years. Based on visual surveys, 103 palms have injury indicative of CRB attack; over 66,000 palms have been surveyed (HDOA 2014).

Coconut Stick Insect

Assessor: Andris Eglitis

Scientific name of pest: *Graeffea crouanii* (LeGuillou) (Orthoptera: Phasmatidae)

Scientific names of hosts: Mainly coconut palm (*Cocos nucifera*); Sago palm (*Cycas revoluta*), *Miscanthus japonicus,* ***Pandanus tectorius***, ***Pandanus*** spp.

Distribution: Australia, Solomon Islands, Caroline Islands, Cook Islands, Fiji, American Samoa, Western Samoa, Society Islands, Marquesas, Mangareva, Tokelau, Tonga, French Polynesia, New Caledonia, Niue, Tuvalu

Summary of natural history and basic biology of the pest: *Graeffea crouanii* is considered a pest of significance on coconut palms in Tuvalu (Hardy et al. 2009), Fiji (Swamy and Deesh 2012), and other islands in Oceania (Hinckley 1967). The coconut stick insect is one of the most widespread species of walkingsticks in Oceania (Nakata 1961). Bedford (1978, citing Swaine 1969), described outbreaks in the Pacific, noting that the most serious damage occurs in palms 24.4 m or more in height, although defoliation and fall-off in crop production can occur in younger palms as well. Outbreaks develop from small areas or pockets of infestation and gradually spread outwards if conditions remain suitable. The buildup and spread of damaging populations is slow, and a severe outbreak may last a year or more before it gradually subsides (Swaine 1969, cited by Bedford 1978). Control of outbreaks in Fiji using chemicals has been effective, but is expensive, and some biological control approaches have been attempted instead, with limited success thus far (Paine 1968).

Female stick insects lay up to 100 eggs, many of which fall to the ground (MAF Biosecurity New Zealand 2009) while others are trapped in the axils of fronds of coconut palms (Bedford 1978). The eggs are enclosed in a very hard protective shell that is resistant to adverse weather conditions (Nakata 1961). There is a lengthy development time before the eggs hatch (Nakata 1961), sometimes up to 100 days (Hardy et al. 2009). Although the eggs are well-protected and resist salt water, they are sensitive to high temperature and desiccation (Rapp 1995). Thus, pest populations are maintained at higher levels when undergrowth beneath palms is high, and decline dramatically when cover is removed (Rapp 1995). Nymphs are highly mobile and can climb from the ground into the fronds of palms (Hardy et al. 2009). Feeding by the stick insects strips the palm fronds, leaving only the midribs and branch veins (Bedford 1978). Female nymphs pass through six instars (males through five) that collectively last for over 100 days (Hardy et al. 2009). Adults are also long lived (167 days for males, 115 for females [Hardy et al. 2009]) and are more susceptible to adverse environmental conditions than the egg stage (Nakata 1961). The males grow to 65 to 70 mm in length and females to 116 mm (Swamy and Deesh 2012). The males disperse through flight, while the females do not (Bedford 1978).

Specific information relating to risk elements:

A. Likelihood of introduction (plant material pathway)

1. Pest with host-commodity at origin potential: **Moderate** (RU) (Applicable rating criteria, from app. 4: c, e)

The coconut walkingstick is widely distributed throughout the Pacific Islands (Nakata 1961). Dharmaraju (1980) reported that in Tuvalu, *G. crouanii* was strongly associated with green *Pandanus* fronds that are very widely used for handicrafts.

2. Entry potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: b)

The egg stage of *G. crouanii* is long lived and very resistant to adverse conditions (Nakata 1961), and if associated with palm or *Pandanus* fronds being transported for use in crafts, could gain entry into a new environment. Nakata (1961) points out that phasmatids, as a rule, have limited powers of dispersal, and probably depend on the egg as the stage most likely to be transported to a new environment. He stated that the possible spread of the widely distributed *G. crouanii* may have occurred through “rafting” where eggs were attached to fronds and transported by ocean currents to new locations (Nakata 1961).

3. Colonization potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: b)

The climatic conditions in Hawai‘i should be suitable for the stick insect, which is widespread throughout many islands in the Pacific.

4. Spread potential: **Low** (MC) (Applicable rating criteria, from app. 4: d)

Pandanus tectorius is widely distributed in Hawai‘i and has been identified as a host for *G. crouanii* (Hardy et al. 2009). Phasmatids have limited powers of dispersal unless assisted by human transport (Nakata 1961).

B. Consequences of introduction

5. Economic damage potential: **Low** (MC) (Applicable rating criteria, from app. 4: c)

Criterion “c” would likely apply if the walkingstick were to become established, as mitigation costs for protecting *Pandanus* would increase.

6. Environmental damage potential: **Low** (MC) (Applicable rating criteria, from app. 4: none)

None of the rating criteria would apply.

7. Social and political considerations: **Moderate** (MC) (Applicable rating criteria, from app. 4: a)

Public concerns could be elevated by the presence of a damaging insect on *P. tectorius.*

C. Pest risk potential:

Moderate (Likelihood of introduction = **low**; Consequences of introduction = **moderate**)

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Rapp, I.G. 1995. Eggs of the stick insect *Graeffea crouanii* Le Guillou (Orthoptera: Phasmidae). Mortality after exposure to natural enemies and high temperature. Journal of Applied Entomology. 119: 89–91.

Swaine, G. 1969. The coconut stick insect *Graeffea crouani* Le Guillon. Oleagineux. 24: 75–77.

Swamy, B.N.; Deesh, A.D. 2012. Management of coconut stick insect—*Graeffea crouanii* (LeGuillou) in Fiji. Tech. Bull. Issue No. 1. Raiwaqa, Fiji: Ministry of Primary Industries. 3 p.

Reviewers' comments: None received.

Erythrina Scale

Assessor: Sheri Smith

Scientific name of pest: *Toumeyella erythrinae* Kondo and Williams (Hemiptera: Coccoidea: Coccidae)

Scientific name of host: *Erythrina coralloides*

Distribution: Mexico

Summary of natural history and basic biology of the pest: Erythrina scale was newly described by Kondo and Williams (2003) after being observed on twigs and branches of *Erythrina coralloides* in Mexico in 1991. According to the scale insects database ScaleNet (Ben-Dov et al. 2010), currently there are 14 species of soft scale insects in the *Toumeyella* genus, which are distributed in Brazil, Cuba, Mexico, and the United States. *Toumeyella* species also are reported on erythrina in Guatemala (*T. sallei* is reported on *E. corallodendron*, and collections of presumed *Toumeyella* spp. have been made from *E. berteroana* and other *Erythrina* spp.) and in Colombia. Fifty-one species of scale insects have been recorded from *Erythrina* spp. worldwide (Ben-Dov et al. 2010).

The biology and injury caused by the erythrina scale were described by Kondo and Williams (2003). The scale is ovoviviparous and has one generation per year. It is a large (up to 2.1 cm long and 2.0 cm wide), bisexual species with males developing alongside the leaf veins on the underside of leaves. Infestation results in localized chlorosis on leaves, defoliation, branch dieback, and often death of the host plant. In some localities in Mexico, it has caused serious injury and plant death; infestation levels have reached 91 percent and mortality 56 percent.

About 115 *Erythrina* spp. have been described. They are globally traded for medicinal and cultural uses and as ornamentals plantings, owing to their conspicuous and beautiful flowers.

Specific information relating to risk elements:

A. Likelihood of introduction (plants for planting).

1. Pest with host-commodity at origin potential (plants for planting): **Moderate** (MC) (Applicable risk criteria from app. 4: b, e, h)

Scale insects can have large increases in populations, particularly in the absence of parasites and predators. Erythrina scale could likely survive and be transported on leaves of live erythrina plants.

2. Entry potential (plants for planting): **High** (MC) (Applicable risk criteria from app. 4: b, c,)

If live erythrina plants are imported, they could easily harbor scale insects.

3. Colonization potential: **Low** (RU) (Applicable risk criteria, from app. 4: b)

It is unknown if erythrina scale would attack *Erythrina* species in Hawai‘i, in particular the native *Erythrina sandwicensis*. Many of the nonnative *Erythrina* spp. in Hawai‘i were killed by the invasive erythrina gall wasp (*Quadrastichus erythrinae*) over the past decade. Remaining ornamentals could serve as potential hosts for scale insects and, depending on distribution, could serve as a pathway to the more remote native trees. Coccids have limited inherent powers of dispersal, and thus, once introduced, expansion would most likely be facilitated by people moving infested material.

4. Spread potential: **Moderate** (RU) (Applicable risk criteria, from app. 4: c, f)

Likelihood of spread beyond any colonized area would depend on host availability and human-assisted transport. Control techniques have been developed for some scale insects; however, eradication would be infeasible in a natural environment.

B. Consequences of introduction

5. Economic damage potential: **Moderate** (RC) (Applicable risk criteria, from app. 4: b, c)

Infestation results in localized chlorosis on leaves, defoliation, branch dieback, and often death of the host plant. In some localities in Mexico, the scale insect has caused serious injury and plant death; infestation levels have reached 91 percent and mortality 56 percent (Kondo and Williams 2003).

6. Environmental damage potential: **Moderate** (RU) (Applicable risk criteria, from app. 4: d)

If attacks and subsequent plant injury or mortality of *Erythrina sandwicensis* were to occur, impacts could be high, as this species has limited distribution and has already experienced high mortality rates owing to the invasive erythrina gall wasp (*Quadrastichus erythrinae*) and reduced seed viability owing to an invasive bruchid beetle (*Specularius impressithorax*).

7. Social and political considerations: **Moderate** (MC) (Applicable risk criteria, from app. 4: a, d)

Public concerns could result if moderate to high levels of tree injury or mortality occur, particularly for native species. Control with pesticides would likely have limited acceptance or be prohibited as a result of potential secondary impacts to other insect species.

C. Pest risk potential:

Moderate (Likelihood of introduction = **low**; Consequences of introduction = **moderate**)

Selected bibliography:

Ben-Dov, Y.; Miller, D.R.; Gibson, G.A.P. 2010. ScaleNet: a database of the scale insects of the world. http://www.sel.barc.usda.gov/scalenet/scalenet.htm. (6 May 2013).

Kondo, T.; Williams, M.L. 2003. A new species of *Toumeyella* (Hemiptera: Coccoidea: Coccidae) on *Erythrina* in Mexico. Revista Especializada en Ciencias Quimico-Biologicas. 6(1): 11–15.

Reviewers’ comments: None received.

Eugenia Psyllid

Assessor: Andris Eglitis

Scientific name of pest: *Trioza eugeniae* Froggatt (Hemiptera: Psyllide)

Scientific names of hosts: *Syzygium paniculatum* (= *Eugenia myrtifolia*), ***Metrosideros excelsa***

Distribution: Native to southeastern Australia; introduced into California (1988) and Florida (1993)

Summary of natural history and basic biology of the pest: The eugenia psyllid, *Trioza eugeniae*, attacks the new growth of *Syzygium paniculatum*, a common ornamental tree in California (Dahlsten et al. 1999). Young (2003) determined that *T. eugeniae* could also complete its development on seven other species of trees belonging to three allied genera in the Myrtaceae. The Eugenia psyllid completes three to five generations per year, determined in part by temperature and the physiological state of the host (Dahlsten et al. 1999). The adult psyllid is chocolate brown, 2 mm long, and membranous-winged (Mead 1994). Mature nymphs are completely ringed with white waxy filaments, a characteristic typical of the Triozinae (Mead 1994). After mating, the females lay yellow football-shaped eggs (more than 100 per female) partially inserted into the edges of new terminal leaves of host plants (Dahlsten et al. 1999). Small mobile nymphs hatch from the eggs and settle on newly expanding leaves, primarily on the underside, where they feed and develop in a cup-shaped pit or gall formed by the plant's response to the psyllid feeding (Dahlsten et al. 1999). The feeding of the psyllids produces a sticky substance called honeydew, which is eventually covered by a black sooty mold. High densities of psyllids produce acute plant damage that includes shoot deformation, distortion of foliage and stems, and inhibition of new shoot formation (Dahlsten et al. 1999). The long-term effects of sustained high infestation include severe weakening of plants, poor growth, and reduced economic value (Dahlsten et al. 1999). Dahlsten et al. (1999) noted that in California, some native natural enemies had been found feeding on the eugenia psyllid, but their effects as control agents were negligible.

In its native Australia, *T. eugeniae* attracts little attention and is not considered a problem (Mead 1994). Mead (1994) describes the host range of the eugenia psyllid as extremely narrow.

The eugenia psyllid is sensitive to both frost and heat. In California, population densities drop off when temperatures exceed 32.2 °C. The psyllid does much better in the cool, mild weather of fall through spring and does best in a cool coastal climate (Mead 1994). In southern California, the eugenia psyllids reproduce the year around (Downer et al. 1991).

Starr et al. (2007) identify *Trioza eugeniae* as a potential pest of ‘ōhi‘a lehua. Several other psyllids have been introduced into the continental United States through the movement of plant material. Two of these psyllids have also been introduced into Hawai‘i (Starr et al. 2007). *Trioza eugeniae* first appeared in California in 1988 and has been moved via nursery stock to several new counties within the state (Dahlsten et al. 1999).

Specific information relating to risk elements:

A. Likelihood of introduction (nursery stock pathway)

1. Pest with host-commodity at origin potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: b, d, e, h)

Female eugenia psyllids produce over 100 eggs per female and can complete several generations per year (Downer et al. 1991). In the past, survival on plant material has been sufficient to allow this insect to be transported into new environments (Dahlsten et al. 1999, Starr et al. 2007).

2. Entry potential: **High** (MC) (Applicable rating criteria, from app. 4: b, c, d)

Light infestations would be difficult to detect, and insects survive in transit, as evidenced by their successful introduction into new environments and further redistribution within California.

3. Colonization potential: **High** (MC) (Applicable rating criteria, from app. 4: a, b, e)

Trioza eugeniae has become established in Florida and California despite having a narrow host range (Mead 1994). There is some disagreement in the literature as to this psyllid's adaptability to new hosts. Although the host range may be narrow, it is important to note that *T. eugeniae* was raised to maturity on seven myrtaceous hosts in three genera (Young 2003), and that a species of *Metrosideros* is an observed host (Dreistadt and Dahlsten 2001). For Hawai‘i, *M. polymorpha* is considered a potential host of concern.

4. Spread potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: b, c, e)

A high reproductive potential combined with a cryptic nature have allowed this insect to be spread widely within California, when moved with infested plant material. *Metrosideros polymorpha,* the key host of concern is widely distributed in the Hawai‘i Islands.

B. Consequences of introduction

5. Economic damage potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: c, d)

If *M. polymorpha* proves to be a suitable host for *T. eugeniae*, feeding damage could lower the value of ‘ōhi‘a lehua or increase the costs of managing the pest. The presence of a quarantine pest is always a factor in trade involving potentially infested species.

6. Environmental damage potential: **Moderate** (RC) (Applicable rating criteria, from app. 4: e)

The most effective controls for psyllids have proven to be biological agents (parasitic wasps). No plants with limited distribution are expected to be hosts for *T. eugeniae*.

7. Social and political considerations: **Moderate** (MC) (Applicable rating criteria, from app. 4: a)

‘Ōhi‘a lehua is an important plant species in Hawai‘i, and additional pests on this plant would be cause for concern from the public.

C. Pest risk potential:

Moderate (Likelihood of introduction = **moderate**; Consequences of introduction = **moderate**)

Selected bibliography:

Dahlsten, D.L.; Rowney, D.L.; Copper, W.A. 1999. Eugenia psyllid biological control. University of California at Berkeley, Center for Biological Control. 4 p. http://www.cnr.berkeley.edu/biocon/dahlsten/eugenia/eug-web.htm. (4 August 2013).

Dahlsten, D.L.; Rowney, D.L.; Robb, K.L.; Downer, J.A.; Shaw, D.A.; Kabashima, J.H. 2002. Biological control of introduced psyllids on *Eucalyptus*. Proceedings of the 1st international symposium on biological control of arthropods. FHTET-03-05. Fort Collins, CO: U.S. Department of Agriculture, Forest Service: 356–361. http://www.fs.fed.us/foresthealth/technology/webpubs/FHTET-2003-05/day5/dahlsten.pdf. (12 May 2013).

Downer, A.J.; Koehler, C.S.; Paine, T.D. 1991. Biology and management of the Eugenia psyllid (*Trioza eugeniae* Froggatt). Journal of Environmental Horticulture. 9(3): 137–141.

Dreistadt, S.H.; Dahlsten, D.L. 2001. Psyllids. Pest Notes. Publication 7423. Davis, CA: University of California, Davis, Agriculture and Natural Resources. http://www.ipm.ucdavis.edu/PDF/PESTNOTES/pnpsyllids.pdf. (13 May 2013)

Mead, F.W. 1994. Eugenia psyllid, *Trioza eugeniae* Froggatt (Homoptera: Psyllidae). Entomology Circular No. 367. Gainsville, FL: Florida Department of Agriculture and Consumer Services. 3 p.

Starr, F.; Starr, K.; Loope, L.L. 2007. Potential pests of ohia (*Metrosideros polymorpha*) and other Myrtaceae. Hawaiian Ecosystems at Risk Project. Draft report. 85 p.

Young, G.R. 2003. Life history, biology, host plants and natural enemies of the lilly pilly psyllid, *Trioza eugeniae* Froggatt (Hemiptera: Triozidae). Australian Entomologist. 30 (1): 31–38.

Reviewers’ comments: In response to a comment under “Environmental damage potential” stating “parasitic wasps … would not be expected to have adverse environmental effects” a reviewer stated: “is home to several endemic *Trioza* species. Introduced biological control agents could devastate populations of these, so there very well could be detrimental environmental effects.” (Culliney)

Response to comments: The comment was removed, rating criterion “e” was added, and the rating for “Environmental damage potential” was changed from “**low**” to “**moderate.**” The overall Pest Risk Potential for *T. eugeniae* was unchanged and remains “**moderate.**”

Keyhole Ambrosia Beetle

Assessor: Andris Eglitis

Scientific name of pest: *Amasa truncata* (Erichson) (Coleoptera: Curculionidae)

Scientific names of hosts: ***Acacia*** spp., *Albizia distachya, Eucalyptus* spp.*, Knightia excelsa, Kunzea ericoides, Leptospermum scoparium,* ***Metrosideros*** spp., *Pinus radiata, Pseudotsuga menziesii, Podocarpus spicatus, Weinmannia racemosa*

Distribution: Australia, New Zealand, Brazil

Summary of natural history and basic biology of the pest: In Australia, the keyhole ambrosia beetle is mainly associated with species of *Eucalyptus* and closely related species within the Myrtaceae, and only in live standing trees (Flechtmann and Cognato 2011). Froggatt (1926) listed saplings of *Eucalyptus saligna* and *E. rostrata* as the key hosts in Australia. Flechtmann and Cognato (2011) summarized the host records reported by other Australian authors and added several species of eucalypts to the host list. The ambrosia beetle has been in New Zealand since 1930, where it appears to have acquired additional hosts beyond those found in Australia. In New Zealand, *A. truncata* has been found breeding in *Albizia lophanta*, *Acacia verticillata*, *A. decurrens*, *Leptospermum ericoides*, *L. scoparium*, *Knightia excelsa*, *Metrosideros robusta*, *M. excelsa*, *Weinmannia racemosa*, and several species of *Eucalyptus* including *E. botryoides*, *E. globulus*, *E. obliqua*, *E. ovata,* and *E. viminalis* (Zondag 1977). Several other hosts including *Pinus radiata* have also been attacked, but no broods were produced in them (Zondag 1977). Zondag (1977) reported that the only living trees to be attacked by *A. truncata* are eucalypts, especially *E. globulus*, in which severe branch dieback can occur. However, Flechtmann and Cognato (2011) report that New Zealand literature also identifies other live myrtaceous hosts for *A. truncata.* Attacks on live trees by the keyhole ambrosia beetle are followed by rapid wilting of the foliage, leading to the conclusion that an associated fungus other than the ambrosia fungus may be responsible for killing the sapwood (Zondag 1977). Despite this capability of producing branch dieback and infesting numerous hosts, *A. truncata* is considered of little economic importance in New Zealand (Zondag 1977).

Flechtmann and Cognato (2011) reported that *A. truncata* has recently been introduced into Brazil, with several individuals trapped in a young plantation of *Eucalyptus grandis* in 2006 and 2007. They speculate that the pathway may have been through solid wood packing material in trade from New Zealand or Australia. They estimate that the ambrosia beetle arrived and became established in Brazil around 1996 (Flechtmann and Cognato 2011).

The keyhole ambrosia beetle is thought to have a life cycle of less than 1 year and may complete two generations in a year (Zondag 1977). The adult female of *A. truncata* bores an entry tunnel into the wood to a depth of about 30 mm. There may be one or two short additional tunnels that branch from the main tunnel (Zondag 1977). Eggs are laid in the far end of the tunnel and small larvae make a small excavation called a "keyhole chamber" where they feed and develop. Eggs are apparently laid over a long period of time, because larvae of all sizes, pupae and young adults can all be found in the gallery at the same time (Zondag 1977). Most of the larvae develop into females, which emerge in the spring and summer (Zondag 1977). Froggatt (1926) reported that feeding is typically near damaged areas on the tree, but later Moore (1959) found that healthy trees may also be attacked.

Specific information relating to risk elements:

A. Likelihood of introduction (untreated wood pathway)

1. Pest with host-commodity at origin potential: **High** (VC) (Applicable rating criteria, from app. 4: a, d, e, f, g, h)

Ambrosia beetles possess a strong ability to locate and colonize hosts, be they standing trees or freshly cut material, and if log moisture remains suitable, they can survive in this material for a sufficient amount of time to be transported to a new environment. Ambrosia beetles are always common on lists of interception records (Brockerhoff et al. 2006, Haack 2001).

2. Entry potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c, d)

Amasa truncata has demonstrated its ability to survive in transit, as it has become established in at least two new environments, New Zealand and Brazil (Brockerhoff et al. 2003, Flechtmann and Cognato 2011).

3. Colonization potential: **High** (RC) (Applicable rating criteria, from app. 4: a, b, c, d)

The keyhole ambrosia beetle has become successfully established in at least two new environments (Brockerhoff et al. 2003, Flechtmann and Cognato 2011) and has taken on new hosts in those settings. Because members of the Mimosaceae (*Acacia* spp.) and Myrtaceae (*Metrosidero*s spp.) are among the known hosts for *A. truncata* (Flechtmann and Cognato 2011), it is believed the ambrosia beetle could encounter suitable hosts in Hawai'i.

4. Spread potential: **High** (MC) (Applicable rating criteria, from app. 4: b, d, e, f, g, h)

Redistribution (criterion b) of *A. truncata* has occurred by virtue of its successful introduction into two new countries. Its host list has become broader than it was in its native environment. The cryptic nature of *A. truncata* would likely ensure that it could become well-established before being detected, and thus, would be difficult to eradicate once found. There is possible reason for concern that the insect has an associated fungus, which may be involved in its ability to kill debilitated hosts.

B. Consequences of introduction

5. Economic damage potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: b, c, d)

In New Zealand, *A. truncata* is not considered economically important (Withers 2001, Zondag 1977). In Australia, however, the ambrosia beetle has been linked to the death of healthy trees and others that were debilitated by psyllids (Moore 1959). There could be reason for concern about the potential for increased virulence of the associated *Ceratocystis* fungus in a new setting, and the fact that the insect appears to have a broad host range that becomes even broader as it becomes established in new environments. In Hawai'i, the species of greatest concern as a potential host is 'ōhi'a lehua (*Metrosideros polymorpha*).

6. Environmental damage potential: **Low** (RU) (Applicable rating criteria, from app. 4: none)

7. Social and political considerations: **Moderate** (RU) (Applicable rating criteria, from app. 4: a)

Public concerns could arise from the introduction of another invasive insect if it were to cause damage to important native or other aesthetically significant plants that are not presently being damaged.

C. Pest risk potential:

High (Likelihood of introduction = **high**; Consequences of introduction = **moderate**)

Selected bibliography:

Brockerhoff, E.G.; Bain, J.; Kimberley, M.; Knizek, M. 2006. Interception frequency of exotic bark and ambrosia beetles (Coleoptera: Scolytinae) and relationship with establishment in New Zealand and worldwide. Canadian Journal of Forest Research. 36: 289–298.

Brockerhoff, E.G.; Knizek, M.; Bain, J. 2003. Checklist of indigenous and adventive bark and ambrosia beetles (Curculionidae: Scolytinae and Platypodinae) of New Zealand and interceptions of exotic species (1952–2000). New Zealand Entomologist. 26: 29–44.

Flechtmann, C.A.H.; Cognato, A.I. 2011. First report of *Amasa truncata* (Erichson) (Coleoptera: Curculionidae: Scolytinae) in Brazil. The Coleopterists Bulletin. 65(4): 417–421.

Froggatt, W.W. 1926. The ridge-tailed borer, *Amasa truncata*, Erickson. The Australian Forestry Journal. 9: 144–146.

Haack, R.A. 2001. Intercepted Scolytidae (Coleoptera) at U.S. ports of entry: 1985-2000. Integrated Pest Management Reviews. 6: 253–282.

Moore, K.M. 1959. Observations on some Australian forest insects. 4. *Xyleborus truncatus* Erichson 1842 (Coleoptera: Scolytidae) associated with dying *Eucalyptus saligna* Smith (Sydney blue-gum). Proceedings of the Linnean Society of New South Wales. 84(2): 186–193.

Withers, T.M. 2001. Colonization of eucalypts in New Zealand by Australian insects. Austral Ecology. 26: 467–476.

Zondag, R. 1977. *Xyleborus truncatus* Erichson (Coleoptera: Scolytidae). Forest and Timber Insects in New Zealand 21. Rotorua, New Zealand: New Zealand Forest Service, Forest Research Institute.

Reviewers' comments: "To clarify why a moderate economic damage potential is concluded, it would be good to mention an example of a host species of economic importance which would be affected." (Martin–GCAPS)

"If the species has demonstrated a capacity to acquire new hosts in regions into which it has been introduced, wouldn't criterion "f" apply? It's hard to believe that there would be no environmental consequences should it become established in Hawaii." (Culliney)

"I suspect this is a tricky species to assess and this may be why I wasn't entirely convinced of its risk potential. I think it would be helpful to explain a few things a bit more. As a reader I was trying to work things out rather than seeing it clearly laid out. For instance, if the only living trees it attacks are Eucalypts, is it likely *A. truncata* will attack other genera of living trees? Is the non-eucalypt host range living or fallen or decayed trees? Are there congeners that might provide some insight into the behaviour of this species? If there is no information to support or explain aspects of the assessment, I think it is worth commenting on that and on areas of uncertainty so the reader understands what has been considered."

Response to comments: The "**moderate**" rating for economic damage potential is derived from the fact that three of the rating criteria apply for that element. A statement was added to the text, identifying *Metrosideros polymorpha* (ohia) as a potential host of economic importance.

Perhaps taking on new hosts can be considered the same as developing higher virulence or more damaging biotypes (criterion "f"). However, even if this criterion were added and environmental damage potential changed from **low** to **moderate**, the overall pest risk potential would remain *"***high.**"

Flechtmann and Cognato (2011) point out that in New Zealand, *Amasa truncata* has been reported from other live myrtaceous hosts besides *Eucalyptus*. *Metrosideros excelsa* is one of those hosts. On this basis, we believe the *"***high***"* pest risk potential (with *M. polymorpha* as a potential host) is warranted.

Lemon Tree Borer

Assessor: Sheri Smith

Scientific name of pest: *Oemona hirta* Fabricius (Coleoptera: Cerambycidae)

Scientific names of hosts: Acacia spp*., Acer pseudoplantanus, Aeculus hippocastanum, Albizia* spp*., Aleurites* spp*., Alectryon excelsus, Alnus glutinosa, Amygdalus* spp*., Aristotelia* spp*., Asparagus* spp*., Avicennia* spp*., Brachyglottis* spp*., Betula* spp*., Callistemon* spp*., Casimiroa* spp*., Cassinia* spp*., Chaenomeles* spp*., Choisya* spp*., Chrysanthemoides spp., Citrus limon, C. reticulata, C. sinensis, Clerodendrum* spp*., Corylus* spp*., Coprosma robusta, Corynocarpus laevigatus, Crateagus* spp*., Cyphormandra* spp*., Cytisusm* spp*., Dahlia* spp*.,* ***Diospyros*** spp*., Eucalyptus* spp*., Euonymus* spp*., Ficus* spp*., Hebe salicifolia, Hibiscus* spp*., Hoheria* spp*., Juglans* spp*., Koelreuteria* spp*., Kunzea ericoides, Leptospermum scoparium, Macadamia* spp*., Malus sylvestris, Melicytus* spp*.,* ***Metrosideros*** spp*.,* ***Myoporum laetum****, Oleana* spp*., Ozothamnus leptophyllus, Pennantia corymbosa, Persea americana, Phyllostachys* spp*., Pinus radiata, Pittosporum crassifolium, P. eugenioides, P. tenuifolium, Platanus* spp*., Populus* spp*., Prunus avium, P. cerasus, P. domestica, P. dulcis, P. persica, Punicia* spp*., Pyrus communis, Quercus* spp*., Rhus* spp*., Ribes grosularia, Rosa* spp*., Salix* spp*., Solanum beteceum, Syzygium* spp*., Tamarix* spp*., Telopea* spp*., Ulex europaeus, Ulmus* spp*.,* ***Vaccinium*** spp*., Vitex* spp*., Vitis vinifera, Wisteria* spp.

Distribution: New Zealand, Malaysia

Summary of natural history and basic biology of the pest: Lemon tree borer, *Oemona hirta*, is a longhorned beetle native to and found throughout New Zealand, where it is considered to be one of the most common insects. It was first recognized as a major pest of citrus trees by Cottier (1938). It is now also reported to be present in Malaysia (APPPC 1987). It is not regarded as established or transient in the United Kingdom; however, a single larva was intercepted in a *Wisteria* sp. plant in 1983 and in a number of

Wisteria sp. rootstocks in June 2010 and again in a *Wisteria* sp. plant in July 2010 (Ostojá-Starzewski et al. 2010). Infested plants were destroyed; however, it is not known if some infested hosts went undetected so there is a chance that *O. hirta* could have escaped and become established, at least in the north of England (FERA 2010).

Lemon tree borer is highly polyphagous, feeding on many tree, shrub, and vine species. Over 130 host genera are listed in New Zealand. The larvae bore into wood of branches and stems, causing serious damage (Wang et al. 1998); adult beetles feed on pollen and nectar. In New Zealand, the native mahoe (*Melicytus* spp.) is suggested to be its principal native host. Lemon tree borer is of great economic importance because it attacks many species of fruit, nut, and vine crops, but also shelter belt trees such as poplar. Such a wide range of hosts is unusual for a longicorn borer that attacks living hosts (Wang 1995). *Oemona hirta* is a species of quarantine importance because it may attack tree and vine crops overseas if introduced accidently (Wang et al. 2002). It is on the European and Mediterranean Plant Protection Organization's Alert List of Quarantine Pests (EPPO 2013).

In New Zealand, the life cycle takes 2 years to complete. Adults are active from the beginning of October through the first week of January, and during this period, they mate and females lay eggs. Eggs are laid singly in leaf/stem junctions, bark crevices, or in fresh pruning scars with each female capable of producing about 82 eggs (Wang et al. 1998), of which 62 percent were oviposited. On hatching, the larvae bore directly into the sapwood and heartwood of hosts and construct long galleries, with periodic (every few centimeters) side branches to the surface to eject frass. The larval stage takes >1 year and can be found year-round; when fully mature (between mid-June and mid-October), they form a cell within the host to pupate (May to early November). Newly formed adults remain within the pupal cell until their integument has hardened, after which they emerge. They do not become sexually mature until 4 days postemergence. Adults live for about 2 months and are good fliers. Feeding and reproductive activities take place mostly at night (Wang and Davis 1998). Female beetles are brown and range from 14 to 31 mm in body length. They are larger than males and have proportionally shorter antennae.

The lines of frass ejection holes are one indication of the presence of live larvae, but their feeding also can cause small twigs to wilt and die, resulting in clusters of dead leaves. Major damage by larger larvae can weaken branches to the point that they break under wind pressure or fruit load or can even be girdled and die.

Specific information relating to risk elements:

A. Likelihood of introduction

1. Pest with host-commodity at origin potential (root stock, live plants): **Moderate** (RC) (Applicable risk criteria from app. 4: d, e, g, h)

Entry of lemon tree borer into Hawai'i would most likely be facilitated via trade of infested host plants for planting, as occurred in the United Kingdom in 1983 and 2010. Likelihood of introduction would increase dependent on how often host plants are imported into Hawai'i from New Zealand. *Oemona hirta* larvae have an extended colonization period of over a year in host tissue, so could easily be transported in that life stage. Over 130 host genera are listed in New Zealand.

2. Entry potential (root stock, live plants): **Moderate** (MC) (Applicable risk criteria from app. 4: b, c, d)

The larval or pupal stage would be the most likely stage to be transported in plant material. Both stages would be protected within the host material and would be difficult to detect. Adults could potentially be hitchhikers in containers or shipping materials, but survival would be less likely.

3. Colonization potential: **High** (MC) (Applicable risk criteria, from app. 4: b, c, e)

Lemon tree borer appears to be reported in Malaysia, but establishment cannot be confirmed based on available information; so criterion (a) is considered not applicable.

Likelihood of colonization will be largely determined by availability of host plants and climate. Several genera of host plants exist in Hawai'i, and the climate is presumed to be suitable. The organism has a broad host range and has demonstrated the ability to utilize new hosts. Assuming both sexes would be transported in the same material, there is some likelihood of reproduction after entry.

4. Spread potential: **Moderate** (MC) (Applicable risk criteria, from app. 4: b, e, f, g)

The rate of spread of cerambycids through natural dispersal varies according to the host within which larvae develop (Hanks 1999). Natural spread could be in the order of a few kilometers per year. If transported within infested plants, the eggs, larvae or pupae of *O. hirta* could be spread to many parts of the Hawai‘i Islands within days. Control of this pest is considered very difficult (Wang and Davis 2005). According to Wang and Shi (1999), once the larvae enter branches and trunks, chemical control becomes impractical, which severely limits options for treatments and clearly puts the emphasis on destruction of any infested host plants. Some of the newer systemic pesticides may be efficacious, but this in unknown.

B. Consequences of introduction

5. Economic damage potential: **Moderate** (RU) (Applicable risk criteria, from app. 4: a, b, d)

There is limited commercial citrus production in Hawai‘i that might be affected by *O. hirta*. However, for nut production, *Macadamia* is listed as a host in New Zealand, and Hawai‘i produced over 49 million pounds of macadamia nuts in the 2011 to 2012 season, valued at over $38 million (NASS 2012). For host species of concern for this risk assessment, *Acacia koa* would likely be the only one with commercial value. Infestations in ornamental nurseries could also cause some economic loss.

6. Environmental damage potential: **Moderate** (RU) (Applicable risk criteria, from app. 4: d)

Extent of injury or mortality of hosts of concern for Hawai‘i is unknown. *Acacia*, *Metrosideros*, *Vaccinium* spp., and *Myoporum laetum* are listed as hosts in New Zealand; so if *O. hirta* established, it is presumed that plant injury or mortality may occur. Just one, or a few larvae, can kill or severely weaken branches of trees or vines (FERA 2010).

7. Social and political considerations: **Low** (RU) (Applicable risk criteria, from app. 4: none)

No criteria were selected based on the likelihood of relatively small social concern and the uncertainty of trade implications. High mortality rates of one of the host species of concern for Hawai‘i could have social implications, but the uncertainty of level of plant injury limits the ability to predict public concern. A permanent infestation could possibly lead to interstate and international quarantine restrictions, but this is likely to be more applicable to agricultural commodities.

C. Pest risk potential:

Moderate (Likelihood of introduction = **moderate**; Consequences of introduction = **moderate**)

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Reviewers' comments: None received.

Platypodid Ambrosia Beetle

Assessor: Sheri Smith

Scientific name of pest: *Megaplatypus mutatus* (= *Platypus mutatus* Chapuis) (Coleoptera: Curculionidae: Platypodinae)

Scientific names of hosts: **Acacia** spp., *Acer negundo, Ailanthus altissima, Balfourodendron riedelianum, Casuarina cunninghamiana, Caesalpinia echinata, Cedrela tubiflora, Citrus* spp., *Calophyllum brasiliense,* ***Erythrina crista-galli***, *Eucalyptus camaldulensis, E. dunni, E. europhylla, E. robusta, E. tereticornis, Eucalyptus* spp., *Fraxinus* spp., *F. excelsior, Grevillea robusta, Oleaceae, Laurus nobilis, Ligustrum lucidum, Liquidambar styraciflua, Luehea divaricata, Magnolia grandiflora, Magnoliacea, Malus sylvestris, Melia azedarach, Pinus* spp., *Platanus* x *acerifolia, Populus alba, P. deltoids, Populus* spp., *Populus* x *euroamericana, Pyrus communis, Quercus borealis, Q. palustris, Q. robur, Robinia pseudo-acacia, Salix alba, S. babylonica, S. nigra, Sebastiana commersoniana, Taxodium distichum, Tilia moltkei, Ulmus pumila, Ulmus* spp., *Vitex megapotamica*

Distribution: Native to South America, more specifically Argentina, Bolivia, Brazil, French Guiana, Paraguay, Peru, Uruguay, and Venezuela, and introduced in Italy.

Summary of natural history and basic biology of the pest: *Megaplatypus mutatus* is a polyphagous ambrosia beetle native to the subtropical and tropical areas of South America. Ambrosia beetles are an important insect group in forest ecosystems. They usually attack felled or weakened trees, where they bore galleries into the wood. The common name "ambrosia beetle" is derived from the symbiotic fungus, which beetles introduce into their galleries and on which the larvae feed. *Megaplatypus mutatus* is different from more typical ambrosia beetles in that it is considered a primary pest; it affects only live trees and does not attack cut wood. It attacks the main stems of trees and bores internal tunnels in the xylem, which weakens the stem and causes breakage during wind events. In addition, the dark staining associated with the ambrosial mycelia reduces wood quality, making it unsuitable for some markets. New hosts continue to be added to an already large list for this insect; the endangered brazilwood, *Caesalpinia echinata*, which is highly resistant to wood decay caused by termites and rot fungi, was recorded as a host of *M. mutatus* in Brazil, and 13 new hosts were confirmed in Argentina in 2003. In addition, Zanuncio et al. (2010) were the first to observe *M. mutatus* in clonal *Eucalyptus* plantations used for sawlogs in Brazil.

Megaplatypus mutatus is particularly prevalent in Argentina. It is a serious problem in commercial plantations of a number of broad leaf trees but is especially damaging to poplars. The beetle's continuing damage to hybrid poplar plantations in Argentina, its wide distribution in South America, and the more recent introduction into Italy have raised concerns regarding its potential for becoming a globally invasive pest of *Populus* species. The discovery of an established population in 2000 in Italy in a poplar plantation demonstrated that this insect can be transported long distances between countries and therefore presents a threat worldwide (Alfaro et al. 2007). It was probably introduced with a single trial consignment of roundwood of poplar with bark, imported in 2000 from Argentina (EPPO 2009). *Megaplatypus mutatus* was added to the European and Mediterranean Plant Protection Organization's A2 alert list of quarantine pests in March 2007.

The biology of *M. mutatus* is summarized in EPPO (2009). It is univoltine in South America and Italy. It overwinters mainly as mature larvae or teneral adults. Adults appear in the field in late spring to early summer (November-December in South America and May-June in Italy). Males start emerging a few days before females and fly to tree trunks >15 cm in diameter, in which they bore a radial gallery directed toward the center of the trunk, and attract females by releasing a specific pheromone. After mating, the two adults bore new galleries inside the trunk, in which the female lays 100 to 200 eggs over a period of 2 to 3 months. Adult beetles inoculate the galleries with *Raphaelea santoroi*, a symbiotic fungus cultivated for larval feeding. The first and second instar larvae feed on the mycelium; as they grow larger, they feed on the wood. Larvae generally reach maturity in 5 months, although Funes et al. (2011) reported development into pupae in 2 to 3 months.

Specific information relating to risk elements:

A. Likelihood of introduction

1. Pest with host-commodity at origin potential (plants for planting, wood and wood products):

Moderate (MC) (Applicable risk criteria from app. 4: e, f, g, h)

The main pathways for introduction (EPPO 2009) are plants for planting with trunks >15 cm diameter, round wood of host plants >15 cm diameter, sawn wood, and wood packaging material. *Megaplatypus mutatus* does not attack declining trees or cut wood and will only be present in them as a result of earlier primary attack. Based on the criteria in app. 4, the rating is **moderate** (owing to meeting four criteria); however, the likelihood for *M. mutatus* reaching Hawai‘i via live plants would be fairly low, unless importation of plants >15 cm in diameter occurs. Wood packaging material or other wood products may present the highest risk, but insect survival may be severely limited as live host material is required to complete development. It should be noted, however, that it was probably introduced into Italy with a single trial consignment of roundwood of poplar with bark, imported in 2000 from Argentina (EPPO 2009). Its distribution throughout South America provides many source populations for potential global transportation. Five adult beetles were detected in wood products at Kahului in 2003 arriving from Indonesia (APHIS foreign reportable raw data).

2. Entry potential (plants for planting, wood and wood products): **High** (MC) (Applicable risk criteria from app. 4: b, c, d)

Criteria b, c, and d are applicable. Alfaro and others (2007) concluded that *M. mutatus* is of concern to California, Oregon, and Washington, where significant plantations of hybrid poplars and a large fruit industry occur and the temperature regimes are favorable. Detection can be difficult, as this insect predominantly resides in the wood tissue throughout its life cycle.

3. Colonization potential: **High** (MC) (Applicable risk criteria, from app. 4: a, b, c)

Megaplatypus mutatus has successfully established in Italy, over 11 000 m from Argentina, where it is presumed to have come. (EPPO 2009). New hosts continue to be added to an already large list; 13 new hosts were confirmed in Argentina in 2003. *Megaplatypus mutatus* attacks *Eucalyptus* plantations used for sawlogs in Brazil. Colonization potential in Hawai‘i would increase with amount of host material available; many ornamental eucalypts occur in Hawai‘i.

4. Spread potential: **High** (MC) (Applicable risk criteria, from app. 4: a, b, c, d, e, f, g)

The polyphagous nature of this insect and its dispersal capability could aid in spread potential once introduced into a new environment. Its distribution in Italy increased from 130 km^2 in 2000 to over 587 km^2 by 2007 (Allegro and Griffo 2008).

B. Consequences of introduction

5. Economic damage potential: **Moderate** (MC) (Applicable risk criteria, from app. 4: b, c, d)

Megaplatypus mutatus development in plant tissue weakens trees, reducing yield and causing breakage by wind, and even killing highly stressed trees. The galleries and staining disqualify the wood from standards required by the plywood industry, thus dramatically lowering its value. Some poplar producers in South Africa have lost their high-quality wood market (EPPO 2009) owing to *M. mutatus*. A permanent infestation could lead to interstate and international quarantine restrictions, affecting Hawai‘i, its trade partners, and other U.S. states. It is unknown if *M. mutatus* would attack *Acacia koa* in Hawai‘i; it is reported to attack *A. meanmsii* in Brazil (Girardi et al. 2006).

6. Environmental damage potential: **Moderate** (MC) (Applicable risk criteria, from app. 4: d, e)

Erythrina crista-galli is listed as a host in South America. It is unknown if *M. mutatus* would attack or be successful in other *Erythrina* species. If attacks and subsequent plant injury or mortality of *E. sandwicensis* were to occur, impacts could be high as this species has limited distribution and has already experienced high mortality rates owing to the invasive erythrina gall wasp (*Quadrastichus erythrinae*) and reduced seed viability owing to an invasive bruchid beetle (*Specularius impressithorax*). Control with pesticides has been highly effective (EPPO 2009); however, treatments are costly and could be potentially harmful to the environment.

7. Social and political considerations: **Moderate** (MC) (Applicable risk criteria, from app. 4: a, c, d)

Public concerns likely would result if moderate to high levels of tree injury or mortality occur, particularly for native species. *Megaplatypus mutatus* is on the quarantine pest list for several countries (EPPO 2009). A permanent infestation could lead to interstate and international quarantine restrictions, affecting Hawai‘i, its trade partners, and other U.S. states. Control with pesticides would likely have limited acceptance or be prohibited owing to potential secondary impacts on other insect species.

C. Pest risk potential:

Moderate (Likelihood of introduction = **moderate**; Consequences of introduction = **moderate**)

Selected bibliography:

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European and Mediterranean Plant Protection Organization [EPP0]. 2009. *Megaplatypus mutatus.* Data sheets on pests recommended for regulation. European and Mediterranean Plant Protection Organization. Bulletin 39: 55–58.

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Reviewers' comments: None received.

Summer Fruit Tortrix Moth

Assessor: Andris Eglitis

Scientific name of pest: *Adoxophyes orana* (Fischer von Roslerstamm, 1834) (Lepidoptera: Tortricidae)

Scientific names of hosts: ***Vaccinium*** spp.; wide host range with over 50 species in several families, especially Rosaceae

Distribution: Throughout Europe and Asia; successfully introduced into England and Greece (Davis et al. 2005b).

Summary of natural history and basic biology of the pest: *Adoxophyes orana* is a multivoltine species that is distributed from Asia throughout northern Europe. It is considered the most damaging leaf roller in Europe (Kamminga and Maguylo 2011). The summer fruit tortrix moth is a major pest of fruit crops, particularly apple and pear, in temperate regions (Davis et al. 2005b). The insect is polyphagous with a host range that includes some forest tree species (Davis et al. 2005b). *Adoxophyes orana* occurs in warm, humid climates and could be closely associated with biomes characterized as tropical and subtropical moist broadleaf forests and temperate broadleaf and mixed forests (Davis et al. 2005b). Since the 1980s, the insect has spread throughout southern Europe and has become a serious pest in many fruit orchards, primarily cherries, peaches, and apples (Milonas and Savopoulou-Soultani 1999). The summer fruit tortrix feeds primarily on host foliage, but when populations are high, the larvae may feed on fruits as well (Milonas and Savopoulou-Soultani 2006). High populations can defoliate host trees (Dickler 1991, cited by Kamminga and Maguylo 2011). The fruit damage of the first summer generation is different from that of the second summer generation. For the first, the damage of the fruits consists of large deep holes. In the second generation, the insects make very superficial and small holes of less than 5 mm in diameter. Usually, several of these holes are adjacent to each other (CPC Report 2011). Damage to the fruit is greatest by fall, coinciding with the time of harvest (Milonas and Savopoulou-Soultani 2006). Crop losses attributed to the summer fruit tortrix range up to 20 percent (Whittle 1985, cited by Kamminga and Maguylo 2011). Most of the important damage that this insect causes is directly to the fruits that it feeds upon, and the additional feeding on foliage may not be very important to plant growth (Davis et al. 2005b). Davis et al. (2005b) pointed out, however, that the impact of *A. orana* on forest productivity has not been well-studied.

Milonas and Savopoulou-Soultani (2006) described the biology of the insect in northern Greece where *A. orana* completes three generations in 1 year. Overwintering larvae become active in early spring and complete their development by the end of April (Milonas and Savopoulou-Soultani 2006). There are three distinct moth flights, with the first occurring in early May and others in July and late August. The females lay eggs in groups (up to 300 eggs per female) on host foliage, branches, and sometimes the bole of the tree (CPC Report 2011). The eggs hatch within 8 to 14 days, and young larvae immediately begin feeding on host leaves and shoots (CPC Report 2011). The larvae pass quickly through five instars and eventually spin pupal shelters under the leaves that have been damaged and stuck together by the larvae (CPC Report 2011).

Adoxophyes orana is not currently found in the United States. However, the insect has established populations in geographic areas with climates closely following the USDA Plant Hardiness Zones 4 to 11 (Kamminga and Maguylo 2011). On this basis, the majority of the United States has a climate that would support the summer fruit tortrix moth. Within the continental United States, Davis et al. (2005b) predicted a potential distribution that would range from Maine to Louisiana and Texas. The similarity of certain climates in the continental United States with those of Hawai‘i is implied by the fact that many continental U.S. pests have been successfully introduced into Hawai‘i in recent years (HDOA 2002).

Davis et al. (2005b) noted that *A. orana* has moved through commerce, and introductions of larvae onto trees and shrubs have been particularly problematic in some areas.

Specific information relating to risk elements:

A. Likelihood of introduction (plant material pathway)

1. Pest with host-commodity at origin potential: **High** (RC) (Applicable rating criteria, from app. 4: a, c, d, g, h)

Although *A. orana* has not specifically been intercepted on very many occasions, note that for Hawai‘i, the tortricid leaf rollers as a group are very commonly intercepted in ports. As such, we apply criterion “a.” A wide host range, broad distribution, and multiple generations all increase the likelihood that *A. orana* could be associated with fruits, foliage, or planting stock.

2. Entry potential: **High** (MC) (Applicable rating criteria, from app. 4: a, b, c)

Adoxophyes orana has not often specifically been intercepted in U.S. ports. However, it has been introduced into Greece and England, probably via infested plant material or fruit (Davis et al. 2005b). Interception records for Hawai‘i from 1985 to 2004 show that members from the family Tortricidae are very commonly intercepted (at least 400 times in the past two decades). Within a 20-year period, unidentified tortricids were intercepted in the continental United States over 10,000 times (Davis et al. 2005b). The most common pathways for these interceptions were international airline baggage (44 percent) and permit cargo (41 percent) (Davis et al. 2005b). There was not a strong association with a particular plant product, as over 100 plant taxa were involved (Davis et al. 2005b).

3. Colonization potential: **High** (MC) (Applicable rating criteria, from app. 4: a, b, e)

As part of its broad geographical range, *A. orana* occurs in tropical and subtropical moist broadleaf forests. The summer fruit tortrix has successfully expanded its range into the Mediterranean region. A broad host range and high biotic potential increase the chances for successful colonization by *A. orana*.

4. Spread potential: **High** (MC) (Applicable rating criteria, from app. 4: b, c, d, e, g)

The summer fruit tortrix moth has poor capacity for dispersal (Kamminga and Maguylo 2011). Adult flights are typically of a short distance, and some larval movement may occur when larvae drop from silken threads and are carried by the wind. Most of the movement into new areas has been via infested plant material (Davis et al. 2005b). A high reproductive potential, broad host range, and somewhat cryptic nature are all factors that could facilitate the movement of this insect if introduced into Hawai‘i.

B. Consequences of introduction

5. Economic damage potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: c, d)

Although the host range includes several forest species, the summer fruit tortrix moth is documented as causing economic damage primarily to apples, pears, and other rosaceous hosts (Kamminga and Maguylo 2011). Where fruit is involved, damage from *A. orana* can be very significant. As leafrollers, these insects use foliage for shelter while feeding on the outer surface of fruit. The larval feeding creates a misshapen appearance and can lead to losses of 10 to 50 percent in fruit-growing regions (Davis et al. 2005b). Because this insect is considered a regulated pest in some countries, its presence in Hawai‘i could result in international quarantines or mitigating treatments affecting trade. The effects of *A. orana* on *Vaccinium* spp. are not likely to be as important as they would be on major fruit crops such as those attacked in Europe.

6. Environmental damage potential: **High** (MC) (Applicable rating criteria, from app. 4: c, d, e)

Adoxophyes orana may have the potential to affect forest composition or reduce biodiversity because of its ability to utilize many hosts. There might be indirect environmental effects if pest-mitigating actions were invoked. There are at least 27 endangered species from six plant families (Urtiaceae, Solonaceae, Rosaceae, Malvaceae, Fabaceae, and Convulvulaceae) in Hawai‘i that may be hosts for the summer fruit tortrix (Kamminga and Maguylo 2011).

7. Social and political considerations: **Moderate** (MC) (Applicable rating criteria, from app. 4: b)

Because this insect is considered a regulated pest in some countries, its presence in Hawai‘i could result in international quarantines or mitigating treatments affecting trade.

C. Pest risk potential:

High (Likelihood of introduction = **high**; Consequences of introduction = **high**)

Selected bibliography:

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Ministry of Agriculture and Forestry, Biosecurity New Zealand. 2009. Import risk analysis: pears (*Pyrus bretschneideri*, *Pyrus pyrifolia*, and *Pyrus* sp. nr. *communis*) fresh fruit from China. Wellington, New Zealand. 454 p.

Reviewers' comments: "This assessment reads well with clear rationale" (D. Anthony)

Response to comments: None needed.

West Indian Sugarcane Borer Weevil

Assessor: Andris Eglitis

Scientific name of pest: *Diaprepes abbreviatus* (Linnaeus) (Coleoptera: Curculionidae)

Scientific names of hosts: ***Diospyros*** spp., *Citrus* spp., *Acacia* spp., ***Erythrina*** spp.; many others

Distribution: West Indies, Central and South America, California, Florida, Texas

Summary of natural history and basic biology of the pest: The West Indian sugarcane borer weevil is originally from the Caribbean, where it is known principally as a pest of sugarcane, citrus, and other crops (Stansly 2011). The weevil was introduced into Florida in 1964 and was commonly collected 4 years later (Woodruff 1968). Since then, it has become a very serious pest to the citrus industry in Florida (Simpson et al. 2011). In 2000, the weevil also became established in a mature citrus grove in Texas (Grafton-Cardwell et al. 2004). Since 1974, *D. abbreviatus* was intercepted numerous times in California (Grafton-Cardwell et al. 2004) and eventually became established in that state in 2008 after eradication attempts were ended owing to a lack of funding (Jetter and Godfrey 2009).

Diaprepes abbreviatus is a large, colorful weevil, measuring 10 to 19 mm in length with numerous color forms ranging from gray to yellow to orange and black (Grafton-Cardwell et al. 2004). Adult weevils can live up to 4 months (Jetter and Godfrey 2009), during which time they can lay up to 5,000 eggs per female (Griffith 1975, Simpson et al.1996). Eggs are laid in masses of around 40, placed between two leaves that are glued together by the female (Griffith 1975). The eggs normally hatch within a week, and the young larvae drop to the ground and work their way into the soil to begin feeding on plant roots (Griffith 1975). The youngest larvae feed on the finest roots, moving to larger roots as they develop (Jetter and Godfrey 2009). The larvae can remain in the soil for a prolonged period, ranging from 2 months to as long as 2 years before maturing into the adult stage (Griffith 1975). The larvae pass through 11 instars, with instars 3 through 9 being the most destructive feeders

(Grafton-Cardwell et al. 2004). Late-instar larvae construct a chamber where they transform into pupae. The pupal stage lasts for 2 to 3 weeks, and in Puerto Rico, the pupal stage can be found in any month of the year (Woodruff 1968). Young adults may remain in the pupal chamber for an extended period of time before emerging (Woodruff 1968). The adult weevils "typically" emerge from the ground in late spring and early summer (Stansly 2011, citing Wolcott 1936), although in Florida, emergence has been found to be quite variable with adults present nearly year-round (Stansly 2011). Adults are sometimes difficult to find because they feed during the early morning and late afternoon, hiding in the foliage during the day (Grafton-Cardwell et al. 2004). Adult feeding is typically limited to leaf edges, producing irregular and semicircular notches (Jetter and Godfrey 2009). Young and tender leaves are preferred. It is important to locate the actual weevil doing the damage because the feeding of *D. abbreviatus* is similar to that of other weevils (Grafton-Cardwell et al. 2004). The most significant losses come from larval feeding, which occurs in the roots. Young trees may be killed outright by larval girdling, while larger trees decline rapidly and fall over or become exposed to root diseases (Jetter and Godfrey 2009). Many citrus trees do not show symptoms of decline until extensive damage has been done to the root system (Grafton-Cardwell et al. 2004).

Although the sugarcane borer weevil is most commonly associated with citrus and other important crops, it has an extremely broad host range that encompasses nearly 300 plant species in 59 families (Simpson et al. 1996). Among those hosts are plants from three genera of concern to this pest risk assessment (*Acacia, Diospyros,* and *Erythrina*). Most of these host plants are ones where adults have been collected and larval feeding has not yet been documented. Nearly 50 of the species have been verified as larval hosts, and many others have been associated with adult feeding or egg laying (Simpson et al. 1996).

Specific information relating to risk elements:

A. Likelihood of introduction (plant material pathway)

1. Pest with host-commodity at origin potential: **High** (MC) (Applicable rating criteria, from app. 4: a, b, c, d, e, g)

Diaprepes abbreviatus has been successfully transported into at least three new locations via plant material containing life stages. A very broad host range and overlapping life stages increase the likelihood that the insect will be associated with transported plant material.

2. Entry potential: **High** (RC) (Applicable rating criteria, from app. 4: a, b, d)

The West Indian weevil was intercepted many times in California before it became established. Even though the weevils are strong fliers, they are probably most effectively moved as "hitchhikers," attached to plants or transported through infested nursery containers (Jetter and Godfrey 2009). Successful entry has been gained into Florida, Texas, and California.

3. Colonization potential: **High** (RC) (Applicable rating criteria, from app. 4: a, b, e)

Diaprepes abbreviatus has been introduced into Florida, Texas, and California. A very broad host range and a high reproductive potential (up to 5,000 eggs per female) increase the chances of successful colonization in a new environment. The weevil has hosts within three of the genera of concern for this risk assessment.

4. Spread potential: **High** (RC) (Applicable rating criteria, from app. 4: b, c, d, e, f, g)

Although the West Indian weevil has strong dispersal capability on its own, it has most likely been aided in its spread by human transport. A broad host range, a high reproductive potential, and somewhat cryptic nature have allowed it to spread beyond quarantine areas in Florida (Griffith 1975). Simpson et al. (1996) believe that the weevil could be well established in an area before being detected. Aggressive but unsuccessful attempts were made at eradication in both Florida and California once the insect was detected.

B. Consequences of introduction

5. Economic damage potential: **High** (MC) (Applicable rating criteria, from app. 4: a, b, c, d, f)

Most of the evaluations of damage by this insect have been associated with the citrus industry, where the economic impacts have been devastating (Hall 1995, Simpson et al. 2011). Three of the Hawai‘i genera of concern in this assessment contain plants that are hosts to the West Indian weevil. If damage in these hosts approached the levels that the weevil has inflicted on citrus, then the impacts would be severe. Criterion "f" is applied because of the experience with the first introduction of the weevil into the United States. When *D. abbreviatus* was discovered in Florida, very aggressive efforts were undertaken to limit the expansion of its range. These efforts involved aerial spraying with assorted insecticides but were not successful and the weevil spread far beyond the quarantine areas (Griffith 1975).

6. Environmental damage potential: **High** (MC) (Applicable rating criteria, from app. 4: d, e)

Given a broad host range, it is possible that *D. abbreviatus* could affect hosts with limited distributions. Thus far, eradication programs have been ineffective and could create their own environmental problems.

7. Social and political considerations: **Moderate** (MC) (Applicable rating criteria, from app. 4: b)

Simpson et al. (1996) stated that, given the high reproductive potential (5,000 eggs per female), a fairly long life cycle, and hidden eggs and larvae, *D. abbreviatus* would probably be well-established before it is detected. The presence of the weevil could lead to quarantine restrictions on trade from Hawai‘i.

C. Pest risk potential:

High (Likelihood of introduction = **high**; Consequences of introduction = **high**)

Selected bibliography:

Grafton-Cardwell, E.E.; Godfrey, K.E.; Peña, J.E.; McCoy, C.W.; Luck, R.F. 2004. *Diaprepes* root weevil. IPM Publication 8131. Davis, CA: University of California, Division of Agriculture and Natural Resources. 7 p.

Griffith, R.J. 1975. The West Indian sugarcane rootstalk borer weevil in Florida. Proceedings of the Florida State Horticultural Society. 88: 87–90.

Hall, D.G. 1995. A revision to the bibliography of the sugarcane rootstalk borer weevil, *Diaprepes abbreviatus* (Coleoptera: Curculionidae). Florida Entomologist. 78 (2): 365–377.

Jetter, K.M.; Godfrey, K. 2009. *Diaprepes* root weevil, a new California pest, will raise costs for pest control and trigger quarantines. California Agriculture. 63(3): 121–126.

Simpson, S.E.; Nigg, H.N.; Coile, N.C.; Adair, R.A. 1996. *Diaprepes abbreviatus* (Coleoptera: Curculionidae) host plant associations. Environmental Entomology. 25(2): 333–349.

Simpson, S.E.; Nigg, H.N.; Knapp, J.L. 2011. Host plants of *Diaprepes* root weevil and their implications to the regulatory process. University of Florida, Florida Citrus Resources. 15 p. http://irrec.ifas.ufl.edu/flcitrus/short_course_and_workshop/diaprepes/host_plants.shtml. (4 August 2013).

Stansly, P.A. 2011. Biology of *Diaprepes abbreviatus* in the laboratory and field. Fort Pierce, FL: University of Florida, Indian River Research and Education Center. 6 p. http://irrec.ifas.ufl.edu/flcitrus/short_course_and_workshop/diaprepes/biology_of_diaprepes_abbreviatus.shtml. (4 August 2013).

Wolcott, G.N. 1936. The life history of *Diaprepes abbreviatus* at Rio Piedras, Puerto Rico. Journal of Agriculture, University of Puerto Rico. 20: 883–914.

Woodruff, R.E. 1968. The present status of a West Indian weevil (*Diaprepes abbreviata* (L.)) in Florida. Entomology Circular No. 77. Gainsville, FL: Florida Department of Agriculture, Division of Plant Industry. 4 p.

Reviewers' comments: In response to *High* rating for "Pest with host-commodity at origin potential"] "I find this a bit surprising—the adults are large and often colourful, therefore one would expect they would be readily detectable during routine inspections, (allowing for very low numbers in large consignments being harder to detect). Are they likely to move or fly when disturbed? I would expect eggs to be the most likely lifestage to be accidentally imported on whole plants, though, depending on the plant, I would think leaves stuck together might arouse some curiosity and masses are more obvious than single or few eggs. If plants are supposed to come in without soil, wouldn't this reduce the likelihood of larvae and pupae entering?" (D. Anthony)

Response to comments: Although adults are large and colorful and should be easily detected (as should plant leaves glued together), the West Indian weevil has been moved into several new environments. Several other criteria also apply, leading to the "**high"** rating for that risk element.

White Wax Scale

Assessor: Andris Eglitis

Scientific names of pest: *Ceroplastes destructor* Newstead (Hemiptera: Coccidae)

Scientific names of hosts: *Citrus* spp., ***Diospyros*** spp., ***Acacia*** spp., ***Dodonaea*** spp.; over 150 others

Distribution: Africa, Australasia, Oceania

Summary of natural history and basic biology of the pest: *Ceroplastes destructor* utilizes several species of *Citrus* as primary hosts (Sullivan and Molet 2011) and has a long list of secondary hosts including some species in the genera *Acacia, Diospyros,* and *Dodonaea* that have representatives in Hawai'i. The white wax scale was once considered a serious pest of *Citrus* spp. in several states of Australia until highly successful biological control agents were introduced from Africa (Sullivan and Molet 2011). These natural enemies also limit the pest importance of the white wax scale in its native range of Africa (Sullivan and Molet 2011).

The white wax scale has three nymphal instars. The early stages are morphologically difficult to distinguish from other *Ceroplastes* species (Sullivan and Molet 2011). Adult females are oval, sometimes with some marginal indentation, and measure from 2.5 to 6.4 mm in length (Sullivan and Molet 2011). The females are immobile and are covered with a white waxy layer. Adult males are unknown. Sullivan and Molet (2011) described the life cycle of the white wax scale in Australia, Africa, and New Zealand. In Australia, *C. destructor* is univoltine and occasionally produces a partial second generation in the warmer areas of citrus growing regions. In Africa, adults are found from March to September, and females oviposit from September to mid-January (Sullivan and Molet 2011). During their lifetime, females will lay an average of over 1,700 eggs (Davis et al. 2005a). Nymphal instars can be found from mid-November to late March, and overwintering can occur in the third instar or adult stage (Sullivan and Molet 2011). In New Zealand, females begin to lay eggs in November, and crawlers emerge in December (Sullivan and Molet 2011). The first instar nymphs initially settle on leaves; later instars move to twigs where they secrete a waxy covering (Davis et al. 2005a). The nymphal feeding reduces the vigor and growth of host plants (Sullivan and Molet 2011). Sooty mold growing on honeydew produced by the feeding instars may inhibit photosynthesis (Davis et al. 2005a). Developmental rate of the scale is dependent on host species, temperature, and water availability (Davis et al. 2005a).

Specific information relating to risk elements:

A. Likelihood of introduction (plant material pathway)

1. Pest with host-commodity at origin potential: **High** (RC) (Applicable rating criteria, from app. 4: b, c, e, f, g, h)

Although *Ceroplastes destructor* has not been intercepted in Hawai'i or the conterminous United States, the third most commonly intercepted insect in Hawai'i ports between 1984 and 2010 was a related scale insect, *C. rubens* (red wax scale) (AQIM Database). *Ceroplastes rubens* has a wider geographical distribution (including Hawai'i) than *C. destructor*, but an equally broad host range (Dekle 2001).

2. Entry potential: **High** (RC) (Applicable rating criteria, from app. 4: a, b, c)

Although *C. destructor* has not been intercepted in port inspections, it has become established in three new environments, demonstrating that interceptions are only loosely tied to establishments. Many *Ceroplastes* interceptions are associated with materials for consumption in passenger baggage (Sullivan and Molet 2011).

3. Colonization potential: **High** (RC) (Applicable rating criteria, from app. 4: a, b)

C. destructor has been successfully introduced into Australia, New Zealand, and other South Pacific Islands (Sullivan and Molet 2011). The climate in Hawai‘i would be similar to many locations where the scale now occurs. In addition, *C. destructor* has hosts in four of the Hawai‘i genera of concern for this risk assessment (Davis et al. 2005a), increasing the likelihood of successful establishment in Hawai‘i.

4. Spread potential: **High** (MC) (Applicable rating criteria, from app. 4: b, c, d, f, g)

The white wax scale has a very broad host range such that elements “d” and “g” could apply. In addition, *C. destructor* has a very high reproductive potential (1,700 eggs per female) (Davis et al. 2005a). Inherent powers of dispersal are limited, mainly involving transport of crawlers.

B. Consequences of introduction

5. Economic damage potential: **High** (RC) (Applicable rating criteria, from app. 4: a, b, c, d)

With a broad host range, economically important host plants could likely be affected by *C. destructor.* The white wax scale has been a major pest of *Citrus* in South Africa (Davis et al. 2005a). Feeding by scales weakens host plants and may predispose them to mortality agents.

6. Environmental damage potential: **High** (MC) (Applicable rating criteria, from app. 4: b, c, d, possibly e)

In their mini risk assessment for the continental United States, Davis et al. (2005a) rated the environmental damage potential of *C. destructor* as “**high**” owing to the potential for degrading ecosystems, reducing biodiversity, and jeopardizing endangered or threatened species. They also pointed out that new pest introductions typically result in greater use of chemical measures to combat infestations or attempt eradication.

7. Social and political considerations: **Moderate** (RC) (Applicable rating criteria, from app. 4: a)

Damage by the white wax scale could lead to increased public concerns. In addition, increases in pesticide use are often met with public resistance.

C. Pest risk potential:

High (Likelihood of introduction = **high**; Consequences of introduction = **high**)

Selected bibliography:

Davis, E.E.; French, S.; Venette, R.C. 2005a. Mini risk assessment. Soft wax scale, *Ceroplastes destructor* Newstead (Hemiptera: Coccidae). Cooperative Agricultural Pest Survey (CAPS) Pest Risk Assessment. 35 p.

Dekle, G.W. 2001. Red wax scale (*Ceroplastes rubens* Maskell). Entomology Circular 15. Gainesville, FL: Florida Department of Agriculture and Consumer Services, Division of Plant Industry. 2 p.

Sullivan, M.; Molet, T. 2011. CPHST Pest Datasheet for *Ceroplastes destructor*. Raleigh, NC: U.S. Department of Agriculture-APHIS-PPQ-CPHST. http://caps.ceris.purdue.edu/webfm_send/1553. (4 August 2013).

Reviewers’ comments: “Criteria “a” states the organism has been intercepted at ports of entry not that an organism/related organism is intercepted. So is it valid to state that criterion “a” applies in this case?” (Martin)

Response to comments: The reviewer makes a valid point. Criterion “a” was dropped from the “Pest with host commodity potential.” Because numerous other criteria apply, the rating for that element remains “**high.**”

Pathogen IPRAs

Acacia Gall Rust

Assessor: Phil Cannon

Scientific names of pest: *Uromycladium tepperianum* (Sacc.) McAlpine

Scientific names of hosts: Species of ***Acacia***, *Albizia,* and *Racosperma* (Fabaceae). The pathogen is known to attack more than 100 species of *Acacia* in Australia (Wood 2012), as well as *Falcataria moluccana* (*Molucca albizia*) and *Paraserianthes falcataria* (syn. *Adenanthera falcataria*) (albizia). The African species of *Acacia* are not susceptible to this fungus (Morris 1987).

Distribution: *Uromycladium tepperianum* is native to Australia. It has spread through much of the Philippines, Sabah in Malaysia, and Java in Indonesia (Rahayu et al. 2010). It is also found in New Zealand, Papua New Guinea, and New Caledonia (Morris 1987). It was introduced to South Africa as a biological control agent for the invasive *Acacia saligna* (Wood 2012).

Summary of natural history and basic biology of the pests: *Uromycladium tepperianum* is a microcyclic rust, producing only teliospores (Morris 1987). It does not produce urediniospores or aeciospores (Rahayu et al. 2010). Teliospores**,** composed of a cluster of three probasidial cells at top of a single pedicel, are depressed globose to globose, cinnamon brown, thickly vertically striate, margin crenulate, wall 2 to 3 µm, at apex up to 5 µm thick, 14 to 22 µm high, 18 to 25 µm wide, one apical germ pore; pedicel hyaline, septate, deciduous (Systematic Mycology and Microbiology Laboratory 2007).

Acacia pycnantha, cultivated in Australia for its bark, is severely affected by *U. tepperianum*; infection causes significant yield losses and eventually host death (Gathe 1971). This rust has potential as a biocontrol agent for weedy acacias outside of Australia; it has been highly effective against *A. saligna* in South Africa (Morris 1991, 1997, 1999; Wood and Morris 2007).

The most characteristic symptom of infection is the formation of reddish brown, globose or irregularly shaped galls at least several centimeters in diameter, on stems and shoots. Witches' brooms of different shapes and sizes can develop. Flowers, phyllodes, and shoot tips can also be infected, causing gross malformation (Gothe 1971). Older galls may turn dark brown and become invaded by tunneling insects (Old et al. 2002). Infected trees can have several galls per stem, which can lead to girdling, death of the stem and repeated branching. Severely infected trees die.

Fresh galls are covered with powdery, cinnamon-colored masses of teliospores. Telia develop on galls on leaves, branches, inflorescences, and fruits. The teliospores from the gall are wind blown, can travel great distances, and can infect virtually any part of a susceptible plant except the thick bark.

During the infection process, the teliospore germinates to produce a basidiospore on the host surface. Under favorable conditions (relative humidity > 90 percent), the basidiospore forms a penetration peg, which penetrates the host cells directly through the epidermis (Rahayu et al. 2010). After penetration, the mycelia of the rust spread inter- and intracellularly. As a result, the periderm and phloem cells become misshapen while the xylem cells become twisted or die. Pycnia are formed after about 7 days; they are the small brown pustules that eventually erupt under the epidermis. Often, no urediniospores are found (Rahayu et al. 2010).

Galls can persist for several years. However, because the rust is an obligate parasite, the rust will die when the cells of the host plant die.

Specific information relating to risk elements:

A. Likelihood of introduction

1. Pest with host-commodity at origin potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d, e, g, h)

The rust can colonize basically any aerial unlignified part of a host plant, and a large number of large, spore-bearing galls form on these tissues and persist as the seedling or tree grows larger. If seedlings of *F. moluccana,* which had been produced in a nursery near an infected mature tree were to be brought to Hawai'i, the likelihood of these seedlings being infected with this rust would be high. However, Hawai'i already has numerous Albizia growing on its islands, so this should significantly lessen the motivation of bringing in such seedlings from abroad. Presumably, spores of this rust could also be introduced with seed or on wood products coming from an infested area, although this would be purely casual and the likelihood of spores brought in by this manner, and also infecting a susceptible host and leading to the formation of galls, seems quite low. The spores of this rust are fairly durable and should be wind dispersed for fairly long distances. Although the possibilities of this rust making it on the wind all the way to Hawai'i from someplace like Asia seem remote (and have not happened, to date), once in Hawai'i, wind dispersal would become important in local spread.

2. Entry potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d)

Uromycladium tepperianum can colonize all aerial nonwoody parts of a plant, so it could be brought into Hawai'i on any infected plant. Presumably spores of this fungus could also be introduced with seed, although this would be purely casual; it should not be a risk on wood products.

3. Colonization potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c, e)

There is a fair amount of *Albizia* on all of the Hawai'i Islands (Dave Bakke, regional pesticide coordinator, USDA Forest Service, personal communication), so presumably *U. tepperanium* could rapidly build up inoculum levels and also very quickly colonize entire stands of these trees as well.

The ability of this fungus to infect and colonize *A. koa*, or any other leguminous trees in Hawai'i, has not yet been evaluated. More than 100 species of *Acacia* in Australia are at least somewhat susceptible to this fungus; *Acacia saligna* has proven to be exceptionally vulnerable to this rust (Wood 2012).

4. Spread potential: **High** (RC) (Applicable rating criteria, from app. 4: a, b, c, d, e, f, g)

Spread in stands of *Albizia* could be expected to be exceptionally high. Spread in locations where this species was absent would probably be much lower.

B. Consequences of introduction

5. Economic damage potential: **Moderate** (RC) (Applicable rating criteria, from app. 4: c, d, f)

Locally, where there are well-established stands of *Albizia*, the economic damage could be considerable, as many of these trees in these stands are huge (50 to 100 cm dbh and 35 m in height). As many of these *Albizia* trees are in semiurban settings, infected trees would become hazard trees as the rust galls will make their branches more malformed and weaker.

The potential for economic damage to native Hawai'i *Acacia* species is not known. Pathogenicity tests to determine whether *A. koa* is susceptible would be worth conducting.

6. Environmental damage potential: **Low** (MC) (Applicable rating criteria, from app. 4: none)

Locally, where there are well-established stands of *A. falcataria* (= *Falcataria moluccana*), the environmental damage could be considerable as many of these trees in these stands are huge (50 to 100 cm dbh and 35 m in height). The potential for environmental damage to native Hawai'i acacia species is not yet known.

7. Social and political considerations: **Low** (MC) (Applicable rating criteria, from app. 4: none)

The social and political impact of having *U. tepperanium* become established in *Albizia* in the state would be a mixed bag. One segment of the Hawaiian population would probably applaud any damage to *Albizia* because it is an invasive species. On the other hand, the impact that this fungus has on *Albizia* is to make it an incredibly ugly tree with an even higher than usual propensity for branch breakage.

The segment of the Hawaiian population that does not object to *Albizia*, and basically all visitors who are unaware that this is not a native species, would probably be appalled at the disfiguration that this rust would be causing to both individual trees and stands of *Albizia*.

As it is not yet known how this rust might affect koa or other leguminous trees currently found on the Hawai'i islands, it is premature to speculate on the social or political impacts that the introduction of this rust fungus might have in Hawai'i.

C. Pest risk potential:

High (Likelihood of introduction = **high**; Consequences of introduction = **moderate**)

Selected bibliography:

Burges, A. 1934. Studies in the genus *Uromycladium* (Uredinaceae) I. Proceedings of the Linnean Society of New South Wales. 59: 212–228.

Dick, M. 1985. *Uromycladium* rusts of *Acacia*. Forest Pathology in New Zealand, No. 15. Rotorua, New Zealand: New Zealand Forest Service. 8 p.

Gathe, J. 1971. Host range and symptoms in Western Australia of gall rust, *Uromycladium tepperianum*. Journal of the Royal Society of Western Australia. 54: 114–118.

Lee, S.S. 2004. Diseases and potential threats to *Acacia mangium* plantations in Malaysia. Unasylva. 217: 31–35.

McAlpine, D. 1906. The rusts of Australia: their structure, nature and classification. Melbourne, Australia: Brain, Department of Agriculture, Victoria. 349 p.

Morris, M.J. 1987. Biology of the *Acacia* gall rust, *Uromycladium tepperianum*. Plant Pathology. 36: 100–106.

Morris, M.J. 1991. The use of plant pathogens for biological weed control in South Africa. Agriculture, Ecosystems and Environment. 37: 239–255.

Morris, M.J. 1997. Impact of the gall-forming rust fungus *Uromycladium tepperianum* on the invasive tree *Acacia saligna* in South Africa. Biological Control. 10: 75–82.

Morris, M.J. 1999. The contribution of the gall-forming rust fungus *Uromycladium tepperianum* (Sacc.) McAlp. to the biological control of *Acacia saligna* (Labill.) Wendl. (Fabaceae) in South Africa. African Entomology Memoir No. 1: 125–128.

Old, K.M.; Vercoe, T.K.; Floyd, R.B.; Wingfield, M.J.; Roux, J.; Neser, S. 2002. FAO/IPGRI Technical Guidelines for the Safe Movement of Germplasm No. 20. *Acacia* spp. Rome: Food and Agriculture Organization of the United Nations, International Plant Genetic Resources Institute. 88 p.

Rahayu, S.; Lee, S.S.; Shukor, N.A.A. 2010. *Uromycladium tepperianum*, the gall rust fungus from *Falcataria moluccana* in Malaysia and Indonesia. Mycoscience. 51: 149–153.

Savile, D.B.O. 1971. Generic disposition and pycnium type in Uredinales. Mycologia. 63: 1089–1091.

Systematic Mycology and Microbiology Laboratory. 2007. Invasive fungi. *Uromycladium tepperianum* on *Acacia* spp. U.S. Department of Agriculture, Agricultural Research Service. http://nt.ars-grin.gov/taxadescriptions/factsheets/pdfPrintFile.cfm?thisApp=Uromycladiumtepperianum. (8 May 2013).

Wood, A.R. 2012. *Uromycladium tepperianium* (a gall forming rust fungus) cause a sustained epidemic on the weed *Acacia saligna* in South Africa. Australasian Plant Pathology. 41: 255–261.

Wood, A.R.; Morris, M.J. 2007. Impact of the gall-forming rust fungus *Uromycladium tepperianum* on the invasive tree *Acacia saligna* in South Africa: 15 years of monitoring. Biological Control. 41: 68–77.

Reviewers' comments: "Wind dispersal is another means of introduction but this depends on the prevailing wind directions." (Su See Lee)

"Don't think there are any studies or reports of this rust on other Albizias—perhaps it may not attack other Albizias? It has been found on some acacias but not on others. In Malaysia, it is present on *F. moluccana* but absent on adjacent *Acacia mangium.*" (Su See Lee)

"In Sabah (Malaysia) and the Philippines infection is much more serious in areas of higher elevation (400 m asl) with persistent early morning fog, low wind speed, and high relative humidity (>90 percent). It is absent in low lying and open areas. So it may not be a threat in semiurban setting." (Su See Lee)

Response to comments: Comments by the reviewer were incorporated.

Aecidium Rusts

Assessor: Gregg DeNitto

Scientific names of pests: see table 7

Scientific names of hosts: see table 7

Distribution: see table 7

Summary of natural history and basic biology of the pests: Species of *Aecidium* are rust fungi that infect primarily foliage of deciduous hosts. The species identified in this analysis likewise affect host foliage, but some species

Table 7—Hosts, country of origin and citations for *Aecidium* spp. on *Diospyros* and *Myoporum* species

Pathogen	Host(s)	Country of origin	Citation
Aecidium atrocrustaceum Syd. & P. Sydow (Pucciniales: Incertae sedis)	*Diospyros discolor*	Philippines	Watson 1971
Aecidium calosporum Juel (Pucciniales: Incertae sedis)	*Diospyros* sp., *Diospyros hispida, Diospyros liriosmoides*	Brazil	Hennen et al. 2005
Aecidium carbonaceum W.T. Dale (Pucciniales: Incertae sedis)	*Diospyros inconstans*	South Africa, Trinidad & Tobago	Dale 1955, Hennen et al. 2005
Aecidium diospyri A.L. Sm. (Pucciniales: Incertae sedis)	*Diospyros mespiliformis*	Angola, South Africa	Watson 1971
Aecidium mabae	*Diospyros piscatorial, Mabea abyssinica*	Ivory Coast, Ethiopia	Watson 1971
Aecidium melaenum Syd. & P. Syd. (Pucciniales: Incertae sedis)	*Diospyros* sp.	India, Philippines	Bagyanarayana and Ramesh 1995, Watson 1971
Aecidium muelleri Thurst. (Pucciniales: Incertae sedis)	*Diospyros* sp.	Brazil	Hennen et al. 2005
Aecidium miliare Berk. & Broome (Pucciniales: Incertae sedis)	*Diospyros embryopteris, D. ovalifolia, D. xanthochlamys,*	India, Ivory Coast, Sri Lanka	De 2000, Watson 1971
Aecidium myopori G. Cunn. (Pucciniales: Incertae sedis)	*Myoporum acuminatum, M. laetum, M. parvifolium, M. tetrandrum*	Australia, New Zealand	Birch 1938, Cunningham 1924, McKenzie 1998
Aecidium ramosii Syd. & P. Syd. (Pucciniales: Incertae sedis)	*Diospyros* sp.	Philippines	Watson 1971
Aecidium reyesii Syd. & P. Syd. (Pucciniales: Incertae sedis)	*Diospyros discolor*	Philippines	Watson 1971
Aecidium rhytismoideum Berk. & Broome (Pucciniales: Incertae sedis)	*Diospyros* sp., *D. discolor, D. embryopteris, D. malabaricus, D. melanoxylon, D. mespiliformis, D. ovalifolia, D. paniculata, D. tomentosa*	Eritrea, Ethiopia, India, Ivory Coast, Java, Philippines, South Africa, Sri Lanka	Hosagoudar 1985, 2006; Watson 1971
Aecidium royenae Cooke & Massee (Pucciniales: Incertae sedis)	*Diospyros pallens, Diospyros* sp.	South Africa	Farr and Rossman, n.d.
Aecidium ulei Henn. (Pucciniales: Incertae sedis)	*Diospyros* sp.	Brazil	Hennen et al. 2005, Watson 1971
Aecidium yapoense Vienn. Bourg. (Pucciniales: Incertae sedis)	*Diospyros gabonensis*	Ivory Coast	Watson 1971

also infect branches, trunks, petioles, inflorescences, and drupes. Some cause the formation of branch swellings and witches' brooms. For the most part, they are limited to species of *Diospyros* or *Myoporum* as hosts. In Malaysia, species of *Aecidium* have been recorded on various hosts, but not *Diospyros* or *Myoporum* (Lee et al. 2012). There are few known rust fungi on the 13 species of concern in this risk assessment in Hawai‘i. Three species of *Atelocauda*, two species of *Endoraecium*, and one species of *Uromyces* have been reported on *Acacia koa* (Gardner 1994). *Pucciniastrum vaccinii* has been reported on *Vaccinium* spp. (Gardner and Hodges 1989) and *Uredo myopori* on *Myoporum sandwicense* (Gardner 1994).

The aecia produced by *Aecidium* are cupulate with a defined peridium. This form-genus houses anamorphs of members of the Order Pucciniales. The associated teleomorph has not been identified for the species in table 7, and the life cycle is not known. Most of the above species have been identified and reported in the literature, but no further information or examination has been completed. There is little biological information published on the species identified in the above table, so much of the following is based on what is known about other *Aecidium* species.

The only consistent reproductive body identified in most *Aecidium* species is the aeciospore. These are produced in cup-like structures, usually on the underside of the leaf. Transmission of *A. mori* to new hosts is mainly by aeciospore transport through the air or by rain splash (Mordue 1991). Infection by aeciospores of *A. mori* from tree to tree has been demonstrated (Mordue 1991) and they are considered to function as an uredinial stage (Hernández 2005).

Specific information relating to risk elements:

A. Likelihood of introduction

1. Pest with host-commodity at origin potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: b, d, e, h)

Aecidium species are somewhat common on host plants in their native ranges. *Diospyros* are used by humans for their fruit, timber, or ornamental purposes, depending on the species. There does not appear to currently be a trade in this genus, other than for persimmons and ebony. Neither of these commodities would likely transport *Aecidium* species. Some *Diospyros* species are suggested for use in ornamental plantings, especially as producers of food for wildlife. *Myoporum* has potential uses for ornamental plantings (Richmond and Ghisalberti 1995) and ground covers. Plants for planting could become traded commodities with either of these genera and, would provide a means of transport of *Aecidium* to Hawai‘i.

2. Entry potential: **High** (MC) (Applicable rating criteria, from app. 4: b, c, d)

Aecidium could readily survive transport on live host tissue, and reproductive structures, aeciospores, could survive on dead tissue. Commodities such as plants for planting could certainly contain and carry fruiting structures of *Aecidium.* Although aecia of these fungi could be visible because of their color, they likely would not be readily visible in the mass of foliage that would be in transport. Witches' brooms that may be present with the infection could be detected upon arrival at the port.

3. Colonization potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: b, e)

The *Aecidium* species evaluated occur in tropical or subtropical climates similar to that of Hawai‘i. Environmental conditions upon arrival would likely be conducive to fungal survival and spread. A limiting factor is the amount of host material near maritime ports. *Diospyros sandwicensis* does occur down to basically sea level. Also, species of *Aecidium* are somewhat host specific, and native hosts of Hawai‘i may not be as susceptible as the rust's native hosts.

4. Spread potential: **High** (RC) (Applicable rating criteria, from app. 4: a, c, d, e, f)

Diospyros sandwicensis and *Myoporum sandwicense* occur on all of the islands with significant maritime ports that deal with imports. *Diospyros hillebrandii* only occurs on Kaua‘i and O‘ahu, both having maritime ports. Because of the moderate temperatures, it is expected that infection in Hawai‘i can occur year-round, and available moisture can accelerate spread. Airborne spread of fungal spores seems to be the primary means for spread of the fungus, so overland movement may be substantial and wide-ranging. Because these fungi do not usually cause host mortality, recognition of their presence could be delayed numerous years from introduction.

B. Consequences of introduction

5. Economic damage potential: **Low** (RU) (Applicable rating criteria, from app. 4: f)

Diospyros species are grown as native plants in some Hawai‘i nurseries. Their slow growth rate may limit their production by these nurseries and their outplanting. Nonnative species that grow faster could become more desirable to the Hawaiian population if planting of *Diospyros* as an ornamental came to be in greater demand. Other economic uses of either *Diospyros* or *Myoporum* are very limited.

6. Environmental damage potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: d)

Diospyros sandwicensis can be a principal or minor part of the dry and mesic forests of Hawai‘i. It once covered large portions of the lowlands on several islands as part of the dry forest community. It can also be found growing in wet forests and open lava fields. *Myoporum sandwicense* grows in mesic to wet forests on all of the major islands. It is a dominant tree species with both cultural and ecological significance. Impacts on either of these species could have significant ecological effects on already altered and degraded ecosystems.

7. Social and political considerations: **Low** (MC) (Applicable rating criteria, from app. 4: none)

The introduction of any *Aecidium* species that infects *Diospyros* or *Myoporum* would likely not have significant social or political impacts. *Myoporum sandwicense* is currently being affected by an introduced thrips species that will likely cause more damage than a species of *Aecidium*. Therefore, introduction of *Aecidium* likely will not increase the current concern. Because a foliar and branch pathogen like *Aecidium* will not cause tree mortality or other highly visible symptoms, the likelihood of public response is considered low.

C. Pest risk potential:

Moderate (Likelihood of introduction = **moderate**; Consequences of introduction = **moderate**)

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Reviewers' comments: The rationale was clear and easy to follow.

Response to comments: No response needed.

Armillaria Root Disease

Assessors: Helen Maffei and Jessie A. Glaeser

Scientific names of pests: *Armillaria luteobubalina* Watling & Kile; *A. tabescens* (Scop.) Emel; *A. limonea* G. Stev.; *Armillaria novae-zelandiae* G. Stev. (Agaricales: Physalacriaceae); *Armillaria* sp., a currently unnamed species from Mexico (Elías-Román et al. 2013). Phylogenetic studies are clarifying species relationships within the genus (Klopfenstein et al. 2012, Maphosa et al. 2006, Pildain et al. 2010, Ross-Davis et al. 2012, Tsykun et al. 2013) and resolving cryptic species (Baumgartner et al. 2011, Elías-Román et al. 2013). Species identifications and distributions in older literature are highly suspect.

Scientific names of hosts: Species of *Armillaria* have broad host ranges and can often colonize both hardwoods and conifers (table 8). Genera of Hawai'i native plants at particular risk to Armillaria root rots are ***Diospyros*, *Acacia*, *Dodonaea*, *Vaccinium*, *Metrosideros*,** and ***Erythrina***.

Summary of natural history and basic biology of the pests: The genus *Armillaria* contains both primary, virulent pathogens and secondary, facultative pathogens. *Armillaria luteobubalina* and *A. tabescens* are generally considered primary pathogens, but the amount of disease that occurs may be influenced by the nature of the host and the environment of the fungus. *Armillaria limonea* and *A. novae-zelandiae* are often secondary pathogens but can also cause significant disease and damage, either alone or in combination with other agents when the host is stressed by factors such as soil compaction, injury, nutrient deficiency or imbalances, drought, wind damage, and other unfavorable environmental conditions. All species of *Armillaria* are facultative necrotrophs that can colonize living roots, kill root tissue, and then use the dead tissue as a source of nutrition, persisting as saprotrophic white rot decay fungi (Baumgartner et al. 2011).

Armillaria luteobubalina is native to Australia and is an agent of mortality in natural ecosystems, forest plantations, fruit crops, and ornamental plants (Kile 1981; Shearer et al. 1997, 1998). It is commonly found in drier, more open eucalypt forests (Guillaumin and Legrand 2013, Kile and Watling 1981, Podger et al. 1978) and is thought to be the most pathogenic and most widespread *Armillaria* species native to Australia (Guillaumin and Legrand 2013, Kile and Watling 1981, Smith and Kile 1981). Stressors, including drought or flooding, can also predispose trees to infection. The fungus is a primary cause of *Eucalyptus* spp. death and forest dieback. Rainfall appears to govern the pathogenicity of *A. luteobubalina*. In intermediate and lower rainfall zones of Australian jarrah forest, the fungus is an aggressive pathogen but causes only minor disease on the same hosts in the wetter, western coastal forests. *Armillaria luteobubalina* has also been reported from southern South America, in Argentina, Chile, and southern Brazil (Guillaumin and Legrand 2013, Pildain et al. 2009). A 2003 study of the molecular phylogenetics and pattern of its distribution

Table 8 —*Armillaria* species of concern, their hosts and distribution

Species	Hosts	Hosts from genera of concern	Distribution	Citation
Armillaria limonea	Wide host range of hardwoods and conifers from multiple families, including species of *Acacia, Chamaecyparis, Citrus, Cryptomeria, Cupressus, Eucalyptus, Larix, Malus, Metrosideros, Nothofagus, Pinus, Pseudotsuga, Podocarpus, Pyrus, Salix, Tsuga*	*Acacia melanoxylon; Metrosideros robusta*	New Zealand	Farr and Rossman, n.d.; Hodges and Hildebrand 2005a; McKenzie et al. 1999
Armillaria luteobubalina	Wide and poorly defined. At least 50 families, primarily hardwoods. Includes species of *Acacia*, *Banksia*, *Cassinia*, *Cedrus*, *Eucalyptus*, *Malas*, *Melaleuca*, *Nothofagus*, *Pinus*, *Prunus*, *Pyrus*, *Vaccinum*, *Vitis*	*Acacia browniana, A. cyclops, A. dealbata, A. extensa, A. howittii, A. longifolia, A. mearnsii, A. melanoxylon, A. mucronata, A. pulchella, A. saligna, A. urophylla, A. verticillata; Dodonaea amblyophylla, D. viscosa; Scaevola nitida; Vaccinium ashei, V. corymbosum*	Australia, Argentina, Chile	CABI 2011a; CIPM 2012a; Falk and Parbery 1995; Farr and Rossman, n.d.; Shaw and Kile 1991; Shearer et al. 1998
Armillaria novae-zelandiae	Wide host range from multiple families of hardwoods and conifers. Includes species of *Acacia, Chamaecyparis, Cedrus, Citrus, Cryptomeria, Cupressus, Eucalyptus, Larix, Malus, Metrosideros, Nothofagus, Pinus, Podocarpus, Prunus, Pseudotsuga, Pyrus, Salix, Tsuga, Vitis*	*Acacia mangium, A. melanoxylon; Metroosideros kermadecensis*	Widespread, especially Oceania (Australia, New Zealand, Malaysia), South America	Farr and Rossman, n.d.; Hodges and Hildebrand 2005b; Shearer et al. 1998
Armillaria tabescens	Wide host range from multiple families; primarily hardwoods but some conifers. Includes species of *Acacia*, *Acer*, *Cedrus*, *Citrus*, *Cupressus*, *Diospyros*, *Erythrina*, *Eucalyptus*, *Malus*, *Melaleuca*, *Metrosideros*, *Pinus*, *Podocarpus*, *Prunus*, *Pyrus*, *Quercus*, *Salix*, *Thuja*, *Vitis*	*Acacia farnesiana; Diospyros* sp., *D. kaki* var. *domestica; Erythrina* sp., *E. crista-galli, E. subumbrans, E. variegata*	United States (primarily South, Central, and South East), Mexico, India, Malaysia, Tanzania, Trinidad and Tobago, Europe, China	Farr and Rossman, n.d.; Lenné 1990; Lushaj et al. 2010

in South America and Australia indicate that *A. luteobubalina* is an ancient species, originating before the separation of the precursor supercontinent Gondwana (Coetzee et al. 2003). At least four distinct polymorphic groups exist within the species, which may eventually be separated into different taxa (Dunne et al. 2002).

Armillaria tabescens is widely distributed (North America, the Caribbean, Europe, India, Africa, Japan, and Malaysia) with a very broad host range. It can act as a primary, aggressive pathogen on highly susceptible hosts or be an opportunistic pathogen on those trees with more resistance. It can persist for many years on dead roots, infecting and colonizing adjacent healthy roots as they grow through the soil. It grows rapidly in a new host if colonization begins in root tissue already dying or recently dead. Symptoms in woody ornamentals are often observed 3 to 4 years after transplant, indicating that wounded roots may be the source of infection. Vigorous plants with undamaged roots often avoid attack. The fungus is favored by higher temperatures. The disease was previously known as "Clitocybe root disease" or "mushroom root rot" (Sinclair and Lyon 2005, Tainter and Baker 1996).

Armillaria limonea is restricted to New Zealand (Coetzee et al. 2001, Hood et al. 1992, McKenzie et al. 1999). It occurs in wet, indigenous podocarpus-hardwood and *Nothofagus* forests where it colonizes stumps, logs, and dead trees and causes a butt rot in living trees (Hood 1989). *Armillaria limonea* often occurs together with *A. novae-zelandiae* on *Pinus radiata* (Shaw et al. 1981). Both fungi are most prevalent on sites once occupied by native forests and can cause losses of up to 30 percent in the first 5 years of *P. radiata* plantations grown on land cleared of indigenous forests, with additional losses in subsequent rotations (Hood et al. 1991).

Armillaria novae-zelandiae is indigenous to Australia, New Zealand, and the higher elevations of Papua-New Guinea. It causes root and butt rot of many native species. It has also been reported from Chile, although differences in internal transcribed spacer sequences suggest that the fungi have been separated for a long period, as observed for *A. luteobubalina* (Coetzee et al. 2003). A study of *P. radiata* colonized by *A. novae-zelandiae* showed that trees younger than 5 years old usually died upon infection and colonization. Colonization in older trees was restricted to bark so that the cambium and living inner phloem were left largely intact, allowing tree survival. Small areas of the cambium were penetrated during the dormant season, but the tree's defenses were able to compartmentalize the area with callus tissue. These trees survived until harvest with a small loss of growth. The stumps of infected trees can serve as a source of inoculum for the succeeding plantation, resulting in the death of young trees (van der Kamp and Hood 2002). In other hosts, the fungus most commonly occurs as a secondary pathogen characterized by epiphytic rhizomorphs or root lesions (Kile et al. 1983). When a large foodbase becomes available through logging or wildfire, massive root and stump infection can result, but little mortality occurs in the regenerating stands of eucalypts and other species. Disease is restricted to the footprint of the preexisting stand (Kile 1980).

Armillaria sp. is a new, currently unnamed species of *Armillaria* that has recently been associated with high incidence of root disease mortality in peach (*Prunus persica*) and other woody species in south-central Mexico (Elías-Román et al. 2013). This species is genetically distinct from other North American species of *Armillaria* and could represent a serious threat to Hawai'i and other regions of the world (Klopfenstein 2014, personal communication). Little is known about its distribution or host specificity.

The infection biology and epidemiology of Armillaria root disease has been reviewed by Guillaumin and Legrand (2013). Wood, primarily tree roots, provides the major source of inoculum for all species of *Armillaria*. The fungi can survive for long periods of time saprotrophically in old stumps and other woody debris (Kile 1980, Rishbeth 1972, Shaw 1975). Infection usually occurs via the roots from contact with infected roots or colonized woody debris in the soil. These fungi also form hard, melanized rhizomorphs that facilitate movement between food sources while preventing desiccation. Although rhizomorphs are seldom observed for *A. tabescens*, Mihail et al. (2002) demonstrated that they can form under conditions of high oxygen availability and moisture near saturation and are capable of establishing new infection centers. Most pathogenic species produce limited rhizomorphs (CABI 2011a), primarily spreading to a new hosts through infected roots/stumps or contaminated wood or mulch (Baumgartner et al. 2011). Several studies have shown that the spread of *Armillaria* root rot in eucalypt forests is associated with infected stumps that remain after an area has been logged (Edgar et al. 1976, Kellas et al. 1987, Pearce et al. 1986). *Armillaria luteobubalina* can persist on these stumps, using them as a source of food, for up to 25 or more years (Kile 1981). In one case reported in Ovens, Victoria, the disease spread to blueberry plants (*Vaccinium* spp.) via buried fragments of infected *Eucalyptus* that remained following preparation of the previously forested site for planting (Falk and Parbery 1995).

The potential importance of basidiospore infection in the spread and establishment of Armillaria root disease is circumstantial. Infection rates in the relatively dry forest of western North America and the dry sclerophyll eucalypt forest appear to be low, possibly because of limited infection courts. Conversely, spore establishment may be more common in wetter forests where moisture conditions are more favorable for frequent and abundant mushroom production and the basidiospore survival on stumps and other infection courts (Kile 1986). Basidiospores may be responsible for long-distance spread and are effective at establishing disease in natural stands that lack competitors (Guillaumin and Legrand 2013). Localized spread is usually vegetative, by contact of healthy roots with infected wood debris and by the spread of infected roots and rhizomorphs. This is particularly common when plantation stands are planted in previously colonized forest soils (Baumgartner et al. 2011, Kliejunas et al. 2001). Variations in virulence among species of *Armillaria* have been observed among isolates of *A. solidipes* from coastal and interior British Columbia (Morrison and Pellow 2002), as well as with *A. limonea* and *A. novae-zelandiae* on *Pinus radiata* in New Zealand (Shaw et al. 1981).

Although species of *Armillaria* are found all over the world, their natural distribution reflects the Holartic or non-Holarctic floral kingdoms that have relatively uniform compositions of plant species. Thus, species from the Holarctic region (North America, Europe, China, and Japan) form one cluster; species from Australia, South America, and New Zealand form a second grouping, and species from Africa represent a third group. Introductions have become established in new areas. North American strains of *A. mellea* are present on planted hosts in South Africa, probably arising from European stock. The spread of these strains is restricted, however, spreading to neighboring plants in urban gardens but not becoming widespread. Similarly, other strains of *A. mellea* in Africa originated in Asia; these could have spread from a single infection center as far as 4000 km, probably by basidiospore dispersal (Baumgartner et al. 2011).

Some species of *Armillaria* already occur in Hawai‘i. Past surveys have noted *A. mellea sensu lato* and *A. nabsnona* on numerous hosts in Hawai‘i, including *Sophora chrysophylla* (māmane) (Burgan and Nelson 1972, Hodges et al. 1986). Kim et al. (2010b) identified *A. gallica* in Hawai‘i, where it was found on *Sophora chrysophylla* (māmane), *Pinus radiata, P. taeda*, and *Prunus salicina* (Methley plum). Recent studies (Brazee and Wick 2009, Klopfenstein et al 2014, Nelson et al 2013) suggest that *A. gallica* can be highly pathogenic and may be an important component of forest decline, especially under increasing stressors such as climate change. The isolation of *A. gallica* from declining stands on both introduced and endemic hosts under drought conditions suggests this pathogen is a contributing factor to forest decline on the island of Hawai‘i.

Specific information relating to risk elements:
Pest risk assessments have been done previously for *A. limonea* (Hodges and Hildebrand 2005a), *A. novae-zelandiae* (Hodges and Hildebrand 2005b), and for the genus as a whole (Kliejunas et al. 2001, 2003).

A. Likelihood of introduction

1. Pest with host-commodity at origin potential: **High** (VC) (Applicable rating criteria, from app. 4: c, d, e, g, h)

Species of *Armillaria* have broad host ranges and can survive in both living and dead wood for extensive periods of time. They can colonize the roots, cambium, and lower boles of host material and can be present in logs, solid wood packing material, chips and mulch, and living nursery stock. Incipient infections are unlikely to be detected.

2. Entry potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d)

The vegetative forms of the fungi, living as saprotrophs, can survive harvest and transport and could continue to grow under conditions of high humidity during transport. Rhizomorphs and mycelia can survive beneath the bark on poorly debarked material and in living plants.

3. Establishment potential: **High** (MC) (Applicable rating criteria, from app. 4: a, b, c, d, f)

Genetic research in Africa has shown that species of *Armillaria* from both Europe and Asia have become established after introduction, probably from contaminated nursery material (Baumgartner et al. 2011). Suitable climate and host species are found at ports of entry in Hawai'i. The wide host range of these fungi and their ability to utilize new hosts increases the probability of establishment. Infection centers may arise either from contact with infected roots from live plants or from contaminated woody material.

4. Spread potential: **High** (VU) (Applicable rating criteria, from app. 4: a, b, c, d, e, f, g)

Although the role of basidiospores in the spread of *Armillaria* species is debated, most studies have concluded that they are responsible for long-distance spread once the fungus becomes established. This likely occurred in spreading Asian isolates of *A. mellea* throughout Africa from infected planting materials (Baumgartner et al. 2011). Newly established infections are likely to go undetected for many years as other agents, including drought and other soil fungi, are thought responsible for forest declines (Hodges et al. 1986).

B. Consequences of introduction

5. Economic damage potential: **High** (VU) (Applicable rating criteria, from app. 4: a, b, c, e, f)

Tree decline and mortality over a broad host range could severely affect forest and agricultural hosts, especially those stressed by other factors. Economic impact might be slow to develop unless basidiospore dispersal results in long-distance establishment of numerous infection centers.

6. Environmental damage potential: **High** (VU) (Applicable rating criteria, from app. 4: c, d)

Armillaria species may have indirect impacts on threatened and endangered species by disrupting sensitive and critical habitat owing to decline and death of native forests, although spread might be slow from a single infection site. The broad host ranges of these fungi endanger native hosts with limited distribution. Variations in virulence have been noted in *A. limonea, A. novae-zelandiae,* and other species of *Armillaria*, so the ability to evolve more virulent strains is always possible.

7. Social and political considerations: **High** (VU) (Applicable rating criteria, from app. 4: a, c, d)

Damage from *Armillaria* species and subsequent death or decline of native Hawai'i tree species would result in public concerns about aesthetics and recreation as well as urban plantings. Removal of affected trees would have limited acceptance by the public. *Armillaria luteobubalina*, a serious pathogen in Australia, is not yet present in North America, and its broad host range includes many important ornamental species. Introduction of the fungus to Hawai'i would interfere with domestic interstate commerce, trade, and traffic.

C. Pest risk potential:

High (Likelihood of introduction = **high**; Consequences of introduction = **high**)

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Reviewers' comments: No comments received except corrections of citations.

Response to comments: Citations corrected.

Calonectria morganii

Assessor: Phil Cannon

Scientific names of pest: *Calonectria morganii* Crous, Alfenas & M.J. Wingf. (anamorph = *Cylindrocladium scoparium* Morgan (imperfect form)). In most locations, it is much more common to find this fungus in the imperfect state.

Scientific names of hosts: The pathogen occurs on a number of hosts but has been particularly common on *Eucalyptus* spp. and *Rhododendron* spp. Other host genera include ***Dodonaea***, *Magnolia*, *Juniperus*, *Mangifera*, *Pistacia*, *Melaleuca*, *Trifolia*, *Ilex*, *Pinus*, *Callistemon*, *Cuphea*, *Picea*, *Juglans*, *Liriodendron, Liquidambar*, *Anacardium*, *Quercus*, *Cornus*, *Cercis*, *Erica*, *Arachis*, *Azalea*, *Solanum*, *Glycine*, *Beta*, *Fragaria*, *Cucumis*, *Mahonia bealei*, *Calluna vulgaris*, ***Metrosideros*** spp., and *Leucotheae catesbaei*.

Distribution: Based on phylogenetic studies, *Calonectria* (*Ca.*) *morganii* has been reported in Brazil, Europe, and the United States (Crous et al. 1993, Overmeyer et al. 1996, Schoch et al. 2000). *Cylindrocladium* (*Cy.*) *scoparium* is especially prevalent in the Eastern United States, Canada, and Brazil. It has also been recorded in the United Kingdom, Poland, Italy, Panama, Brunei, New Zealand, Tunisia (Lombard et al. 2010a), Malaysia (Lee and Manap 1983), and India (Old et al. 2000).

Summary of natural history and basic biology of the pest: To understand *Ca. morganii*, a cursory understanding of the whole genus is useful. Fungi in the genus *Calonectria* were initially regarded as saprobes, as no disease symptoms could be induced by inoculating a suspected host (Graves 1915). The first proof of pathogenicity of these fungi was provided by Massey (1917), and subsequently by Anderson (1919), who proved pathogenicity of *Ca. morganii* (as *Cy. scoparium*). Subsequently, *Calonectria* spp. have been reported worldwide from agricultural and forestry nurseries (Crous 2002; Crous et al. 1991; Lombard et al. 2009, 2010a, b, c), whereas in Europe, they have only been reported from commercial ornamental nurseries (Crous 2002; Henricot and Culham 2002; Lombard et al. 2010a; Polizzi 2000; Polizzi and Crous 1999; Polizzi et al. 2007a, 2007b; 2009; Vitale and Polizzi 2008). At present, 52 *Cylindrocladium* spp. and 37 *Calonectria* spp. are recognized based on sexual compatibility, morphology, and phylogenetic inference (Lombard et al. 2010a).

Calonectria morganii and *Ca. pauciramosa* are the most common *Calonectria* spp. found in ornamental nurseries in the Northern Hemisphere (Polizzi 2000; Polizzi and Catara 2001; Polizzi and Crous 1999; Polizzi et al. 2006a, 2006b, 2007a, 2007b) and of these two, *C. pauciramosa* has wider global distribution and is adapted to a wider array of different environmental conditions (Chen et al. 2011, Crous 2002, Lombard et al. 2010b). *Calonectria pauciramosa* was also regarded as the dominant pathogen in nurseries in Australia and South Africa (Crous 2002, Lombard et al. 2010b, Schoch et al. 2001).

Species of *Calonectria* are common pathogens of a wide range of plant hosts cultivated through seedings or vegetative propagation in nurseries (Crous 2002, Lombard et al. 2010a). Nursery disease symptoms associated with these fungi include crown, collar and root rot, leaf spots, and cutting rot (Crous 2002, Lombard et al. 2010a, Polizzi et al. 2009, Vitale and Polizzi 2008). Infection causes damping-off, root rot and blight, stem lesions, stem canker, stem dieback, stunting, leaf spots, wilted leaves, defoliation, and fruit rot (Alfenas et al. 2004, Cordell and Rowen 1975).

In the past, several authors have indicated that *Calonectria* species cause one or more of these kinds of disease symptoms on plants residing in about 30 plant families (Booth and Gibson 1973, Peerally 1991). Upon closer inspection, the number of susceptible plant families is actually closer to 100, and includes about 335 plant host species (Crous 2002). The plant hosts include important forestry, agricultural, and horticultural crops, and the impact of these plant pathogens has likely been underestimated.

Perithecia and ascospores, indicative of the perfect state of *Ca. morganii*, may occasionally be produced, but they are rare. Far more common are the imperfect spore stages of *Cy. scoparium*, which in addition to microsclerotia, include the fairly long, uniquely-shaped conidia, which have a single septation. Both of these spore types are much more likely to be produced under conditions of high humidity and rainfall and can be spread by wind and rain.

Cylindrocladium spp. can also survive drought and cold as microsclerotia for up to several years in infected and dead plant tissues and in infested soil (Overmeyer et al. 1996). When seedling roots come in contact with the microsclerotia, the microsclerotia germinate and infection occurs. Inadvertent transport of microsclerotia is the main means by which this fungus is distributed to new environments.

Hodges and May (1972) first identified *Ca. morganii* in Brazil, although at that time, they called it by its imperfect name *Cy. scoparium*. In 1993, Crous et al. (1993) found the teleomorph and gave it the name *Calonectria morganii* (to honor Dr. Morgan). Since 1973, it has received a lot of attention in the forest nurseries of Brazil but has never been so intensively studied as in recent years. Alfenas et al. (2013) published a report on *Ca. metrosideri*, which was given that name because it was an exceptionally aggressive pathogen growing on and occasionally killing some ʻōhiʻa lehua seedlings growing in a nursery in Vicosa. Subsequent work has shown that there are at least another 24 new species in the *Ca. morganii* complex of phylogenetic species, and most of these are expected to be highly pathogenic on the Myrtaceae (A. Alfenas, Univesidade Federal de Viçosa, Viçosa Brazil, personal communication).

At present, the only key to disease control is the use of healthy cuttings, seedlings, and plants. One way to deal with *Calonectria* populations in a nursery is to swap nursery locations (Thies and Patton 1966) or to simply insist that soil substrates used in beds or for potting media are free of the microsclerotial propagules. Although these microsclerotia are resistant to many common fungicides, good control has been achieved by using tabuconazole, epoxyconozole, tetraconazole, triamendol, and a mix of epoxyconozole and pyraclostrobin (Alfenas et al. 2004).

Specific information relating to risk elements:

A. Likelihood of introduction

1. Pest with host-commodity at origin potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d, e, g, h)

The transportability of *Ca. morganii* has been clearly demonstrated by the fact that it can colonize basically any part of a small host plant. It is capable of infecting a broad range of host plants, several of which are brought to Hawaiʻi as cut plants and some as whole plants. Its highly viable microsclerotia can survive in a dormant state for years in organic matter or soil; so potentially this pathogen could be introduced into Hawaiʻi in infested soil, as well as through a broad range of plants.

2. Entry potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d)

Calonectria morganii can colonize any part of a plant, so it could be brought into Hawaiʻi on any infected plant. Also, its ability to form microsclerotia, which can survive in infested soil for long periods of time and endure great drought, and its tolerance of a wide range of pH make it hard to sanitize with many fungicides.

3. Colonization potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c, e)

The capacity of this fungus to colonize host plants will vary by the species of plant being infected, the physiological condition of that plant, and the environmental conditions that are prevailing at the time that infection is taking place. Some susceptible tree species are found in abundance in Hawaiʻi nurseries where the environmental conditions will be optimal for infection by this pathogen.

The exact colonization potential cannot be known, but the fact that natural Hawai'i forests are largely populated with species in genera that have been shown to be highly vulnerable to fungi in the *Ca. morganii* complex suggest that the colonization potential might be fairly high.

The greatest opportunity for colonizing wide areas of Hawai'i would come through the infestation of nurseries. Nurseries, with their millions of young susceptible plants per acre and high soil and air humidities, provide the perfect conditions for a rapid buildup of this pathogen and the formation of large numbers of microsclerotia.

4. Spread potential: **High** (RC) (Applicable rating criteria, from app. 4: b, c, d, e, f)

Spread under natural forest circumstances in most parts of Hawai'i would not be especially high because air conditions are not near the point of saturation much of the time. However, Hawai'i nurseries are producing fairly large numbers of seedlings of tree species that are susceptible to *Ca. morganii*, and if several crops of infected seedlings were to be produced, the subsequent distribution of these seedlings might quickly hasten the distribution of this fungus around the islands. This spread potential could easily be reduced to **moderate** by using nursery practices that would limit the buildup and distribution of the microscletrotia.

B. Consequences of introduction

5. Economic damage potential: **Moderate** (RC) (Applicable rating criteria, from app. 4: b, d, f)

Loss of flower production and wood for timber could have some economic impact in Hawai'i. Damage to landscape trees around the islands may have more significant impacts. Because of the wide host range of *Ca. morganii,* introduction to Hawai'i could result in quarantines put in place by a number of countries of potential export goods.

6. Environmental damage potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: d)

The capacity that this fungus has to destroy seedlings of eucalypts is quite substantial (Alfenas et al. 2013). However, this is under nursery conditions, which are conducive to the development of this fungus. If introduced into Hawai'i, impacts on native forests could be significant. If 'ōhi'a lehua were to be a host of *Ca. morganii*, damage to native forests across the islands could affect water quantity and quality, as well as wildlife habitat.

7. Social and political considerations: **Low** (MC) (Applicable rating criteria, from app. 4: none)

Although it is not known if *M. polymorpha* may be a host of *Ca. morganii*, if the pathogen was introduced and infected *M. polymorpha,* some public concern could be raised similar to that raised during the 1960s and 1970s when *M. polymorpha* underwent dramatic diebacks. Impacts to *D. viscosa* may receive somewhat less public concern because of its more limited distribution across the islands.

C. Pest risk potential

High (Likelihood of introduction = **high**; Consequences of introduction = **moderate**)

Although this brief pest risk analysis has focused on *Ca. morganii*, there are two other closely related species of *Calonectria* that might also present a tremendous problem for Hawai'i. One of these is *Ca. metrosideri*, which was found vigorously attacking (and commonly killing) a large proportion of 'ōhi'a lehua seedlings in a nursery in Viçosa, Brazil (Alfenas et al. 2013). This fungus was slightly less pathogenic on *Metrosideros tremuloides*. The other is *Ca. pauciramosa*, which has an even more global distribution than *Ca. morganii*, and which has been a dominant pathogen in nurseries of South Africa and Australia (Crous 2002, Lombard et al. 2010a).

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Reviewers' comments: "In Malaysia, on seeds of *Maesopsis eminii* and *Shorea roxburghii*" (Su See Lee)

"*Cy. reteaudii* is a major foliar pathogen of eucalypts in areas of high humidity and frequent rainfall in SE Asia, particularly in Vietnam. Old KM, Wingfield MJ & Yuan ZQ. 2003. A Manual of Diseases of Eucalyptus in South East

Asia. CIFOR, Bogor, Indonesia; Thu PQ et al. 2010. Healthy plantations. A field guide to pests and pathogens of *Acacia*, *Eucalyptus* and *Pinus* in Vietnam. DEEDI, Queensland, Australia." (Su See Lee)

Response to comments: References for report on seeds in Malaysia added to text and bibliography. Reference for *Cy. reteaudii* on *Acacia*, *Eucalyptus,* and *Pinus* in Vietnam added.

Fomitiporia spp.

Assessor: Jessie A. Glaeser

Scientific names of pests: *Fomitiporia australiensis* M. Fisch., J. Edwards, Cunningt. & Pascoe, *F. mediterranea* M. Fisch., *F. punctata* (Pilát) Murrill–species complex, *F. robusta* (P. Karst.) Fiasson & Niemelä–species complex, *F. sonorae* (Gilb.) Y.C. Dai.

F. australiensis, *F. punctata*, and *F. robusta* make up a cluster of sibling species with *F. mediterranea* that are genetically distinct but cannot be distinguished using traditional characters, including fruiting body macro- or microscopic morphology (Fischer 2000, Fischer et al. 2005). The taxonomy of *Fomitiporia* is largely unresolved with many new species being described by phylogenetic analysis from what used to be the *F. punctata* and *F. robusta* species complexes (Amalfi and Decock 2013, 2014; Amalfi et al. 2012; Brazee 2013; Campos-Santana et al. 2013; Decock et al. 2005, 2007; Fischer 2006; Ota et al. 2014; Pollastro et al. 2000; Terashima 2013; Vlasák and Kout 2011). *Fomitiporia sonorae* is a member of the *F. robusta* complex (Gilbertson and Ryvarden 1987). Because of this taxonomic uncertainty, the host lists and geographical distributions reported in the older literature are highly suspect. Three of these "species"—*F. mediterranea*, *F. australiensis*, and *F. punctata*—have been associated with the white heart rot associated with esca disease of grapes (*Vitis vinifera*), in Australia and Europe. A pest risk assessment has been prepared for esca disease by the Centre for Agricultural Bioscience International (CABI 2011c).

Scientific names of hosts: The genus *Fomitiporia* is widespread on conifers and hardwoods worldwide. Hosts that have been associated with *F. australiensis* and the *F. punctata* and *F. robusta* species complexes include:

Acacia spp. (wattle), *Acer negudo* (box elder), *Actinidia chinensis* (Chinese gooseberry), *A. deliciosa* (kiwi fruit), *Celtis* spp., *Cornus mas* (Cornelian cherry), *Corylus* spp., ***Dodonaea viscosa*** (hop bush), *Eucalyptus* spp., *Fraxinus excelsior* (European ash), *Juniperus phoenicea* (Phoenician juniper), *Lagerstroemia indica* (Indian crepe myrtle), *Laurus nobilis* (sweet bay), *Ligustrum* spp. (privet), ***Myoporum acuminatum*** (waterbush), *Olea europaea* (olive), *Pinus halepensis* (aleppo pine), *Quercus* spp. (oak), *Rhamnus cathartica* (common buckthorn), *Robinia* spp., *Salix* spp. (willow), *Sorbus aucuparia* (European mountain ash), *Syringea vulgaris* (lilac), *Vitis vinifera* (grapevine), *Ulex* spp. (gorse) (CABI 2011c, Decock et al. 2007, Farr and Rossman, n.d.; Fischer 2002, Fischer et al. 2005)

Distribution: *Fomitiporia australiensis* is limited to Australia and has been reported only on *V. vinifera* and *Dodonaea viscosa* (Fischer et al. 2005). *Fomitiporia mediterranea* is found on numerous hardwood hosts in Italy and southern Europe, but seems to be confined to *V. vinifera* throughout the rest of Europe. The *F. punctata* and *F. robusta* species complexes are widespread in tropical, semitropical, and temperate climates, and are polyphyletic, consisting of many undescribed and newly described species. *Fomitiporia sonorae*, reported as a possible root rot pathogen on *D. viscosa* in Arizona, is part of the *F. robusta* species complex (Gilbertson and Ryvarden 1987). *Fomitiporia punctata* has been reported on *Acacia* in Portugal and is cosmopolitan on *Myoporum accuminatum* (Farr and Rossman, n.d.).

Summary of natural history and basic biology of the pests: These species of *Fomitiporia*, including those in the *F. robusta* and *F. punctata* species complexes, are strong white-rot fungi of both living and dead hardwoods. *Fomitiporia sonorae* is associated specifically with dead and dying *D. viscosa* and fruits at the base of dead and dying plants, suggesting that it could be a root rot pathogen (Gilbertson and Ryvarden 1987). Esca disease of grapes is the most economically important disease associated with *Fomitiporia* and has been the focus of most research on the basic biology of the pathogen (Fischer 2000). The fruiting bodies of *Fomitiporia* species are perennial and long lived (Fischer 2002). In Central Europe, spore production by *F. mediterranea* occurs throughout the year with maximum spore production occurring when average daily temperatures are above 10 °C. Fruiting body formation is preceded by a vegetative phase, where the fungus grows within the host for several years. Dispersal of the fungus is believed to be airborne, through the production of basidiospores. Genetic testing through the use of random amplified polymorphic DNA (RAPD) markers and somatic incompatibility types have revealed a large degree of genetic diversity of *F. mediterranea* within Italian vineyards, indicative of sexual reproduction, even when fruiting bodies were not observed in large numbers within the vineyard. That amount of genetic diversity did not indicate that the pathogen was spread by root grafts or pruning utensils. It is thought that other hosts outside of the vineyards could be the source of airborne spores (Cortesi et al. 2000, Fischer 2002) as these fungi have a broad host range. Basidiospores enter the tree through wounds. Decay is evident in the trunk and in the main branches and is usually associated with older plants. Mycelium and basidiospores may also survive in the soil (CABI 2011c). Fruiting bodies are resupinate (crust-like) and difficult to observe. They form on standing, mostly dead, plants or plant parts, and can persist on dead standing or fallen trees, stumps, or branches (Fischer 2002, Fischer and Kassemeyer 2003). *Fomitiporia mediterranea* is able to act as a primary pathogen. Artificial inoculations have resulted in white rot formation within 2 years at the infection site (Sparapano et al. 2000). The fungus can survive and be transmitted in the bark, stems, sapwood and heartwood of infected hosts, as well as infested soil (CABI 2011c).

Specific information relating to risk elements: Pest risk assessments for root-, sapwood- and heart-rots (Kliejunas et al. 2001) and for esca disease (CABI 2011c) are available in the literature and were consulted in assessing risk elements.

A. Likelihood of introduction

1. Pest with host-commodity at origin potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d, e, g, h)

Root- and stem-rot fungi have a good chance of being present in the heartwood or sapwood when logs are harvested and could survive drying if kiln temperatures are not uniform during the drying process. They could also survive saprotrophically in wood chips and noncomposted mulch. Most stem decays are associated with older plants, so "Plants for Planting" seedlings are probably not an issue, although esca disease seems to be spreading throughout the world with the establishment of viticulture. Mycelium and spores could be present in soil.

2. Entry potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d)

These fungi are capable of surviving saprotrophically and would remain viable during transport. They would be difficult to detect, especially if being transported in the mycelial stage within wood. Fruiting bodies are dark, resupinate, and difficult to observe.

3. Colonization potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c)

To become established, the pathogen would have to fruit, and wind-dispersed basidiospores would need to find susceptible hosts. Many *Fomitiporia* species are distributed throughout tropical and subtropical areas and have broad host ranges, so conditions in Hawai'i would favor fruiting and spore release from infected material.

4. Spread potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c, d, f, g)

Wind dispersal of spores is the common means of spread for most basidiomycete decay fungi. This has been demonstrated for *Fomitiporia* through genetic testing, which has shown that esca disease of grapes is spread by air dispersal of basidiospores rather than by root grafts or infected pruning tools. The disease has followed the establishment of viticulture throughout most countries where wine is produced. Eradication efforts are difficult, as the disease takes many years to become established and is often confused with other declines and saprotrophic wound decays.

B. Consequences of introduction

5. Economic damage potential: **Moderate** (VC) (Applicable rating criteria, from app. 4: a, b, c)

These *Fomitiporia* species would threaten Hawai‘i native plants, including *Dodonaea*, *Acacia*, and *Myoporum*, which are important components of the native forest and also landscape trees. These fungi would also threaten the small Hawai‘i viticulture industry.

6. Environmental damage potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d)

The danger towards native Hawai‘i plant species is significant, resulting in direct impacts on those species (*Acacia*, *Dodonaea*, and *Myoporum*). These fungi have broad host ranges and could affect other trees in native forests and landscapes, thus indirectly affecting the health of native species.

7. Social and political considerations: **High** (VC) (Applicable rating criteria, from app. 4: a, d) Damage from the organisms and subsequent death or decline of native Hawai‘i tree species would result in public concerns in aesthetics and recreation, as well as in urban plantings. Removal of affected trees would have limited acceptance by the public.

C. Pest risk potential:

High (Likelihood of introduction = **high**; Consequences of introduction = **high**)

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Reviewers' comments: "The table presentation (as used in tables [10] and [11]) showing distribution and reference attached per species is helpful." (DJE338).

Response to comments: The description of distribution and hosts of *Fomitiporia* species was kept in a textual format. Many of the described species are actually polyphyletic species complexes that will be changing as more research is conducted on this genus.

Guava Rust/Eucalyptus Rust

Assessor: Phil Cannon

Scientific names of pest: *Puccinia psidii* Winter (anamorph = *Uredo psidii*)

Synonyms/ variants of the *P. psidii* sensu lato complex: *Aecidium glaziovii* P. Henn., *Bullaria psidii* G. Winter (Arthur & Mains), *Caeoma eugeniarum* Link, *Puccina grumixamae* Rangel, *P. rochaei* Putt., *P. actinostemonis* H.S. Jackson & Holway, *P. barbacensis* Rangel, *P. brittoi* Rangel, *P. camargoi* Putt., *P. cambucae* Putt., *P. eugeniae* Rangel, *P. jambolana* Rangel, *P. jambosae* P. Henn., *P. neurophila* Speg., *Uredo cambucae* P. Henn., *U. eugeniarum* P. Henn., *U. flavidula* Wint., *U. goeldiana* P. Henn., *U. myrciae* Mayor, *U. myrtacearum* Paz., *U. neurophila* Speg., *U. puttemansii* P. Henn., *U. rangelii* J.A. Simpson, K. Thomas & C.A. Grgurinovic, *U. rochaei* Putt., *U. seclua* H.S. Jackson & Holway

Scientific names of hosts: About 130 species in 45 genera of the family Myrtaceae (including the former Heteropyxidaceae) are hosts for *P. psidii* (Carnegie and Lidbetter 2012, Clark 2011, Simpson et al. 2006). All genera in the family are potentially susceptible (Old et al. 2003). Some economically or environmentally important genera with species affected by the rust include *Eucalyptus* (eucalypts), *Eugenia* (Surinam cherry; others, including the endangered *Eugenia koolauensis*), *Melaleuca* (paperbark tree), ***Metrosideros*** (ʻōhiʻa lehua), *Myrciaria* (jaboticaba), *Pimenta* (allspice), *Psidium* (guava), *Syzygium* (rose apple).

Distribution: First reported in 1884 on guava in Brazil (Winter 1884), the rust has since been detected in other South America countries (Argentina, Colombia, Paraguay, Uruguay (Telachea et al. 2003), Venezuela); Central America (Costa Rica and Panama); the Caribbean (Cuba, Dominica, Dominican Republic, Jamaica [MacLachan 1938] Puerto Rico, Trinidad and Tobago, Virgin Islands); Mexico (Gallegos and Cummins 1981); the United States including Florida [Marlatt and Kimbrough 1979], California [Zambino and Nolan 2011], and Hawaiʻi [Uchida et al. 2006]); and most recently Australia (Carnegie et al. 2010), Japan (Kawanishi et al. 2009), and South Africa (Roux et al. 2013). It has been reported once in Taiwan (Wang 1992) but has not been found there since. Very recently it has been found in New Caledonia (Giblin 2013).

Summary of natural history and basic biology of the pests: *Puccinia psidii* is an autoecious, macrocyclic rust fungus that infects plants of the family Myrtaceae. Evidence of host specialization exists within the pathogen, so isolates from one host genus may or may not infect other genera within Myrtaceae (Old et al. 2003). Many variants have been recognized and collectively are known as the *P. psidii* sensu lato (s.l.) complex (Carnegie et al 2010). The complex includes the newly described taxon *Uredo rangelii*, which was detected in Australia in April 2010.

Under natural conditions, *P. psidii* produces abundant urediniospores, with teliospores and basidiospores being relatively rare. Aecia and aeciospores are morphologically identical to the uredinia and urediniospores (Glen et al. 2007). The dominant phase of the life cycle is the production of uredinia and urediniospores, with the urediniospores being responsible for aerial spread and infection. The urediniospores infect young tissues of new leaves, fruits, flowers, shoots, and succulent twigs. Infection first appears as chlorotic specks that develop into uredinial pustules, which produce yellow masses of urediniospores. The uredial pustules—pale yellow to yellow-orange dusty spots, 0.1 to 0.5 mm in diameter—often coalesce, and parts of the plant can be completely covered with pustules (Liberato et al. 2006). Uredinia occur mostly on the underside of leaves, on stems, and on flowers and fruit. Urediniospores are globose and ellipsoid to ovoid in shape, measuring 19 to 27 by 15 to 26 µm. The spore cell walls are echinulate, hyaline to yellowish in color, and 1.5 to 2.5 µm thick with germ pores obscure (Hernández 2006).

Urediniospore germination and infection are affected by temperature, leaf wetness, light intensity, and photoperiod (Ruiz et al. 1989). Temperatures in the range of 15 to 25 °C favor infection (Carvalho et al. 1994, Ruiz et al. 1989). High humidity or leaf wetness and low light for a minimum of 6 hours following inoculation are necessary for successful germination and infection (Piza and Ribeiro 1988, Ruiz et al. 1989).

The rust pathogen causes deformation of leaves, defoliation of branches, dieback, stunted growth, and sometimes death. *Puccinia psidii* s.l. has caused severe damage in some years on *Pimenta dioica* (allspice) in Jamaica (MacLachlan 1938), *Eucalyptus grandis* (Junghans et al. 2003) and *Psidium guajava* (guava) in Brazil (Ribeiro and Pommer 2004), *Syzygium jambos* (rose apple) in Hawaiʻi (Uchida and Loope 2009), and *Melaleuca quinquenervia* in Florida (Rayachhetry et al. 1997). Several races or biotypes of *P. psidii* exist, differing in host specificity, environmental tolerances, characteristics of sporulation and spore survival, and virulence (Glen et al. 2007, MacLachlan 1938, Marlatt and Kimbrough 1979). Studies by Costa da Silva et al. (2014) have demonstrated that these different strains of *P. psidii* can have remarkably different levels of pathogenicity on a given host species such as *Metrosideros polymorpha*. Based on analysis of microsatellite markers, *P. psidii* populations from South America are distinct from the rust populations that became established in California and Hawaiʻi, suggesting that the Hawaiʻi and California isolates did not come directly from South America (Graça et al. 2011b).

Quarantine restrictions are the most effective means of preventing introductions of potentially virulent strains of *Puccinia psidii* (Loope and La Rosa 2008). In 2007, the Hawaiʻi State Board of Agriculture passed an interim rule, which banned any plant or plant products of the Myrtaceae family from California, Florida, and South America that could be disease hosts; the ban expired, however, 1 year later (Loope 2010). A long-term rule is in development. The ban includes any plants of the Myrtaceae family (GISD 2010b).

Specific information relating to risk elements:

A. Likelihood of introduction

1. Pest with host-commodity at origin potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c, d, e, g, h)

The rust has a wide host range, and can infect basically any part of the aerial parts of a myrtaceous plant, including succulent tissue in leaves, flowers, and small-diameter branches. It does not colonize seed, but it can infect capsules; seed produced on eucalypts may have chance contamination with infections that might be taking place on the same or neighboring trees from where the seed collections take place.

2. Entry potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c, d)

Recent introductions of the rust to Australia, California, Florida, Hawaiʻi, and Japan are evidence that the biological characteristics of *P. psidii* make it a pathogen easily moved to new environments. The most dangerous pathway for spread of the pathogen to a new region is by germplasm, including rooted cuttings and other vegetatively propagated trees, seed, and pollen (Old et al. 2003). In 2007, *P. psidii* arrived in Japan, on *Metrosideros polymorpha* cuttings imported from Hawaiʻi. The likelihood of this fungus being introduced on a living seedling of the family Myrtaceae or a recently cut branch or flower would be high.

3. Colonization potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c, e)

The potential for *P. psidii* to colonize new hosts in Hawaiʻi has already been demonstrated. One introduction of the pathogen into Honolulu resulted in spread to, and colonization of, hosts on all of the major islands within 6 months (Killgore and Heu 2007). The moist tropical and montane tropical climate of Hawaiʻi is an ideal environment for *P. psidii* infection.

4. Spread potential: **High** (RC) (Applicable rating criteria, from app. 4: a, b, c, d, e, f)

The occurrence of numerous Myrtaceae in Hawaiʻi, the rust's known ability for natural spread, and its high reproductive potential would result in a high spread potential. The current strain of the rust in Hawaiʻi has spread to all parts of the state that have a favorable environment for infection.

B. Consequences of introduction

5. Economic damage potential: **High** (RC) (Applicable rating criteria, from app. 4: a, c. d, e, f)

Currently, only a single *P. psidii* genotype has been found in Hawai‘i; introduction of new *P. psidii* genotypes to Hawai‘i represents an additional threat to native and exotic myrtaceous species by potentially increasing the host range and the severity of the disease.

There are many species of Myrtaceae in Hawai‘i (about 80) and, so far, 37 of these have shown that they are susceptible, at least to some degree, to the strain of *P. psidii* currently in Hawai‘i. One species, *Syzygium jambos*, an invasive species that occupies tens of thousands of hectares in the Hawai‘i Islands, is exceptionally vulnerable to this strain of the rust; especially on the more humid sides of the Hawai‘i Islands. The endangered *Eugenia koolauensis* has also shown a high vulnerability to this strain of the rust. Fortunately, most other Myrtaceous species—including *Metrosideros polymorpha,* which is very widely distributed in Hawai‘i and comprises about 80 percent of the native forests—have shown only a slight susceptibility to this strain of the rust.

This situation could change substantially if other strains of the rust were introduced into Hawai‘i. Costa da Silva et al. (2014) have shown that some of these strains can be especially virulent on *M. polymorpha* under environmental conditions favorable for the development of the fungus.

There is probably very little financial loss that would occur directly as a result of having less lumber being produced from ‘ōhi‘a lehua trees; this species is not used significantly for wood products, in part because only a very small percentage of its trees reach merchantable dimensions; however, a massive loss of ‘ōhi‘a lehua trees, which currently comprise about 80 percent of all trees in Hawai‘i's native forests, could have some very unfortunate environmental consequences (see next section), and some of these could be costly.

6. Environmental damage potential: **High** (MC) (Applicable rating criteria, from app. 4: a, b, c, f)

Eucalyptus rust threatens to disrupt ecosystems by causing damage to dominant forest trees, such as the ‘ōhi‘a lehua in Hawai‘i. The ‘ōhi‘a lehua tree is a cornerstone species in the natural forests of Hawai‘i and most of the islands native fauna have evolved to live in these ‘ōhi‘a lehua forests. Outbreaks of *P. psidii,* which affect these dominant trees could result in significant changes to the structure, composition, and potentially, the function, of forests on a landscape level. This would likely affect the biodiversity of other flora and fauna in these ecosystems (Loope and La Rosa 2008).

7. Social and political considerations: **High** (MC) (Applicable rating criteria, from app. 4: a, b, c)

Presence of the current strain of *P. psidii* in Hawai‘i has affected export of hosts to countries where the rust is not yet present. Occurrence of additional strains would increase public concern and export restrictions.

C. Pest risk potential:

High (Likelihood of introduction = **high**; Consequences of introduction = **high**)

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Reviewers' comments: "Most recent report is from Africa."

Response to comments: The 2013 citation for report in South Africa was added, as was a report of the pathogen in New Caledonia.

Pestalotia and *Pestalotiopsis*

Assessor: Gregg DeNitto

Scientific names of pests: see table 9

Scientific names of hosts: see table 9

Distribution: see table 9

Summary of natural history and basic biology of the pests: *Pestalotia* and *Pestalotiopsis* contain numerous species of pathogens, endophytes, and saprophytes; however, the taxonomy of the species and of the two genera is poorly understood and under debate (Maharachchikumbura et al.2011). There is differing mycological opinion whether these genera are distinct (Maharachchikumbura et al. 2011). *Pestalotiopsis* is a common genus on a wide range of hosts in tropical and temperate climates (Maharachchikumbura et al. 2011, Yang et al. 2012).

When these species occur as pathogens they commonly affect leaves or fruit. They cause leaf blights and spotting and fruit rot. Often fruit rot occurs postharvest during storage and transport (Kwon et al.2004). They are usually considered weak pathogens, often found on stressed or weakened host plants (Pirone 1978).

A sexual stage for many of these species has not been identified. Initial infection usually occurs from conidia contact with the host. Secondary infections can occur and increase disease severity. Conidia disperse in the air and in rain splash. Maharachchikumbura et al. (2011) provide a generalize disease cycle for *Pestalotiopsis. Pestalotia* likely has a similar life cycle.

Specific information relating to risk elements:

A. Likelihood of introduction

1. Pest with host-commodity at origin potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d, e, g, h)

Many of the species of *Pestalotia* and *Pestalotiopsis* have a wide host range and are usually found associated with foliage and other nonwoody green tissue. They are among the most commonly isolated endophytic fungi of tropical plants (Yang et al. 2012). These same authors state that, globally, *Pestalotiopsis* may represent one of the largest biomasses of any plant-associated endophytic fungus.

Table 9 —Hosts, country of origin, and citations, for *Pestalotia* and *Pestalotiopsis* species of concern

Pathogen	Host(s)	Country of origin	Citation
Pestalotia acaciae Thüm. (Xylariales: Amphispaeriaceae)	***Acacia crassicarpa, A. longifolia, A. comosus****, Chamaecyparis pisifera, Cucumis sativus,* ***Diospyros kaki****, Durio zibethinus, Musa* spp., *Pachira macrocarpa, Pinus thunbergii, Quercus glauca*	Australia, China, Japan, Philippines, Portugal	Farr and Rossman, n.d.
Pestalotia angustata (Pers.) Arx (syn. Truncatella angustata (Pers.) S. Hughes)	*Vaccinium* spp.	Chile	Espinoza et al. 2008
Pestalotia cibotii R.P. White (Xylariales: Amphisphaeriaceae)	***Cibotium schiedei****, Araucaria imbricata, Illicium verum*	United States (New Jersey), China, Scotland	White 1935
Pestalotia diospyri Syd. & P. Syd. (syn. *Pestalatiopsis diospyri* (Syd. & P. Syd.) Rib.) Souza (Xylariales: Amphisphaeriaceae)	***Diospyros chinensis, D. kaki, D. kaki* var. *domestica, D. peregrina****, Euonymus alatus, E. japonicus, E. sieboldianus, Podocarpus macrophyllus, Rhus javanica, R. javanica* var. *roxburghii, Smilax china*	China, India, Japan, Korea, Spain	Blanco et al. 2008; Farr and Rossman, n.d.; Kobayashi 2007
Pestalotia dodonaea Canonaco (Xylariales: Amphisphaeriaceae)	***Dodonaea viscosa***	Eritrea, Ethiopia	Farr and Rossman, n.d.
Pestalotia pandani Verona (Xylariales: Amphisphaeriaceae)	***Pandanus tectorius, P. tessellatus, P. pedunculatus*** var. ***stradbrookeensis, P. pedunculatus f. lofuensis, P. odoratissimus***	Taiwan, Cook Islands, Australia, Loyalty Islands	Farr and Rossman, n.d.; McKenzie and Hyde 1996
Pestalotia vaccinii (Shear) Guba (Xylariales: Amphisphaeriaceae)	***Vaccinium angustifolium, V. ashei, V. australe, V. corymbosum, V. macrocarpon, Vaccinium* sp., *V. stamineum***	New Zealand, United States (Maine, Michigan), Latvia	Farr and Rossman, n.d.; Vilka et al. 2009
Pestalotiopsis sp. (Xylariales: Amphisphaeriaceae)	***Scaevola hainanensis***	Hong Kong	Farr and Rossman, n.d.
Pestalotiopsis breviseta (Sacc.) Steyaert (Xylariales: Amphisphaeriaceae)	***Vaccinium ashei****, Viburnum awabuki,* ***Diospyros kaki* var. *domestica****, Podocarpus macrophyllus, Prunus tomentosa, Rhaphiolepis umbellata, Rhododendron ponticum, Arenga engleri, Celastrus orbiculatus, Cercis chinensis, Trochodendron aralioides*	Japan, United States, Russia, Italy	Farr and Rossman, n.d.; Kobayashi 2007

Table 9 —Hosts, country of origin, and citations, for *Pestalotia* and *Pestalotiopsis* species of concern (continued)

Pathogen	Host(s)	Country of origin	Citation
Pestalotiopsis clavispora G.F. Atk. (Xylariales: Amphisphaeriaceae)	***Vaccinium* spp**.	Chile	Espinoza et al. 2008
*Pestalotiopsis glandicola (*Castagne) Steyaert (syn. *Robillarda glandicola* Cast.; *Pestalotia glandicola* (Castagne) Guba) (Xylariales: Amphisphaeriaceae)	***Diospyros kaki, Pandanus tectorius****,* *Quercus ilex, Q. acuta, Mangifera indica,* ***Vaccinium oldhamii***; numerous others	China, India, Japan, Bangalore	Farr and Rossman, n.d.; Kobayashi 2007; Ullasa and Rawal 1989; Yasuda et al. 2003
Pestalotiopsis neglecta	***Vaccinium* spp.**	Chile	Espinoza et al. 2008
Pestalotiopsis palmarum (Cooke) Steyaert (Xylariales: Amphisphaeriaceae)	***Pandanus whiteanus***	American Samoa	Brooks 2006
Pestalotiopsis photiniae (Thüm.) Y.X. Chen (Xylariales: Amphisphaeriaceae)	*Acer palmatum, Camellia japonica, C. sasanqua, C. sinensis, Dendrobium devonianum, D. thyrsiflorum, Fragaria spp., Photinia glabra, P. serrulata, Pinus massoniana, Podocarpus macrophyllus, P. nagi, Roystonea regia, Taxus chinensis****, Vaccinium angustifolium, Vaccinium* spp.**	Australia, China, Japan, Korea, Viet Nam	Farr and Rossman, n.d.
Pestalotiopsis theae (Sawada) Steyaert (syn. *Pestalotia theae* Sawada) (Xylariales: Amphisphaeriaceae)	***Diospyros kaki, D. kaki* var. *domestica, Diospyros* sp., *D. samoensis****, Camelia sinensis, Illicium religiosum, Turpinia ternate;* numerous hosts	Asia, Australia, Europe, USSR, Africa, South America	Farr and Rossman, n.d.; Kobayashi 2007; Watson 1971
Pestalotiopsis uvicola (Speg.) Bisset (Xylariales: Amphisphaeriaceae)	***Metrosideros kermadecensis***	Italy	Grasso and Granata 2008
Pestalotiopsis versicolor (Speg.) Steyaert (Xylariales: Amphisphaeriaceae)	***Pandanus tectorius****, Tamarindus indica,* ***Acacia melanoxylon,*** *Oryza sativa, Musa* sp., *Jatropha curcas, Mangifera indica*; numerous hosts	Europe, Australia, South America, Central America, Asia, Africa, Papua New Guinea, Solomon Islands, Caribbean Islands	Farr and Rossman, n.d.

It is probable that inoculum can increase rapidly through secondary infections when environmental conditions are met. Once infection occurs, these fungi can survive easily within host tissue; conidia can survive during harsh weather conditions (Maharachchikumbura et al. 2011). Likely pathways for introduction include cut foliage, live plants, fruit, and live cuttings.

2. Entry potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d)

They can readily survive transport in infected leaves or fruit with limited symptoms expressed. For example, *P. longiseta* was isolated from blackberry seedlings with shoot blight shipped from the United States to Japan (Dai et al. 1990). Detection of leaf spots or fruit rot from these fungi is difficult, especially in larger shipments of foliage and foliage-bearing material.

3. Colonization potential: **Moderate** (VC) (Applicable rating criteria, from app. 4: b, e)

Most of the host plants of concern exist at or near likely ports of entry. Because of the wide host range of some of the species, it is possible other species could become infected around ports with subsequent spread to the host species of concern in this report. Weather conditions favorable for infection occur most of the year. Conidia of these fungi are known to spread through the air to cause infection.

4. Spread potential: **High** (RC) (Applicable rating criteria, from app. 4: a, c, d, e, f)

These fungi spread readily and rapidly through the air and in rain splash. Spread distance is not known but may be considerable. Spread between islands may be limited unless human movement of infected material occurs.

B. Consequences of introduction

5. Economic damage potential: **Low** (RC) (Applicable rating criteria, from app. 4: f)

These fungi are generally not known as significant pathogens in their native range. The hosts of concern have limited direct economic benefit and, except for some ornamental plantings, are not commercially produced. Control techniques for these fungi would be limited to greenhouse and potted plant situations.

6. Environmental damage potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: d) Damage from these fungi is limited and does not normally result in significant growth or mortality impacts. Some of the hosts of concern have limited distribution; therefore, if they were to become infected, some ecosystem damage might occur.

7. Social and political considerations: **Low** (MC) (Applicable rating criteria, from app. 4: none)

Most damage from the presence of these fungi would be aesthetic. None of the hosts are currently involved in any trade. It is unlikely their presence in Hawai‘i would cause significant public response.

C. Pest risk potential:

Moderate (Likelihood of introduction = **moderate**; Consequences of introduction = **moderate**)

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Reviewers' comments: A reviewer was interested in pathways that these fungi might follow.

Response to comments: Likely pathways were identified in the IPRA.

Phellinus noxius

Assessor: Jessie A. Glaeser

Scientific name of pest: *Phellinus noxius* (Corner) G. Cunn.
Synonym: *Fomes noxius* Corner
Phellinidium noxium (Corner) Bondartseva & S. Herrera

Scientific names of hosts: More than 120 genera and nearly 300 species of tropical forest, plantation and landscape trees, and woody shrubs. Economically important plantation hosts of *P. noxius* include the conifer genera *Araucaria* and *Pinus*, and the hardwood genera *Eucalyptus*, *Swietenia,* and ***Acacia***. Other economically important crops include *Artocarpus altilis* (bread fruit), *Camellia sinensis* (tea), *Elaeis guineensis* (oil palm), *Heavea brasiliensis* (rubber), and *Theobroma cacao* (cocoa). Host lists are available at the Crop Protection Compendium (CABI 2011d) and the Global Pest and Disease Database (CIPM 2012b). Genera of Hawai'i native plants that are known to be susceptible include ***Acacia, Diospyros*** and ***Erythrina***. The species within these genera that have been reported as hosts are *A. aulacocarpa*, *A. auriculiformis*, *A. confusa, A. crassicarpa*, *A. decurrens*, *A. mangium*, *A. mearnsii*, *D. decandra*, *D. ferrea* var. *buxifolia*, *D. kaki*, *D. oldhamii*, *D. samoensis*, *E. variegata*, and *E. variegata var. orientalis* (CIPM 2012b). The pathogen is nonspecialized with a very broad host range. Other Hawai'i native plants may prove to be susceptible but have not yet been exposed to the pathogen.

Distribution: *Phellinus noxius* is pantropical and subtropical. It has been reported in east and central Africa, east and southeast Asia, Australasia and the South Pacific, including many of the islands, Central America and the Caribbean, but not from North or South America (Hodges 2005). It is found on species of *Acacia* in Taiwan and the Solomon Islands, on *Diospyros* in Taiwan, and on *Erythrina* in and from Japan (Farr and Rossman, n.d.).

Summary of natural history and basic biology of the pests: *Phellinus noxius* causes a severe root rot in many different tree species throughout the tropics and subtropics. It occurs within native forests but is particularly damaging in plantations of forest trees and commercial crops, such as breadfruit, rubber, cocoa, and oil palm (Pegler and Waterston 1968). The fungus is a strong white rotter, although it is commonly referred to as "brown root rot" owing to the dark color of the fungal mycelium and fruiting body. Two forms of fruit bodies, only forming after extended periods of rainfall, can be produced. The resupinate form is smooth, flat, and grows flush with the underside of logs or roots. The bracket form—with a dark brown to black, rough textured, upper surface, and a charcoal grey undersurface—can be leathery or woody and hard. The most striking characteristic of the disease is the presence of a brown encrustation, composed of fungal mycelium and incorporated soil and debris, that covers the surface of colonized roots. This crust grows toward the root collar of the tree and may be visible above ground level, in some cases reaching 2 m or more from the root collar. It can eventually girdle the tree and kill the cambium and sapwood (Brooks 2002b). Dark lines are present in the wood resulting from the presence of pigmented hyphae. The fungus can colonize both sapwood and heartwood of most hosts. The wood eventually becomes light, dry, and friable and honeycombed; windthrow is common in trees with advanced root decay. The disease is often first recognized by an overall wilting of the canopy or a more gradual dieback owing to loss of water transport by the root system. The fungus can survive for up to 10 years in colonized roots and stumps after the death of the host but declines quickly in the absence of wood debris or in heavy, wet soils. One type of preventive control measure is to flood fields before the establishment of new plantations (Chang 1996).

The principal mode of infection among neighboring trees is by root-to-root contact (Hattori et al. 1996, Lewis and Arentz 1988). Fruiting bodies are often rare or absent, depending on the specific host but may form on dead and dying trees and stumps. Airborne basidiospores can initiate new infection centers on freshly cut stumps or through wounds on living trees, with subsequent spread to neighboring trees through root to root contact (Hattori et al. 1996). Although asexual conidiospores have been formed in culture, they do not appear to occur in the field (Brooks 2002a). Differences in virulence have been detected from within the same host and between different hosts (Nandris et al.1987, Nicole et al. 1985, Sahashi et al. 2010). The fungus does not seem to exhibit host specificity or physiological specialization. Cross inoculation studies with isolates from 12 different hosts were able to uniformly colonize all 12 hosts (Chang 1995). Woody horticultural species vary greatly in their susceptibility to *P. noxius* (Ann et al. 1999).

Phellinus noxius is present in many isolated islands in the Pacific, and has likely been introduced there by human activities. On the island of Rota, the oldest disease center is located next to the airport and was likely introduced through imported woody material (Hodges and Tenorio 1984).

Phellinus noxius is also associated with a serious heart rot problem in young plantations of *Acacia mangium* in Malaysia (Lee and Yahya 1999, as described by Hodges 2005). In this host, the disease manifests as a heartrot that may extend for several meters within the tree. Infection occurs from airborne basidiospores through pruning wounds or broken branches. Pathways for possible introduction would include seedlings grown in infested soil, soil, and wood products.

Specific information relating to risk elements: *Phellinus noxius* is the subject of previous pest risk assessments (Hodges 2005; Kliejunas et al. 2001, 2003). Information summaries also appear in the Global Invasive Species Database (GISD 2006), the Crop Protection Compendium (CABI 2011d), and the Global Pest and Disease Database (CIPM 2012b). *Phellinus noxius* is on many different targeted pest lists, including the CAPS FY2012 Priority

Pest List–Commodity and Taxonomic Surveys List, and the CAPS FY2009 Pest of National Concern, and is considered of quarantine significance (CIPM 2012b).

A. Likelihood of introduction

1. Pest with host-commodity at origin potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d, e, g, h)

Phellinus noxius can colonize roots, sapwood, and heartwood of affected plants, and has a good chance of being present when logs are harvested. It could also survive saprotrophically in wood chips and noncomposted mulch. Seedlings could transmit the pathogen if they are grown in infested soils. Mycelium and spores could be present in soil.

2. Entry potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d)

The fungus is capable of surviving saprotrophically in wood or in soil and would remain viable during transport. It would be difficult to detect, especially if being transported in the mycelial stage within wood. Fruiting bodies are relatively conspicuous when present, but they can be remarkably rare or even totally absent in many cases.

3. Colonization potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c, e)

To become established, the pathogen would have to fruit and wind-dispersed basidiospores would need to find susceptible hosts. Conditions in Hawai‘i would favor fruiting and spore release from infected material, and the broad host range would make it likely that the fungus could become established. It is likely that this has already occurred on other Pacific islands (Hodges and Tenorio 1984).

4. Spread potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c, d, e, f, g)

Wind dispersal of spores is the common means of spread for most basidiomycete decay fungi. This has been demonstrated for *P. noxius*, where it has been shown that tree-to-tree spread is usually through root contact but that disease centers are initiated with genetically diverse basidiospores (Hattori et al. 1996, Lewis and Arentz 1988). Eradication efforts are difficult since the disease takes many years to become established, and the indicative brown crust may escape notice.

B. Consequences of introduction

5. Economic damage potential: **Moderate** (VC) (Applicable rating criteria, from app. 4: a, b, c, d, e, f) *Phellinus noxius* would threaten Hawai‘i native plants, including species of *Acacia*, *Diospyros*, *Erythrina*, and possibly others. These are important components of the native forest and also landscape trees. The very broad host range of *P. noxius* would make this fungus also a threat to other commodities, forests, and landscape plantings.

6. Environmental damage potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c, d, e, f) The danger towards native Hawai‘i plant species is significant, resulting in direct impacts on those species (*Acacia, Diospyros,* and *Erythrina*). The fungus has a broad host range and could affect other trees in native forests and landscapes, thus indirectly affecting the health of native species. Eradication program would involve large-scale tree destruction and probably not be effective once the fungus becomes established in the soil.

7. Social and political considerations: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c, d) Damage from *P. noxius* and subsequent death or decline of native Hawai‘i tree species would result in public concerns in aesthetics and recreation as well as in urban plantings. Removal of affected trees would have limited acceptance by the public. *Phellinus noxius* is not yet present in North America, and its broad host range includes many important ornamental species. Introduction of the fungus to Hawai‘i would interfere with domestic interstate commerce, trade, and traffic.

C. Pest risk potential:

High (Likelihood of introduction = **high**; Consequences of introduction = **high**)

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Reviewers' comments: "CABI doesn't reference its host lists so is useful as a starting point but probably better to use referenced hosts. I would also be cautious about using the word 'complete'." (DJAE)

"I suspect this record is incorrect as current records state it is absent from New Zealand. Will have confirmation after Oct 3." (DJAE)

"Certain fungal synonyms are incorrect." (Yuko Ota)

"I could not find the result showing "in light, well-drained soils" in Chang's paper." (Yuko Ota)

"I could not find the result that there is no evidence of root decay and no external mycelial sheath in *Acacia mangium* in Malaysia in Lee and Yahya, 1999 or that tree growth was not affected." (Yuko Ota)

"Additional literature suggested." (Yuko Ota)

Response to comments: The word "complete" has been removed in connection with the list of hosts. New Zealand has been removed as a geographic location of the pathogen pending confirmation. Fungal synonyms were rechecked and corrected. The reference to "light, well-drained soils" has been removed. It was an inference based on the authors' data about decay in heavy, wet soils. This information has been deleted pending reexamination of the original paper. The reference by Sahashi et al. 2010 was added.

Pink Disease

Assessor: Jessie A. Glaeser

Scientific names of pest: *Erythricium salmonicolor* (Berk. & Broome) Burds.

Synonym: *Phanerochaete salmonicolor* (Berk. & Broome) Jülich

Aleurodiscus javanicus Henn.

Botryobasidium salmonicolor (Berk. & Broome) Venkatar.

Corticium javanicum (Henn.) Sacc. & P. Syd.

Corticium salmonicolor Berk. & Broome

Corticium zimmermannii Sacc. & P. Syd.,

Necator decretus Massee

Pellicularia salmonicolor (Berk. & Broome) Dastur

Terana salmonicolor (Berk. & Broome) Kuntze

The taxonomic position of this fungus has been debated; some authors still recognize *Phanerochaete salmonicolor* as the current name. Molecular biosystematic studies (Diederich et al. 2011, Ghobad-Nejhad et al. 2010, Roux and Coetzee 2005) have shown that it groups with other species of *Erythricium* in the Corticiales. *Phanerochaete* is now known to be in the Polyporales (Wu et al. 2010) so is not closely related.

Scientific names of hosts: More than 140 species in 104 genera including those from the following families: Annonaceae, Apocynaceae, Aquifoliaceae, Bombacaceae, Buxaceae, Casuarinaceae, Euphorbiaceae, Fabaceae, Magnoliaceae, Malvaceae, Moraceae, Myrtaceae, Oleaceae, Pittosporaceae, Rosaceae, Rubiaceae, Rutaceae, Sterculiaceae, Theaceae, and Verbenaceae. Important commodity crops include *Hevea brasilliensis* (rubber), *Coffea* spp. (coffee), *Camellia sinensis* (tea), *Theobroma cacao* (cocoa); fruits such as *Citrus* spp., *Malus* spp., and *Litchi chinensis*; woody ornamentals such as *Cercis canadensis*, *Gardenia* spp., and *Ilex* spp.; commercial forest plantations species such as *Eucalyptus* spp., ***Acacia*** spp., and *Paraserianthes falcataria* (Hodges 2004). ***Erythrina*** spp. include *Erythrina lithosperma, E. subumbrans* (India) (CABI 2012; Farr and Rossman, n.d. *Acacia* spp. include *A. confusa*, *A. mangium*, *A. auriculiformis*, *A. aulacocarpa, A. crassicarpa, A. decurrens,* and *A. mearnsii* (Farr and Rossman, n.d.; Old and Davidson 2000).

Distribution: Throughout the humid tropics of Africa, Southeast Asia, Australasia, Oceania, some Pacific Islands, Central America, South America, and North America. In North America, it is present in Florida, Louisiana, and Mississippi. It has not been reported from American Samoa, Guam, Hawai'i, Northern Mariana Islands, or Puerto Rico (Hodges 2004).

Summary of natural history and basic biology of the pests: Pink disease, caused by the fungus *Erythricium salmonicolor*, is widely distributed in the tropics and subtropics but appears to cause serious disease only in areas that receive over 2000 mm of rain per year (Seth et al. 1978). The fungus has a very wide host range and would be a danger to most endemic tree species. It can infect and colonize intact, healthy trees (Old et al. 2003) by forming stem and branch cankers. In general, young trees (2 to 8 years old in rubber, 2 to 6 years old in cocoa) are affected more severely than older trees (Brown and Friend 1973, Holliday 1980). The main stem of young trees can be girdled entirely, causing repeated dieback and possible tree mortality. Nongirdling cankers are formed in older, larger trees, decreasing growth and increasing susceptibility to branch breakage and other agents of mortality. *Eucalyptus* plantations in India have suffered 100 percent mortality from pink disease (Seth et al. 1978), although the disease is not that severe in other areas. In Brazil, it is estimated that citrus crop production is reduced 10 percent by pink disease (Sebastianes et al. 2007). Disease incidences of 80 percent or more have been reported in *Albizia* (Eusebio et al. 1979), cocoa (Schneider-Christians et al. 1986), and *Eucalyptus* (Deo et al. 1986). Pink disease is considered one of the main threats to new timber plantations in Indonesia (Hadi et al. 1996).

Hyphal growth is seasonal and favored by rain. The fungus survives through dry periods in dormant cankers (Luz 1983). The fungus initially colonizes the outer bark surface and enters into the xylem through lenticels or wounds. Four different growth stages have been observed, termed “cobwebby,” “pustule,” “necator,” and “pink incrustation.” Growth appears initially as a thin layer of vegetative mycelium on the bark surface during wet weather. Pink to salmon-colored pustules and crusts, composed of sterile tissue, form rapidly on the bark and in bark cracks. Cankers develop as the fungus colonizes and kills the inner bark, cambial layer, and outer layers of xylem, leading to the death of branches and small stems. Fruiting occurs as host tissues are dying. Initially the asexual “necator” stage consists of orange sporodochia that form hyaline, unicellular, ellipsoid conidia (10 to 18 by 6 to 12 μm) (Mordue and Gibson 1976). Conidia are probably distributed by rain splash and air currents. The importance of this stage varies with host (CABI 2012). Conidia were recorded in less than 3 percent of infected cocoa branches in Western Samoa (Schneider-Christians et al. 1986) but were considered the main means of spread, by rain splash, on apples in China (Leng et al. 1982). The conidia are viable for up to 20 days in dry weather, but high humidity is required for germination. The conidial stage is followed by the “pink incrustation” stage under conditions of high rainfall (Giambelluca et al. 2012). This is the sexual stage of the fungus; basidiospores are hyaline, ellipsoid, inamyloid, and measure 10 to 13 by 6 to 9 μm (Mordue and Gibson 1976). Basidiospores are also dispersed by rain splash and by air currents (Ciesla et al. 1996). Release of basidiospores occurs after the basidioma has become thoroughly wetted, usually 20 to 80 minutes after heavy rainfall begins. High humidity or heavy dew is not sufficient to trigger spore release. Basidiospore release continues for up to 14 hours after rainfall has stopped (Schneider-Christians et al. 1986). Basidiospores rapidly lose viability under conditions of low humidity and may only be viable for 24 hours after release (Hodges 2004, Kliejunas et al. 2001) but are thought to be more important than conidia in spreading the disease in some crops (Almeida and Luz 1986). Relative production of basidial and conidial stages on infected apple trees is influenced by air temperature and relative humidity (Verma 1991). Optimum air temperature for growth is 28 °C (Shamsuri et al. 1997). Vegetative propagules may also spread as colonized bark flakes from the tree (Seth et al. 1978), and the fungus can most likely survive in the soil. It can remain viable for lengthy periods of time when affected branches are removed from the tree (CABI 2012). In more temperate climes, the fungus overwinters as dormant mycelium and sterile pustules (Leng et al. 1982).

The genetic and pathogenic variability of the *E. salmonicolor* is not well understood. Culture filtrates from two different isolates of *E. salmonicolor* collected from different parts of India showed differential responses on *Eucalyptus* shoots, suggesting differences in pathogenicity (Sharma et al. 1988). RAPD analysis of 19 isolates of *E. salmonicolor* from different regions of Brazil, primarily from citrus but also from fig, apple, and *Psidium cattleianum*, revealed six different genetic groupings. There was no correlation of clades with pathogenicity, geographic region, or host. The same study showed that isolates from different hosts could undergo hyphal anastomosis, demonstrating that gene flow can occur between isolates from different hosts (Sebastianes et al. 2007). Phylogenetic analysis of ribosomal large subunit DNA has shown that isolates from Egypt and South Africa grouped closely together in a subclade, separate from isolates from South America and Asia, but this was with a limited number of isolates (Roux and Coetzee 2005).

Centre for Agricultural Bioscience International (2012) predicts that the plant parts most likely to carry the fungus in trade/transport include bark, leaves, and stems, including shoots, trunks, and branches. Kliejunas et al. (2001) also suggested that long-distance transport of logs and wood chips could harbor the fungus because it invades and kills outer layers of sapwood.

Specific information relating to risk elements:

Pest risk assessments for *E. salmonicolor* are available in the literature (CABI 2012, Hodges 2004, Kliejunas et al. 2001, Starr et al. 2007) and were consulted in assessing risk elements.

A. Likelihood of introduction

1. Pest with host-commodity at origin potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d, e, g, h)

Pink disease is widespread throughout the tropics and subtropics on many different hosts including common agricultural commodities. A high incidence of disease only occurs in climates with very high levels of rainfall, but the fungus can survive in soil and sapwood under drier conditions. As the fungus spreads by both conidia and basidiospores, and because it has many potential hosts in forests, landscape plantings, agricultural and agroforestry, it has a high potential for large-scale population increases. Mycelia and sterile pustules can survive in cankers, cracks in the bark, and on the surface of both living and dead trees, allowing a prolonged release of numerous generations of spores.

2. Entry potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d)

Transit of logs, mulch, soil, or colonized rootstock will not affect fungus survival once it is established. The likelihood of detection by inspectors is low unless plant material is dead. Pustules are relatively small, although their pink color may attract the attention of inspectors. The fungus can grow through the sapwood in addition to bark and cambium (Subramaniam and Ramaswamy 1987). Transport of materials in sealed containers will result in humid conditions that are favorable for fungal fruiting and spore development.

3. Colonization potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c, d, f)

Pink disease has a very wide host range with many hosts that are widespread throughout Hawai‘i in agriculture and landscape plantings. As the fungus is widespread throughout the tropics, it has already demonstrated the ability to become established outside of its native distribution, which is unknown. There is a high probability of finding favorable climatic conditions in Hawai‘i. The most suitable environment for colonization is probably on the southern and eastern sides of the islands where rainfall is greater than 2000 mm per year (Giambelluca et al. 2012). Spores could probably spread to suitable habitat from ports in drier areas by westerly wind currents.

4. Spread potential: **High** (VC) (Applicable rating criteria, from app. 4: a, c, d, e, f, g)

Spread potential is high in the areas of the islands with high rainfall as spores can be spread by both rain splash and air currents. Host presence will not be a limiting factor because of the extremely large host range, providing a continuous distribution of host species. Newly established populations may go undetected for years owing to the cryptic nature of the pathogen; initial infections may only appear as minor dieback or a few dead branches before larger trunk cankers are evident. Control techniques have been developed for some high-value crops using fungicides, but widespread application of fungicides in native forests is not possible and would probably not be effective at eradication.

B. Consequences of introduction

5. Economic damage potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c)

Introduction to Hawai‘i could result in significant damage to agricultural crops as well as native species. The fungus can result in tree death or predispose trees to mortality by other agents. The development of dead trees, dead branches or large stem cankers will reduce value of landscape plantings. Significant impact is expected in the floriculture industry.

6. Environmental damage potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d)

Introduction to Hawai‘i would expose susceptible native plants with limited distributions to colonization by this fungus, resulting in severe losses in areas of high rainfall. Organism is expected to have direct and indirect impacts on species listed by federal and state agencies as endangered, threatened, or candidate, including death of hosts and disruption of sensitive or critical habitat.

7. Social and political considerations: **High** (VC) (Applicable rating criteria, from app. 4: a, d)

Damage by this organism to native plants would cause public concern. This concern would extend to agricultural, forest and landscape plantings as well as native plants. The widespread application of fungicides as a control measure would not be accepted by the public, although application to specific agriculture crops or certain high-value individual trees would be accepted.

C. Pest risk potential:

High (Likelihood of introduction = **high**; Consequences of introduction = **high**)

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Reviewers' comments: None received.

Ramorum Blight/Sudden Oak Death

Assessor: Phil Cannon

Scientific name of pest: *Phytophthora ramorum* Werres, de Cock, & Man in't Veld

Scientific names of hosts: *Phytophthora ramorum* is a generalist pathogen with a broad and diverse host range. See APHIS (2013c) for the current list of regulated hosts (naturally infected by *P. ramorum* and Koch's postulates completed) and associated hosts (found naturally infected, and *P. ramorum* has been cultured and detected using PCR, but Koch's postulates have not been completed or documented and reviewed).

Of the 13 taxa of concern in Hawai‘i, 3 have been identified as potential hosts of *P. ramorum*, namely ***A. koa***, ***L. tameiameiae***, and ***Vaccinium*** spp. (Reeser et al. 2008).

Distribution: The native distribution of *P. ramorum* is not known; it has recently been introduced, separately, to the United States, Canada, and Europe. Current known distribution includes (CABI 2014, EPPO 2014, Sansford et al. 2009):

Canada (British Columbia), restricted to nurseries, subject to official control.

Europe—under regulatory control. Belgium (nurseries, parks), Croatia (imported plants), Czech Republic (imported plants), Denmark (imported plants, garden centers), Estonia (imported plants, garden center, eradicated), Finland (imported plants, garden center), France (nurseries), Germany (nurseries, garden centers, forests, parks), Greece (nurseries), Ireland (nurseries, garden centers, parks, forests), Italy (nurseries), Latvia (imported plants, absent), Lithuania (nurseries), Luxembourg, Netherlands (nurseries, parks), Norway (imported plants, nurseries, gardens), Poland (imported plants, nurseries), Portugal, Serbia (parks), Slovenia (nurseries, garden centers), Spain (imported plants, nurseries), Sweden (imported plants), Switzerland (nurseries), and the United Kingdom (Channel Islands, England, Wales, Scotland) (nurseries, garden centers, parks, forests). In many cases, these introductions have stayed largely in nurseries and garden centers, but in Belgium, Germany, Ireland, Luxembourg, the Netherlands, Norway, Serbia, and the United Kingdom, these introductions have led to invasions of managed parks, gardens, or in some cases, forest plantations and wildlands (most notably in *Larix kaempferi* in the United Kingdom).

United States, subject to official control.

California: established in the environment and quarantined in the counties of Alameda, Contra Costa, Humboldt, Lake, Marin, Mendocino, Monterey, Napa, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, and Trinity. Regulated in the remainder of the state.

Oregon: established in the environment and under quarantine in about 106 ha within Curry County. Regulated in the remainder of the state.

Washington: periodically detected in nurseries; detected in streams or ditches in seven western counties (Kitsap, King, Clallam, Clark, Lewis, Pierce, and Thurston) (Omdal and Ramsey-Koll 2013). Regulated in the state.

Infected nursery stock has been detected and destroyed in the following states: Alabama, Arkansas, Arizona, California, Colorado, Connecticut, Florida, Georgia, Louisiana, Maryland, Mississippi, New Jersey, New Mexico, New York, North Carolina, Oklahoma, Oregon, Pennsylvania, South Carolina, Tennessee, Texas, Virginia, and Washington (APHIS 2005). The number of nursery detections through March 31, 2014, was 543 (APHIS 2014).

Has been detected in nurseries and waterways in nine other states, but has been contained and under eradication: Alabama, Florida, Georgia, Maryland, Mississippi, New Jersey, North Carolina, Pennsylvania, South Carolina (Kliejunas 2010, Oak et al. 2013).

Phytophthora ramorum is a member of *Phytophthora* Clade 8c. Populations in North America and Europe are clonal and belong to four distinct lineages (NA1, NA2, EU1, and EU2). NA1, NA2, and EU1 have been identified in the United States (Van Poucke et al. 2012).

Summary of natural history and basic biology of the pest: *Phytophthora ramorum* is a fungus-like micro-organism (Kingdom Stramenophila: Class Oomycetes), related to diatoms and brown algae. In culture, the pathogen is identified by the production of large, abundant chlamydospores and elongated, ellipsoidal, semipapillate, deciduous sporangia (Werres and Kaminsky 2005, Werres et al. 2001). Motile, asexual, zoospores are produced in the sporangia. *Phytophthora ramorum* is heterothallic and has two mating types, A1 and A2.

The pathogen was first isolated from ornamental rhododendrons in Germany and the Netherlands in 1993 (Werres and Marwitz 1997), and subsequently from dying *Notholithocarpus densiflorus* and *Quercus* spp. in California in 2000 (Rizzo et al. 2002). *Phytophthora ramorum* was formally described in 2001 (Werres et al. 2001).

Symptoms produced by *P. ramorum* are diverse and depend on the host and host part infected. In general, the pathogen causes three different diseases with differing symptoms. Stem cankers are formed on oaks and tanoaks in native forests of the western coastal United States. Some of these cankers can produce bleeding lesions and may be lethal. Leaf blight and branch dieback symptoms develop in *Rhododendron* spp., *Pieris* spp., *Rhamnus* spp. and certain conifer species. Branches develop cankers with associated leaf lesions. Leaf spots, blotches, and scorch are produced in some hosts with no associated branch damages. These lesions often have an irregular margin. *Umbellularia californica* and *Sequoia sempervirens* are species that show these symptoms (Grünwald et al. 2008, Hansen et al. 2002). On some hosts, notably *L. kaempferi* in forests and plantations in England and Wales, foliage infection and twig blight has led to extensive tree mortality (Webber et al. 2010). The pathogen has been isolated from asymptomatic host tissue, including roots of tanoak seedlings (Parke et al. 2006), stems and roots of rhododendron (Bienapfl et al. 2005), and leaves of rhododendron (Werres et al. 2001), camellia (Shishkoff 2006), holm oak (Denman et al. 2009), and Japanese larch (Brasier and Webber 2010).

Phytophthora ramorum is considered a cool-temperature organism, with optimal growth between 18 and 22 °C (Werres et al. 2001). The pathogen produces sporangia on the surfaces of infected leaves and twigs of foliar hosts that can be splash-dispersed to neighboring hosts (Davidson et al. 2002, 2005), or spread longer distances by wind and rain (Davidson et al. 2005, Hansen 2008). *Phytophthora ramorum* is also spread downstream of infested areas in rivers and streams and can be carried in infested soil. Long-distance dispersal occurs primarily through the movement of infected plant material moved in trade, primarily commercial nursery trade (CABI 2014). Inoculum production occurs under a wide range of temperature and moisture conditions. In one study, zoospores were produced at a range of temperatures from 5 to 25 °C, with the highest numbers produced at 15 to 20 °C. The optimum germination range was 20 to 30 °C (Kliejunas 2010).

Upon contact with a suitable host and environment, the sporangia germinate to produce zoospores that encyst, penetrate the host, and initiate a new infection. The presence of free water or high humidity favors zoospore germination and infection (Garbelotto et al. 2003). Chlamydospores are readily produced in infected plant material and can survive up to 12 months in potting media and soil substrate. (Osterbauer 2010). They may serve as resting structures in soil, allowing the pathogen to survive adverse conditions. Examination of chlamydospore production and survival in *Umbellularia californica* leaves, however, identified large numbers of chlamydospore production depending on site, but germination was not observed (Fichtner et al. 2009). Moisture is essential for survival and sporulation, and the duration, frequency, and timing of rain events plays a key role in inoculum production (Kliejunas 2010).

Like most *Phytophthora* species, *P. ramorum* survives during conditions unfavorable for growth—such as hot, dry summer months in California—in host tissues or in various nonhost substrates (such as soil, and potting media) as hyphae or as asexual structures (Kliejunas 2010).

Specific information relating to risk elements

Research on sudden oak death through 2009 has been summarized (Kliejunas 2010). Previous risk assessments have been completed for *P. ramorum* in North America (Kliejunas 2003), the United States (Cave et al. 2008), the state of Oregon (Osterbauer 2010), Canada (CFIA 2012), the United Kingdom (Sansford et al. 2003), the European Union (EPPO

2013; RAPRA 2009), Norway (Sundheim et al.2009), and Australia (online at http://pbt.padil.gov.au).

A. Likelihood of introduction

1. Pest with host-commodity at origin potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c, d, e, g, h).

Phytophthora ramorum appears to have been transported globally with separate introductions at least four times (Grünwald et al. 2012). Plant import data from 2004 to 2010 indicated 30,125 units of high-risk plants arrived in Honolulu (APHIS 2011). This was the third leading port of entry in the United States. Nursery stock, cut flowers and greenery commonly arrive in Hawai‘i from areas of California where there has been some history of *P. ramorum* occurrence. The quantity of material imported into Hawai‘i from the regulated area was not available for this assessment. Some of this material might possibly be infected or might carry *P. ramorum* spores. Identified host species from quarantined areas of California and Oregon cannot be exported except with an APHIS-provided certificate or from nurseries with compliance agreements with APHIS. Although this material has a high chance of receiving a phytosanitary check upon arrival in Hawai‘i, inoculum and diseased material could still go undetected. Some of the known hosts have few if any easily identifiable symptoms and could be missed during inspections.

Recent regulations by APHIS permit nurseries outside of regulated and quarantined areas in the United States to move host plants interstate unless *P. ramorum* has been detected at the nursery in the previous 3 years (on or after March 31, 2011) (APHIS Order DA-2014-02). Similarly, nurseries within regulated areas of California, Oregon, and Washington will be allowed to move host plants interstate as long as *P. ramorum* has not been detected in the nursery on or after March 31, 2011 (APHIS Order DA-2014-02).

There is also interest in transferring conifer seedlings currently growing in nurseries not too far outside of *P. ramorum*-infested parts of the west coast of the mainland United States into Hawai‘i. Hawai‘i is interested in starting its own Christmas tree program using conifers from the west coast. This shipment would be very carefully monitored for *P. ramorum* and other pathogens and would come from nurseries outside the current *P. ramorum* quarantine zone; so the risk of this leading to the introduction of the pathogen into Hawai‘i should be low.

2. Entry potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c, d)

Phytophthora ramorum can colonize most aerial parts of a plant and could therefore be brought into Hawai‘i on any infected plant. A fair, but unknown, amount of movement of plant species is vulnerable to leaf infections. However, phytosanitary regulations for this pathogen are in place for west coast nurseries, and Hawai‘i regulators are looking for *P. ramorum* symptoms. Symptoms, though, may not be easily observed on some hosts. The possible introduction on wood products or seed should be close to nil.

3. Colonization potential: **High** (VC) (Applicable rating criteria, from app. 4: a, b, c, e)

The ability of this fungus to infect plant species in Hawai‘i has not been thoroughly evaluated. A small test with some of Hawai‘i’s more significant native species (including koa (*Acacia koa*), ohelo (*Vaccinium calycinum*), ohia (*Metrosideros polymorpha*), and pukiawe (*Leptocophylla tameiameiae*) indicated that all of these species could be affected by *P. ramorum* when inoculated with a heavy load of zoospores under environmental conditions conducive for infection. However, *P. ramorum* could be re-isolated from a few of the inoculated leaves of ohelo, koa, and pukiawe (Reeser et al. 2008). Of these four potential hosts, only *L. tameiameiae, M. polymorpha,* and *A. koa* have ranges that coincide with known air and maritime ports (Price et al. 2012).

One feature of this pathogen that would make it unlikely to colonize forests in Hawai‘i is that below 700 m or above 1500 m sea level, temperatures for the growth and sporulation of this pathogen will be outside its optimal range of 18 to 22 °C. Much of Hawai‘i is too dry for this pathogen to likely establish. However, there are a number of areas on several of the islands where rainfall amounts are significant, exceeding 2500 mm annually and generally equally distributed year round. This includes the islands of Hawai‘i, Kauai, Maui, and O‘ahu (Giambelluca et al. 2013).

Areas that receive international travel and imports with higher levels of rainfall (>1600 mm annually) within 6.4 km include Hilo, Honolulu, and Kahului (Giambelluca et al. 2013). Elevations with higher levels of rainfall range from near sea level to over 1.2 km. There may be some areas in Hawai'i that are at risk because of having both favorable temperatures and humidity.

4. Spread potential: **High** (RC) (Applicable rating criteria, from app. 4: a, b, c, d, e, f)

Once established around some port areas, this pathogen could spread into native forests in more moist areas of Hawai'i. Long-distance spread of the pathogen through human-assisted movement has been identified based on genetic analysis of distant infection sites in California (Grünwald et al. 2012). The amount of inoculum produced by hosts in Hawai'i is not known, so the spread potential into native forests is not known. Areas where spread could occur would most likely be located between 1000 and 1400 m above sea level on the windward side of each of the Hawai'i Islands. Of course, even then, the species in the forest would also need to be susceptible to infection and capable of supporting spore production as well. We know the susceptibility of only a few of the most common Hawai'i species to *P. ramorum* to date, and although most of those that were tested were susceptible to colonization to some degree, the conditions used for these tests were extraordinarily favorable for pathogen development (Reeser et al. 2008). Reeser et al (2008) felt that most plant species would be susceptible to leaf infections with the environmental conditions that were used. Within limited localities of Hawai'i where environmental conditions are conducive for *P. ramorum* infection and sporulation (approximately 18 to 22 °C temperature and extended periods with high humidity), there might be small areas of Hawai'i that meet the climatic requirements for this pathogen. But, even then, these areas would have to be composed of a number of trees of species that were susceptible before there was any risk as well, and it is likely that these areas will be fairly localized. Mid-elevation sites on the windward (rainy) sides of Hawai'i and Kaua'i might be among the most likely locations to be wary of some *P. ramorum* activity if there are susceptible species growing in these areas.

5. Economic damage potential: **High** (RC) (Applicable rating criteria, from app. 4: b, c, d, f)

In California, of the 150 species that have shown some susceptibility to *P. ramorum*, only 5 have any propensity at all for developing lethal cankers, the most common way that this pathogen can kill. Recent identification of a foliage blight causing mortality of *L. kaempferi* in the United Kingdom (Brasier and Webber 2010) suggests the possibility that other hosts could be affected similarly. Grünwald et al. (2012) noted that *P. ramorum* has had significant impacts on forests because of reductions in recreational, cultural, or commodity values and the costs of monitoring and eradication efforts.

This combination of very limited environmental windows where *P. ramorum* would be favored and what will probably prove to be a very limited number of susceptible tree species suggests that the economic damage potential of *P. ramorum* in Hawai'i might be very localized and limited. Also, the economic value of the possible native hosts in Hawai'i is small. However, establishment of the pathogen in the state would affect the international and domestic movement of plants and plant products and result in restrictions in trade and movement. Direct costs of eradication, suppression, and prevention would be high.

6. Environmental damage potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: d)

As there are likely to be only a limited number of locations in Hawai'i and a limited number of species that might be vulnerable within these areas where damage might take place, the environmental consequences are expected to be limited. Furthermore, even if one species is heavily affected in one of these limited areas, there may well be dozens of other tree species that could fill into their space and thereby fulfill some of the other key environmental functions. Some of these species may not fulfill all of the functions or may be nondesirable invasive species.

7. Social and political considerations: **High** (MC) (Applicable rating criteria, from app. 4: a, b, c, d)

As a new exotic invasive pathogen that has killed millions of tanoaks in the San Francisco Bay Area and millions of Japanese larch in the United Kingdom, *P. ramorum* has garnered political and social attention resulting in implementation of quarantines in over 60 countries (Sansford et al. 2003. It has caused a significant legislative and media interest in California, Oregon, and the United Kingdom political arenas; and has caused concern in other U.S. states and European nations. Thus, if even a small population of *P. ramorum* were to get started in Hawai‘i, it would almost certainly cause an immediate alarm amongst Hawaiians and trading partners.

C. Pest risk potential

High (Likelihood of introduction = **high**; Consequences of introduction = **high**)

Although the pest risk potential for this pathogen is high, the environmental conditions optimal for infection, development, and sporulation by *P. ramorum* are limited to relatively small areas on any of the Hawai‘i Islands. Therefore, the risk may be limited to the wettest, mid-elevation sites, principally on the islands of Hawai‘i, Maui, and Oahu.

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Reviewers’ comments: “This distribution list could be misleading since it doesn’t state if it is nursery, garden, or wildland.” (S. Frankel)

“Not clear what this (infested stock shipped to many states) refers to. What states? Add something about number of US nursery detections and number of states.” (S. Frankel)

“Nurseries in California, Oregon, and Washington were added to the regulation in 2004/5. The risk from nursery stock movement is not just from within the infested counties of California!!” (S. Frankel)

“Can you provide a map of Hawai‘i showing locations of forests with high rainfall and relatively cool temperatures. In all sections, there isn’t much evidence provided for each rating.” (S. Frankel)

“Most of your references and citations are old. There are many review papers (and other papers) that need to be included.” (S. Frankel)

Response to comments: The first three reviewer comments were addressed by clarifying additions to the text. Information on types of situations where *P. ramorum* occurs in various locations was added. Maps with rainfall distribution were evaluated, although not included in this document, and information related to rainfall was added to the assessment. Elevation was used as a proxy for temperature distribution. Several recent review papers were added to the selected bibliography.

Uromyces Rusts

Assessor: Gregg DeNitto

Scientific names of pests: see table 10

Scientific names of hosts: see table 10

Distribution: see table 10

Summary of natural history and basic biology of the pests: Rust fungi, members of the Pucciniaceae, are found around the world, except Antarctica, in both natural and human ecosystems. They are obligate parasites, with either one (autoecious) or two (heteroecious) hosts required for completion of their life cycle. They have been recognized as a group of fungi that cause serious diseases affecting many ornamental plants that are produced commercially (Wise et al. 2004). Spore stages of these fungi are transported naturally either by wind or rain splash. They can be readily moved by transport of infected host tissue, such as cuttings, live plants, and other tissues.

Uromyces truncicola causes a canker of *Sophora japonica* nursery seedlings in Japan (Kusano 1904, Orwa et al. 2009). It is an autoecious, macrocyclic rust fungus. Four spore stages—teliospores, sporidia, pycniospores, and urediospores—are produced (Zinno and Hayashi 1980). Pycniospores develop on cankers in late May to early July. Urediospores follow in early June to mid-July. Teliospores are produced on stem cankers from late July into the fall. Sporidia are produced the following spring and cause the primary infection on new shoots. In addition to seedling cankers, *U. truncicola* causes multiple cankers on older trees, causing branch dieback and eventual tree death (Kusano 1904).

Uromyces sophorae-japonicae and *U. scaevolae* both affect the foliage only. *Uromyces sophorae-japonicae* has been reported to have a life cycle similar to *U. truncicola* with the four spore stages (Kusano 1904). However, all of the spore stages of *U. sophoreae-japonicae* are found on the leaf, blade, or petiole of its host. Information on the biology of *U. scaevolae* could not be found, but it is assumed to have similarities to these other two species.

Sophora japonica is native to China, Japan, and Korea. It is grown as an ornamental species for gardens, parks, and road-side plantings. Several cultivars are available. Exotic plantings include Croatia, Italy, Spain, Thailand, United Kingdom, United States, and Vietnam (Orwa et al. 2009).

Specific information relating to risk elements

A. Likelihood of introduction

Table 10—Hosts, country of origin and citations for *Uromyces* species of concern

Pathogen	Host(s)	Country of origin	Citation
Uromyces scaevolae G. Cunn. (Pucciniales: Pucciniaceae)	*Scaevola albida, Scaevola* sp., *Scaevola spinescens, Selliera radicans*	Australia, New Zealand	Farr and Rossman, n.d.
Uromyces sophorae-japonicae Dietel (Pucciniales: Pucciniaceae)	*Sophora japonica*	Japan	Kusano 1904
Uromyces truncicola Hennings & Shirai (Pucciniales: Pucciniaceae)	*Sophora japonica*	China, Japan, Korea	Kusano 1904, Orwa et al. 2009

1. Pest with host-commodity at origin potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: b, h)

These rust fungi are persistent with their host as long as the host tissue is living. *Uromyces truncicola* is perennial because of its infecting stem tissue, so it is likely to be present on the host year round. The other two species may only be present with their host during the growing season when foliage is on the plant. Rust fungi generally have a high population increase potential, and this is expected with these species. Once these fungi infect their host, mycelium is buried within the tissue and would not be dislodged during any harvesting or handling.

2. Entry potential: **High** (MC) (Applicable rating criteria, from app. 4: b, c, d)

The movement of either infected stems or foliage, depending on the fungal species, could transport these fungi to new areas. Mycelium within host tissue would likely not be a concern with entry, but infective spores that may be carried with the host or be produced upon arrival are the likely forms of subsequent infection. Like many fungi, cursory examination of infected hosts may not reveal their presence because they are microscopic and well concealed. The probability that a pathogen is detected at a port of entry is a function of visible symptoms or signs and the level of inspection sampling. *Uromyces truncicola* may be more apparent because of the hypertrophy of stem tissue that can occur.

3. Colonization potential: **Moderate** (MC) (Applicable rating criteria, from app. 4: b, e)

Sporidia is the only fungal stage to cause new infections. Teliospores can be transported and later germinate to produce sporidia that can then cause new infections. Infection is dependent on the availability of viable sporidia and the proper temperature and humidity requirements of these fungi. Only *Sophora* have been identified as hosts, and it is not known if the native Hawai‘i species are susceptible. The occurrence of *Sophora* near sea level indicates that it can be in proximity to areas of trade.

4. Spread potential: **Moderate** (RC) (Applicable rating criteria, from app. 4: a, c, e, f)

Once infection of native Hawai‘i *Sophora* occurs, it is likely that these fungi could spread farther, at least on the island where they are introduced. Interisland spread is less likely without human assistance.

B. Consequences of introduction

5. Economic damage potential: **Low** (RC) (Applicable rating criteria, from app. 4: f)

None of these fungi cause significant economic damage in their native range. If commercial propagation of *Sophora* species came into existence in Hawai‘i, then it is possible that some economic damage could occur if these fungi were introduced.

6. Environmental damage potential: **High** (RU) (Applicable rating criteria, from app. 4: b, d)

None of these fungi appear to cause significant levels of host mortality unless other stress factors are present. Impacts to other functions of these plants, such as foliage, flower, or seed production, do not seem significant. If branch cankers and dieback became significant, flower and seed production might be affected. This could have a negative effect on the endangered padilla bird.

7. Social and political considerations: **Low** (MC) (Applicable rating criteria, from app. 4: none)

The introduction of any *Uromyces* species that infects *Sophora* would likely not have significant social or political impacts.

C. Pest risk potential:

High (Likelihood of introduction = **moderate**; Consequences of introduction = **high**)

Selected bibliography:

Farr, D.F.; Rossman, A.Y. [N.d.]. Systematic mycology and microbiology [Database]. http://nt.ars-grin.gov/fungaldatabases/. (13 March 2013).

Kusano, S. 1904. Notes on the Japanese fungi. I. Uredineae on *Sophora*. Botanical Magazine Tokyo. 18: 1–6.

Orwa, C.; Mutua, A.; Kindt, R.; Jamnadass, R.; Simons, A. 2009. Agroforestree database: a tree reference and selection guide version 4.0. http://www.worldagroforestry.org/treedb2/speciesprofile.php?Spid=18098. (13 May 2013).

Wise, K.A.; Mueller, D.S.; Buck, J.W. 2004. Quarantines and ornamental rusts. APSnetFeature-2004-0204. doi:10.1094/. (13 August 2013).

Zinno, Y.; Hayashi, H. 1980. Life history of *Uromyces truncicola* causing the canker disease of *Sophora japonica* seedlings. Transactions of the Mycological Society of Japan. 21: 87–95.

Reviewers' comments: None received.

White-Thread Blight/Black Rot

Assessor: Jessie A. Glaeser

Scientific names of pest: *Ceratobasidium noxium* (Donk) P. Roberts
Synonym: *Pellicularia koleroga* Cooke
Corticium koleroga (Cooke) Hőhn
Botryobasidium koleroga Venkatar.

Other species of *Ceratobasidium*, including *C. anceps*, *C. cornigerum*, and two unnamed but phylogenetically distinct species on tea (*Camillia sinensis*) and persimmon (*Diospyros kaki*) from Brazil (Ceresini et al. 2012), all cause similar diseases, termed "white-thread blight" and "black rot." *Ceratobasidium anceps* and *C. cornigerum* are associated with temperate climes (Farr and Rossman, n.d.) and have not been reported on genera of host plants of interest in this pest risk assessment.

Scientific names of hosts: Very wide host range from many families, including economically important crops such as several species of *Citrus*, *Coffea arabica* (coffee), *Hevea brasiliensis* (rubber tree), *Malus domestica* (apple), *Mangifera indica* (mango), *Melia azedarach* (chinaberry), *Piper nigrum* (black pepper), *Theobroma cacao* (cocoa), and *Vanilla planifolia* (vanilla). It is also found on many important ornamental and forest tree species; for a complete list see Farr and Rossman (n.d.). Two phylogenetically distinct species of *Ceratobasidium* on tea (*Camillia sinensis*) and Asian persimmon (***Diospyros kaki***) from Brazil (Ceresini et al. 2012) cause similar disease etiology and may have been reported as *C. noxium* or its synonyms in the older literature. Genera of Hawai'i native plants at particular risk are ***Diospyros*** sp. and ***Erythina*** sp. *Ceratobasidium* white thread pathogens have been reported on *D. texana* in Florida, *D. virginiana* in Louisiana and Tennessee, *D. kaki* from Brazil, and *Erythrina* sp. in Florida (CABI 2011b; Ceresini et al. 2012; Farr and Rossman, n.d).

Distribution: *Ceratobasidium noxium* is widely distributed in tropical and semitropical areas of Asia, Africa, the Americas, Greece, and Oceania, including American Samoa, Fiji, Micronesia, New Caledonia, Papua New Guinea, Samoa, and Vanuatu but has not been observed in Australia or New Zealand. In North America, it has been reported from Indiana but is usually associated with Southern states, including Florida, North Carolina, South Carolina, Louisiana, Mississippi, Texas, Tennessee, and Puerto Rico. (CABI 2011b; Farr and Rossman, n.d.).

Summary of natural history and basic biology of the pests: *Ceratobasidium noxium* and closely related species are responsible for a number of diseases on a wide variety of different hosts in the tropics and subtropics. These diseases have been termed "white-thread disease," "black rot," and "koleroga disease." Although wide-spread, it is usually not an overly destructive pathogen except under narrowly defined environmental conditions. Humidity appears to be the most important parameter for fungal growth and disease development. Heavy mists, poor air circulation, continuous and persistent light showers, and cloudy skies are more conducive to disease development than extremely heavy rainstorms followed by sun. In India, the disease is observed on coffee plants in regions that exceed 152.4 cm of rain per year and is severe only in those areas that experience heavy South West Monsoon rains from June to September or where microclimate provides high humidity for extensive time periods (Mathew 1954). The temperature optimum of *C. noxium* is 22 to 25 °C (Matsumoto and Yamamoto 1934). Cool, humid conditions favor disease development. The fungus is able to infect all portions of the plant including young shoots, leaves, and berries (Mathew 1954).

Disease is characterized by the presence of black, rotting leaves that continue to hang on the branches owing to the presence of mycelial threads that run along the twigs and petioles. Mycelial mats are formed on the lower surfaces of the leaves where both basidiospores and sclerotia are formed. The fungus penetrates the leaves through the stomata on the lower surface and invades the palisade cells and vascular system, thus spreading throughout the plant. Basidiospore formation on coffee is associated with continuous rainfall, but the fungus seems to be spread primarily by mycelial threads carried by wind or by contact from detached, infected leaves. Basidiospores lose viability rapidly on account of desiccation—up to 80 percent of spores lost the ability to germinate after 2 weeks on water agar—and may only be able to infect and colonize highly susceptible hosts in proximity to diseased plants under narrowly defined environmental conditions. The fungus appears to survive dry periods as vegetative mycelium within dead twigs, branches, and wood. The role of sclerotia in spreading the pathogen is unknown; pathogenicity testing using fresh and 1-year-old sclerotia as inoculum on coffee leaves was unsuccessful, but only a small number of plants were used in the experiment (Mathew 1954).

Although the two unnamed species in Brazil are phylogenetically distinct and show host preferences for either tea (*Camillia sinensis*) or Asian persimmon (*Diospyros kaki*), they are able to cause disease on both hosts as well as on coffee and citrus in pathogenicity experiments. Eight varieties of *D. kaki* showed no resistance to the disease (Souza et al. 2009).

Specific information relating to risk elements:

Uncertainties in this assessment are due to a lack of literature on the biology of the fungus. Basic work on disease physiology is restricted to the fungus on coffee (*Coffea arabica)* in India (Mathew 1954) and on Asian persimmon and tea (Souza et al. 2009) in Brazil.

A. Likelihood of introduction

1. Pest with host-commodity at origin potential: **High** (VC) (Applicable rating criteria, from app. 4: b, c, d, g, h)

The fungus has a very broad host range with a very wide geographic distribution in tropical and subtropical regions of the world. It is able to survive in soil and dried plant material, and can also increase its population rapidly under certain environmental conditions through the formation of basidiospores and sclerotia.

2. Entry potential: **High** (RC) (Applicable rating criteria, from app. 4: b, c, d)

Fungus can survive within vascular tissues of the wood as well as in leaves and stems. It is difficult to detect as the mycelial threads are small and only formed during periods of high humidity. The presence of dead leaves could be due to many different causes and would not attract attention.

3. Colonization potential: **High** (RC) (Applicable rating criteria, from app. 4: a, b, c, e)

The worldwide distribution of the pathogen, even to remote Pacific islands, shows that it is capable of colonization and spread after transport.

4. Spread potential: **High** (RC) (Applicable rating criteria, from app. 4: a, b, c, d, f, g)

This pathogen has many potential hosts with overlapping ranges. Newly established populations could go undetected for many years as the disease often occurs at a low level and is limited to geographic areas and times of the year of extreme humidity and rainfall. The eastern, wetter portions of the islands would be particularly suitable for establishment of the fungus. The uncertainty in this criterion is due to the lack of information on the role of basidiospores and sclerotia in establishing the pathogen.

B. Consequences of introduction

5. Economic damage potential: **Moderate** (VC) (Applicable rating criteria, from app. 4: a, b, c)

The pathogen can cause plant death and decreased production in many different economically important host plants.

6. Environmental damage potential: **Moderate** (RC) (Applicable rating criteria, from app. 4: d)

The pathogen is active and causes leaf death and defoliation under conditions of extreme humidity, usually restricted to the monsoon or rainy season. Mortality can occur owing to host decline and predisposing the host to other mortality agents, but the fungus does not appear to be a primary pathogen in most situations.

7. Social and political considerations: **Moderate** (RC) (Applicable rating criteria, from app. 4: a)

The public would become concerned with the formation of dead, rotted leaves on plants in native forests and landscapes.

C. Pest risk potential

High (Likelihood of introduction = **high**; Consequences of introduction = **moderate**)

Selected bibliography:

Centre for Agricultural Bioscience International [CABI]. 2011b. Crop protection compendium: *Corticium koleroga* (thread blight). Wallingford, United Kingdom: CAB International. http://www.cabi.org/cpc. (20 May 2013).

Ceresini, P.C.; Costa-Souza, E.; Zala, M.; Furtado, E.L.; Souza, N.L. 2012. Evidence that the *Ceratobasidium*-like white-thread blight and black rot fungal pathogens from persimmon and tea crops in the Brazilian Atlantic Forest agroecosystem are two distinct phylospecies. Genetics and Molecular Biology. 35: 480–497.

Farr, D.F.; Rossman, A.Y. [N.d.]. Systematic mycology and microbiology [Database]. http://nt.ars-grin.gov/fungaldatabases/. (18 June 2014).

Mathew, K.T. 1954. Studies on the black rot of coffee: I. The disease in South India and some general considerations. Proceedings of the Indian Academy of Sciences-Section B. 39: 133–170.

Matsumoto, T.; Yamamoto, W. 1935. *Hypochnus sasakii* Shirai in comparison with *Corticium stevensii* Burt and *Corticium koleroga* (Cooke) v. Hőhn. Transactions of the Natural History Society of Formosa. 25: 161–175.

Souza, E.C.; Basseto, M.A.; Boliani, A.C; Takada, H.M.; Ceresini, P.C. 2009. Cross pathogenicity of *Ceratobasdium* spp. from kaki (*Diospyros kaki*) and tea (*Camellia sinensis*) and reaction of kaki varieties to the pathogen. Summa Phytopathologica. 35: 9–14.

Reviewers' comments: None received.

Chapter 5: Summary and Conclusions

Summary

Hawai'i is unique amongst the 50 states. As noted in chapter 2, it was formed and developed over the millennia independently of any other land mass. This has resulted in very unique and distinct species and ecosystems on each island. Because of its isolation, the state also has a rare economic situation, with almost all goods needing to arrive from other locations. This status of Hawai'i has been a driver during this assessment and underlies many of the issues the state faces with respect to invasive species.

A major challenge of this analysis was to determine which of the world's 400,000 fungal species and 900,000 insect species known to feed on plant/plant parts are not yet found in Hawai'i and pose a risk to 13 key forest tree taxa in the Hawaiian Islands.

The approach taken for this exercise followed protocols established by the international plant protection community. For each of the 13 Hawai'i forest taxa, we examined the literature and determined the insects and pathogens recorded on them in Hawai'i. We compiled a similar list of insects and pathogens world-wide and not known to occur in Hawai'i and recorded in association with the taxa or other species of the same genera. Although this process may seem straightforward, the lists that were produced of potential pests and pathogens for each of the 13 taxa are considerable in length. For some species, like *Acacia koa*, this process produced lists of literally thousands of fungi and insect species that have been associated with *Acacia* species. This is, in large measure, due to the abundance of land area worldwide covered by the 700 different species of *Acacia* and the fact that thousands of forest health personnel, mycologists, entomologists, etc. have spent large portions of their careers looking at the flora and fauna that affect species in this genus. *Metrosideros polymorpha* was another key species that had numerous fungi associated with it, no doubt because there are so many *Metrosideros* species scattered across the Pacific. By contrast, some of the other species, like *Sophora chrysophylla*, *Myoporum sandwicensis,* and *Scaevola* spp. had very short lists associated with them because their genera are composed of a relatively small number of species, and individuals or pests are underreported owing to their noneconomic nature.

We examined the lists of exotic fungal and insect species for those considered to have capacity to be effective pathogens or pests on living trees. We relied on information presented in the literature, when this was available, and also on the experience of the authors and reviewers of this document. This helped to narrow the list to the about 400 insect pests and 300 pathogens shown in tables 7-1 and 7-2, respectively (app. 7)[1]. These tables represent what we consider the insect pests and pathogens with the most potential for damage to the taxa should they gain entry into Hawai'i.

Besides providing lists of which insects and pathogens have potential to cause damage, it is also important to evaluate the potential for these agents to be introduced and become established in Hawai'i and also the amount of damage they might cause. This evaluation is done via individual pest risk assessments (IPRA). We identified 12 insect pests and 12 pathogens to include in the IPRAs, which represent examples of insects and pathogens found on seeds, roots, bark, sapwood, and heartwood that would have the greatest potential risk to forests and other tree resources of Hawai'i. They are representative of the diversity of insects and pathogens that might inhabit the hosts of concern. By necessity, the IPRAs focus on those insects and pathogens for which biological information was available. The location on the host and a summary of the risk potential for each of the 24 organisms is presented in table 11.

We received over 400 comments on the draft risk assessment. These comments came from people in various agencies and countries identified in appendix 1. Our team is extremely grateful for the time and effort expended by reviewers, who clearly dedicated substantial energy to the review process and provided thoughtful feedback that made our final report much more robust.

The complexity of this project was clearly reflected in many of the comments that we received. Some reviewers felt that the scope of the risk assessment was limited and should be expanded (not all pathways were considered), while others stated that the content was overwhelming and made the document difficult to read. We felt that this project

[1] Appendices for this report are available online at: http://www.fs.fed.us/psw/publications/documents/psw_gtr250/ psw_gtr250_appendix.pdf.

Table 11—Summary of risk potentials for pests of concern to 13 Hawai‘i forest hosts

	Likelihood of introduction				Consequences of introduction			
Common name (scientific name)/location on host	**Host association**	**Entry potential**	**Colonization potential**	**Spread potential**	**Economic damage**	**Environmental damage**	**Social/political**	**Pest risk potential**
Insects								
Apple stem borer (*Aeolesthes holosericea*)/bark/cambium, sapwood, heartwood	H[a]	H	H	H	H	H	M	H
Botany Bay diamond weevil (*Chryosolopus spectabilis*)/roots, foliage/other, bark/cambium	M	H	M	M	M	M	L	M
Coconut rhinoceros beetle (*Oryctes rhinoceros*)/foliage/other	H	H	H	H	M	M	M	H
Coconut stick insect (*Graeffea crouanii*)/foliage/other	M	M	M	L	L	L	M	M
Erythrina scale (*Toumeyella erythrinae*)/foliage/other, bark cambium	M	H	L	M	M	M	M	M
Eugenia psyllid (*Trioza eugeniae*)/foliage/other	M	H	H	M	M	M	M	M
Keyhole ambrosia beetle (*Amasa truncata*)/bark/cambium	H	H	H	H	M	L	M	H
Lemon tree borer (*Oemona hirta*)/bark/cambium, sapwood, heartwood	M	M	H	M	M	M	L	M
Platypodid ambrosia beetle (*Megaplatypus mutatus*)/bark/cambium	M	H	H	H	M	M	M	M
Summer fruit tortrix moth (*Adoxophyes orana*)/foliage/other (fruit surface)	H	H	H	H	M	H	M	H

Table 11—Summary of risk potentials for pests of concern to 13 Hawai‘i forest hosts (continued)

	Likelihood of introduction				Consequences of introduction			
Common name (scientific name)/location on host	Host association	Entry potential	Colonization potential	Spread potential	Economic damage	Environmental damage	Social/political	Pest risk potential
West Indian sugarcane borer weevil (*Diaprepes abbreviatus*)/roots, foliage/other	H	H	H	H	H	H	M	H
White wax scale (*Ceroplastes destructor*)/foliage/other	H	H	H	H	H	H	M	H
Pathogens								
Acacia gall rust (*Uromycladium tepperianum*)/foliage/other, bark/cambium	H	H	H	H	M	M	M	H
Aecidium rusts (*Aecidium atrocrustaceum, A. calosporum, A. carbonaceum, A. diospyri, A. mabae, A. melaenum, A. muelleri, A. myopori, A. ramosii, A. reyesii, A. rhytismoideum, A. royenae, A. ulei, A. yapoense*)/foliage/other, bark/cambium	M	H	M	H	L	M	L	M
Armillaria root disease (*Armillaria limonea*, *A. luteobubalina*, *A. novae-zelandiae*, *A. tabescens*)/roots, bark/cambium, sapwood, heartwood	H	H	H	H	H	H	H	H
Calonectria morganii/seeds, roots, foliage/other, bark/cambium	H	H	H	H	M	M	L	H
Fomitiporia spp. (*Fomitiporia australiensis, F. mediterranea, F. punctata, F. robusta, F. sonorae*)/roots, bark/cambium, sapwood, heartwood	H	H	H	H	M	H	H	H

Table 11—Summary of risk potentials for pests of concern to 13 Hawai‘i forest hosts (continued)

	Likelihood of introduction				Consequences of introduction			
Common name (scientific name)/location on host	Host association	Entry potential	Colonization potential	Spread potential	Economic damage	Environmental damage	Social/political	Pest risk potential
Guava rust/eucalyptus rust (*Puccinia psidii*)/foliage/other	H	H	H	H	H	H	H	H
Pestalotia and *Pestalotiopsis* (*Pestalotia acacia, P. cibotii, P. diospyri, P. dodonaea, P. pandani, vaccinii; Pestalotiopsis* sp., *P. breviseta, P. glandicola, P. palmarum, P. photiniae, P. theae, P. uvicola, P. versicolor*)/foliage/other	H	H	M	H	L	M	L	M
Phellinus noxius/roots, bark/cambium, sapwood, heartwood	H	H	H	H	M	H	H	H
Pink disease (*Erythricium salmonicolor*)/bark/cambium	H	H	H	H	H	H	H	H
Ramorum blight/sudden oak death (*Phytophthora ramorum*)/foliage/other, bark/cambium	H	H	H	H	H	M	H	H
Uromyces rusts (*Uromyces scaevolae, U. sophorae- japonicae, U. truncicola*)/foliage/other	M	H	M	M	L	H	L	H
White thread blight/black rot (*Ceratobasidium noxium*)/foliage/other	H	H	H	H	M	M	M	H

[a] H = high, M = moderate, and L = low.

was very broad in scope and as such, provided a challenge for concise organization and documentation.

Other comments addressed issues of document clarity and readability, stating that we sometimes strayed beyond our objectives in some of our conclusions. We gathered data from many sources including previous risk assessments for Hawai‘i and the Caribbean countries. Some reviewers felt that some of the data were used or interpreted incorrectly or were simply erroneous. We made every attempt to correct or clarify those mistakes. Readability was improved by moving the tables and other information from the body to appendices.

Within the tables of existing and potential insects and pathogens, reviewers identified a number of organisms with incorrect information; the appropriate edits were made by the team.

Within our risk assessment process, there was some confusion about regulations that govern movement of commodities and inspection for pests. Reviewers clarified the roles of state and federal regulatory agencies for us in order to clear up confusion.

Issues and Findings

We identified a number of issues and findings in this pest risk assessment. Some of them have been reported in other assessments (Culliney et al. [n.d.], Meissner et al. 2009) and were adopted by us as appropriate for Hawai‘i because they are integral to invasive species transport and risk around the world. Some are more peculiar to Hawai‘i. We present these findings in the following pages. We considered six findings most important and discuss at length. Other findings are more briefly mentioned.

1. Inspection alone is not 100 percent effective in preventing introductions. In fact, some studies have shown that port inspections, alone, have relatively low interception efficiency (Meissner et al. 2009).

Inspection success might be improved by assessing commodities scheduled to arrive in Hawai‘i, including their type, source, quantity, and timing, for their potential to be carrying actionable pests. This could aid inspectors in determining where to focus their inspection efforts on arriving shipments and also in indicating the pest or pathogen that needs to be searched for in these inspections. The main action that needs to be considered jointly by Animal and Plant Health Inspection Service (APHIS), U.S. Customs and Border Patrol (CBP), and the Hawai‘i Department of Agriculture (HDOA) is whether or not some of the pests and pathogens in this present report should be put on the “actionable” lists and receive focused attention. The exact way of getting this to happen is beyond the scope of this report. However, the importance of handling this well is illustrated by Beardsley (1991) who estimated that an average of 3.5 new pest arthropods and mollusks establish in Hawai‘i on an annual basis. This number has likely increased over the past two decades despite increased inspections and regulatory efforts

Another way to reduce the odds of an exotic pest or pathogen becoming established would be to have a survey/monitoring program in place for detecting pests and pathogens that might have recently escaped into the environs immediately surrounding the ports (e.g., an early detection system). Potentially invasive insects have often been trapped in such exercises using traps with species-specific lures.

2. The primary sources of introductions are mainland United States and Asia-Pacific.

Hawai‘i is located over 3218 km from the nearest continental coast, resulting in nearly absolute dependence on ocean surface transportation or air transport for human sustenance. In addition, the tropical paradise is a tourist destination for millions of people via aircraft or cruise ships. The increasing volume of goods and people coming into the state each year, combined with the year-round tropical/temperate climate, has greatly increased exotic pest introduction and establishment. There appears to be no end in sight. It is estimated that 20 to 40 new terrestrial arthropod introductions occured in Hawai‘i each year from 1937 to 1967 (Beardsley 1979a), with about 10 percent becoming significant pests. At the Kahului Airport on Maui, there were 10.8 insect interceptions per day (of species not known to occur in Hawai‘i, known to be established in Hawai‘i, or of undetermined status) in just 130 days of inspections during 2000-2001 (HDOA 2002).

During a good economic period, Honolulu Harbor accommodated more than 1 million 20-ft equivalent units (TEUs) per year. These were distributed on O‘ahu, to other islands, and shipped to overseas ports. Installation of new facilities could increase capacity from 950,000 to 1,500,000 TEUs per year. In addition, in 2013, over 8.2 million people came to Hawai‘i either on cruise ships or airplanes (Hawai‘i Tourism Authority 2014). The majority of visitors came from the U.S. mainland (60 percent) and Japan (18 percent) (Hawai‘i Tourism Authority 2014).

Increased understanding of the prevalence of pests on ships (including military), in cargo containers, and aboard aircraft (and other high-risk pathways), and their origin, can lead to more targeted inspections and potentially reduce the number of pest introductions and establishments. Eighty percent of all consumer goods are imported into Hawai‘i, 98 percent of which comes through commercial harbors. Hawai‘i received 25.3 million metric tons (tonnes) of sea cargo from domestic trade and 7.6 million metric tons from foreign trade in 2005 (Culliney et al., n.d.: table 4-1). Any such numbers can be misleading though, as much of the domestic cargo from the U.S. mainland is foreign in origin and is then shipped to Hawai‘i as domestic cargo (Kosciuk 2007) and is subject to different phytosanitary inspection standards.

Between 2004 and 2006, the majority of shipments of propagative material classified as foreign came from Indonesia, Canada, and Thailand. This did not include foreign plants shipped to the U.S. mainland and then sent to Hawai‘i as domestic cargo (see above). Shipments from Indonesia represented over 100 plant genera and two shipments of lumber products. Shipments from Canada and Thailand also contained over 100 different plant genera (Culliney et al., n.d.). Over 1,500 plant pests, representing 140 species not known to occur in Hawai‘i, were on shipments arriving from the U.S. mainland between 2004 and 2006. This includes pests intercepted on material that originated in a foreign country, but was classified as domestic cargo upon arrival in Hawai‘i (Culliney et al., n.d.).

People can transport pests in checked and carry-on baggage as hitchhikers or on goods brought into the state. For international travelers coming into Honolulu Airport, an analysis of data from 2005 through 2006 shows travelers from Japan to be the source of the highest number of quarantine materials (primarily citrus), followed by Australia and Guam. Although no plant pest interceptions were recorded for the over 7,000 passenger groups sampled, 426 pests were recorded in the PestID database (USDA 2007a) for the same years, potentially indicating a low interception efficiency rate. For visitors from the U.S. mainland, quarantine inspections by HDOA resulted in over 300 pest interceptions in domestic air passenger carry-on baggage between 1995 and 1996 (HDOA 2007), demonstrating that visitors entering by air from the U.S. mainland are a significant pathway for introduction of exotic pests. Pests that were repeatedly intercepted included scales, ants, leafminers, noctuids (owlet moths), mealybugs, and codling moths. Although the pest risk associated with airline passengers cannot be completely quantified owing to lack of data, it is likely significant (Culliney et al., n.d.).

Most foreign and domestic fresh agricultural shipments into Hawai‘i arrive by aircraft. Inspection blitzes were conducted between September 2000 and July 2001 at the Kahului Airport on Maui. Most daily flights originated from the U.S. mainland (81 percent), with the remainder coming from Canada. Each blitz lasted over a 3- to 4-week period during which intensive inspections were made of checked and carry-on baggage, aircraft cabins and cargo holds, and all agricultural products shipped by air cargo (HDOA 2002). In total, 1,897 flights were inspected, 81 percent of which had agricultural commodities (flowers, plants, and produce) in the baggage or in the cabin.

The KARA air cargo inspections involved 1,495 shipments containing 168,351 cases of over 400 different agricultural commodities. Most of the shipments from domestic ports were from California. Foreign shipments primarily came from Australia, Ecuador, Guatemala, Holland, Mexico, and New Zealand. Pests were found in 9.8 percent of the cases that underwent 100 percent inspection. Domestic shipments had a higher percentage of pests not known to exist in Hawai‘i (45 percent) compared to foreign shipments (33 percent). Foreign shipments had a higher percentage of pests already established in Hawai‘i (52 percent) compared to domestic shipments (37 percent). During the period 1980-2002, two-hundred sixty-six insects and other arthropods were recorded as new state records for Hawai'i (HDOA 2002); an average of 12 new arthropods established per year. Most of these are not pests or are of minor significance. Some were purposely introduced to control other pests. Of these 266 insects and other arthropods, 46 are considered moderate to serious pests by the HDOA. Twenty-five of these 46 pests are of foreign origin, and the other 21 pests are known to occur on the U.S. mainland.

Although pests in Hawai'i have come from a variety of origins, many have come from the U.S. mainland and Asia-Pacific countries and islands. The lack of ability to inspect everything coming into Hawai'i (owing to the amount of goods and number of passengers, limited funding, lack of reliable detection methods, and other reasons), and knowing that a significant number of imminent pests have the potential to be introduced via multiple pathways, combined with the alarming rate of pest establishments, point to the need to increase inspections and improve targeting for pests. Having reliable and accurate data on pest interceptions and where pests come from can facilitate more informed decisions regarding where to use inspection resources, while having improved detection methods can decrease the likelihood of pest establishment.

3. There is a strong need to make visitors aware that they are a significant potential source of unwanted introductions. Given what we know about plant materials as an important pathway of pest introduction, increased efforts are needed to persuade visitors to voluntarily stop bringing live plant material into Hawai'i.
Hawai'i receives a large number of visitors each year from a wide variety of geographic regions and cultures. The largest number of visitors come from the U.S. mainland and Japan with minor, but significant, origins including Asian Pacific countries like Australia, South Korea (rapidly increasing), and China. Most visitors arrive in the Hawai'i Islands by air; although cruise ship visits also contribute large numbers of people. For all modes of travel, the level of phytosanitary inspection is generally insufficient to mitigate pest risk predominantly from live plant material (see previous sections). It is therefore important preemptively to persuade passengers not to bring live plants into Hawai'i. In essence, passengers need to inspect and regulate the contents of their baggage. Public outreach is probably the most efficient way to effect this change with a majority of the visitors, most of whom presumably want to do the right thing. Important basic topics to address in any outreach should include:

- Why live plant material brought in by visitors from outside Hawai'i threatens native Hawai'i forests.
- What are some of "the really bad actors," and why is it important to avoid introducing them.
- What types of behavior inadvertently introduce pests.
- Contact information for questions and information, including how visitors can help.
- Understanding why visitors bring live plants into Hawai'i. While interception statistics show that visitors bring many potentially problematic live plants into Hawai'i, there has been little available information on the types of motivations visitors have for doing so. Understanding different motives for live plant introduction may in turn result in better techniques to persuade visitors to not bring live plants to Hawai'i. For example, many live plants may reach Hawai'i simply because of visitor oversight, while others may be deliberately brought in to fill a need (e.g., cultural or culinary need) because they are thought to be (or are) unavailable in Hawai'i. If this is a common situation, providing information on local sources of these plants might reduce the incentive to bring these plants from outside Hawai'i.

To encourage visitors to avoid behaviors that place Hawai'i's native forests at risk, we suggest an active and coordinated outreach program to visitors. This outreach should ideally start before travelers board their plane or ship, reinforced during the flight or voyage, and before they disembark into Hawai'i. International air or cruise ship travelers as well as travelers from the mainland should be clearly told the types of plant material that threaten's native forests should they inadvertently or purposely pack them either in their luggage or on their person. During their stay, these ideas could be reinforced again at appropriate attractions that showcase native forest and species, giving visitors an opportunity to feel a connection with what they are being asked to protect. Many of those who visit Hawai‘i return. Once the message is understood and integrated into routine good practices, these return visitors can be recruited to help spread the word to other visitors. Continue to use methods currently in place to obtain information from passengers (e.g., inspection forms required upon arrival into Hawai‘i). Suggested specific actions that could be taken include:

Alert visitors prior to boarding:

- Work with airlines to provide a brief online message to travelers warning about the dangers of introducing live plant materials from outside Hawai‘i to native forest and agriculture (on the boarding pass, reservation site, luggage tags, etc.). Provide a link to a website with more information about threats to Hawai‘i's forests.
- Post signs at marinas and departure gates for flights to Hawai‘i to educate visitors about the potential consequences of transporting exotic insect pests and pathogens on vessels.
- Increase presence and visibility of inspectors at marinas and airports, mainly as a deterrent measure. Publicize interceptions as a warning to potential violators.

Educate travelers prior to departure and arrival about the potential consequences (economic, environmental, and personal) of transporting agricultural and other vegetative products. Remind travelers to consume or properly discard prohibited materials during travel. Implement risk communication strategies to educate local residents and business owners on the pest risks associated with trade such as the following:

- Informational brochures available during flight (include supporting statistics regarding interceptions of potentially harmful insects or pathogens, as well as several examples of serious pest introductions)
- Announcements
- Articles in in-flight magazines
- Hand out free pens with the message about the dangers of transporting live pests for visitors who are filling out the declaration form.

Reinforce the message at tourist areas when the visitor is actually in a position to see and experience native plants or forest ecosystems and develop an appreciation for them:

- Post signs at eco-tourism sites describing acceptable behavior while visiting the site. Visitors should be instructed to remain on marked paths and not to bring into or take out of the area any plants, plant parts, or animals. Botanical gardens that include native trees can also provide opportunities for interpretation and build an appreciation for the value of native plants.
- Instruct visitors to clean shoes and clothing when entering or leaving a natural or agricultural area. Visitors should remove soil and plant seeds from shoes and clothing and inspect cuffs and Velcro® closures. (Where appropriate, consider the use of water hoses, disinfectant shoe baths, metal grates in ground for cleaning shoes, and other measures.)
- Work with tour guides and other staff at natural areas, parks, or agricultural areas to educate visitors on the potential environmental and economic effects of exotic species. Good examples of public education are increasingly common on the islands in important wildlife habitat areas and could be applied in some cases to raising public awareness of invasive species. For example, visitors kayaking to Flat Island Bird Sanctuary on O‘ahu are educated on proper behavior with respect to the birds prior to being able to rent a watercraft such as a kayak or paddle board. They are also charged a fee if they land on the islands, which is used to protect bird habitat.
- Raise money by providing products such as postcards, t-shirts, calendars, or souvenirs to visitors who give a donation (Johnson 2006). Use the money towards the prevention of exotic pest introductions. The products themselves can be educational by providing information on exotic pests of concern, dispersal mechanisms, and possible preventative actions.
- Implement a user fee system for eco-tourist destinations. Funds raised through ecotourism should go to exotic species prevention and management (Hypolite et al. 2002).

- Conduct biodiversity impact studies for ecotourism sites to anticipate environmental and economic impacts of exotic species introduction.
- Limit access to very sensitive sites by restricting the number of visitors, access for vehicles, density of roads and trails, availability of accommodations, etc.
- Let visitors know they can help by spreading the word.

After the visitor has returned home:

- Visitors returning from Hawai‘i may convey what they have learned to future visitors and become advocates for guarding native forest from invasives.
- Attractive souvenirs may promote discussion with future visitors.

4. Plant materials, especially live plants, are by far the most important source of pest problems for Hawai‘i.
Plant materials include propagative material (seeds, pods, seedlings, cuttings), fruits and vegetables, and cut flowers and plant parts for crafts or decorations. The sources and traffic patterns associated with the movement of plant materials into Hawai‘i have been thoroughly addressed in other risk assessments in addition to ours. The patterns are very complex and involve international trade and tourism, among other avenues.

We examined the APHIS interception records for Hawai‘i ports between 1984 and 2010. During that time, over 10,000 pests were intercepted. Most of the sources of these interceptions were Asian countries, Australia and other countries of the Pacific. Over 20 countries were the sources of at least 100 interceptions each during this time period. Passenger baggage was listed nearly two-thirds of the time under the category “where intercepted.” Nearly 85 percent of the intercepted pests were connected with plant materials, with “fruit” being the source of over 30 percent of the total records.

Our pest risk assessment focuses on 13 taxa of native Hawai‘i plants and therefore, it logically follows that the plant pathway would be the primary source of introduction of potential pests.

As noted above, a pest risk assessment for the island of Maui (HDOA 2002) found that between 1980 and 2002, two-hundred sixty-six insects and other arthropods were recorded as new state records for Hawai‘i. Of these 266 introduced insects and other arthropods, 46 are considered moderate to serious pests by HDOA. Twenty-five of these 46 pests are of foreign origin, and the other 21 pests are known to occur on the U.S. mainland. Considering the biology of these “moderate to serious” pests, it is likely that as many as 40 of the 46 species could have had a plant pathway as their means of entry into Hawai‘i.

The high rate of new pest establishment in Hawai‘i is very disturbing and needs to be addressed in new ways that go beyond existing inspection measures and current approaches to regulation. When situations arise in the continental United States or elsewhere that involve exotic pests and host plants with representatives on the Hawai‘i Islands, an aggressive approach should be taken to ensure that pests do not gain entry into Hawai‘i. This approach should include the prohibition of movement of the affected plant species into Hawai‘i. A particularly disturbing example would be the establishment in Hawai‘i in 2008 of the highly damaging, newly described thrips species associated with *Myoporum* in California (Conant et al. 2009, Loope and LaRosa 2010).

We also believe it is important to strengthen the Pest Risk Committee, which deals with emerging issues involving plant pests (Culliney et al., n.d.).

5. The solid wood packing material (SWPM) pathway needs more scrutiny. Many pests using this pathway have already become established in Hawai‘i, and many more are on the list of potentials. Because HDOA can only inspect wood packing material that is associated with agricultural commodities, and because wood packing material is not necessarily specified as associated with cargo, it seems as if this is a pathway that is being insufficiently inspected and regulated.
Solid wood packing material, ubiquitous in international trade, is an important pathway for the introduction of potentially invasive species, as described in chapter 3. Because of international concern and the large number of bark- and wood-infesting insects that became established outside of their native ranges during the 1990s, international efforts at standardizing phytosanitary treatments of SWPM resulted

in the adoption of ISPM 15, a standard that requires all SWPM to be either heat treated for 30 minutes at 56 °C or fumigated with methyl bromide. In the most recent revision of ISPM 15 (IPPC 2009), the amount and size of residual bark remaining on SWPM was also restricted to patches less than 50 cm^2 as it was determined that bark patches were a prime source of beetle survival and recolonization after treatment (Haack and Petrice 2009). As of 2011, 70 countries require that SWPM meet the standards of ISPM 15 (Haack and Brockerhoff 2011).

The efficacy of treatments required by ISPM 15 has been questioned. Surveys of individual pieces of SWPM treated to ISPM 15 standards in Australia, the European Union, and the United States resulted in the detection of live beetles in 0.1 to 0.5 percent of the inspected items, usually in association with patches of bark (Haack and Brockerhoff 2011). The Australia survey examined 20,000 pieces of SWPM in Australia from containerized sea cargo that resulted in a 9 percent detection rate for items of overall quarantine concern, including 8.5 percent bark, 5.9 percent fungi, 3.2 percent live insects, 2.8 percent frass, and 1.7 percent soil–these items not being mutually exclusive (Zahid et al. 2008). In Honolulu, a 2-year survey from 2005 to 2007 conducted randomly by the USDA Agricultural Quarantine Inspection Monitoring (AQIM) program resulted in similar conclusions. Of 116 inspections of SWPM, four shipments contained live insects; single shipments were also found that contained soil, unidentified noxious weeds, and an "unidentified pest." Five shipments had no ISPM 15 identifying marks. Only 50 percent of the wood surface was examined; however, and no attempt was made to determine whether pests were inside of the wood or whether dead pests were present at the bottom of the shipping containers (Culliney et al., n.d.]). Inspections by the New Zealand Ministry of Agriculture and Forestry of about 1,500 containers with SWPM determined that 16 percent had contaminations that resulted in phytosanitary action, such as fumigation or incineration. Organisms that were detected included fungi, insects, isopods, millipedes, and mites. Hitchhiking plant materials, spiders, mollusks, and reptiles were also found; these do not represent a failure of ISPM protocols (MAF 2003). An evaluation of ISPM 15-treated SWPM in Chile also found important quarantine insects in or on the wood. These included *Sinoxylon anale*, *S. conigerum*, *Monochamus alternatus* (Coleoptera: Cerambycidae), *Pissodes castaneus* (Coleoptera: Curculionidae), *Tomicus piniperda*, *Heterobostrychus aequalis* (Coleoptera: Bostrichidae), *Sirex noctilio* (Hymenoptera: Siricidae), *Ips* spp. (Coleoptera: Curculionidae: Scolytinae), and other *Pissodes* spp. (Sanchez Salinas 2007).

These are disturbing survey results. Possible reasons for pest survival include tolerance of certain insects to the mitigation treatments; recolonization after treatment has occurred, especially when bark is present; improper application of treatment owing to defective equipment or facilities; and outright fraud where the treatment mark is applied to nontreated wood (Haack and Brockerhoff 2011). With the exception of the Australian study, comparable surveys have not been done for the detection of fungi and other pathogens. Another concern is that SWPM is usually reused multiple times so it does not necessarily originate from the site of the commodity with which it is associated. Currently, there is no way to track the origin of SWPM and the potential pests and pathogens associated with that place of origin, or when and where it was treated for ISPM 15 compliance (Haack and Brockerhoff 2011).

The current inspection system is not adequate to detect pests and pathogens associated with SWPM. During the Honolulu AQIM assessment, only about 10 percent of the volume was inspected, but the rate of interception was 10 percent higher than typically seen (HDOA 2007) (as reported in Culliney et al., n.d.). Inspectors from the HDOA cannot inspect nonagricultural shipments unless referred by another agency even though SWPM associated with nonagricultural commodities is a major risk factor. The AQIM data set included pests intercepted on marble slabs, granite and stone from China, and on furniture from Indonesia (Culliney et al., n.d.). Regular phytosanitary inspections of maritime cargo at the port of Honolulu (not AQIM data) by APHIS-PPQ and CBP inspectors from October 2005 to April 2007 resulted in 29 interceptions of insects on or in woody materials, all associated with nonagricultural commodities such as tile, granite, marble, and furniture (Culliney et al., n.d.). It is estimated that most port inspections intercept only 30 percent or fewer of incoming pests (Meissner et al. 2003).

The level of training of all port inspectors is also of concern. Often inspectors are not well trained in detecting pests and pathogens associated with SWPM, which are difficult materials to inspect for the untrained eye. Interception rates by inspectors in the Southwestern United States dramatically increased for wood-boring insects after training in methods to detect scolytid beetles (Meissner et al. 2009). Targeted training for inspectors in the detection of pests associated with SWPM would be an inexpensive and cost-effective way of increasing inspection efficacy and could reduce additional introductions of unwanted pests.

Many insects that have been associated with SWPM are already established and invasive in Hawai'i and have probably arrived in the islands via this pathway, thus demonstrating the dangers associated with SWPM. These insects include the following, as compiled by Culliney et al., n.d.: *Chlorophorus annularis*, *Euwallacea fornicatus, Hypothenemus obscurus*, *Xyleborus perforans*, *Xylosandrus compactus*, *X. crassiusculus*, and *X. morigerus*. Many potential pests have not yet reached Hawai'i but may be introduced by SWPM if steps are not taken to increase the number and efficacy of inspections. Culliney et al. (n.d.) listed 81 different species of insects that have the potential to be introduced to Hawai'i in SWPM, with scolytid beetles being predominant. Other potential pests and pathogens associated with SWPM are assessed in the current document in individual pest risk assessments (chapter 4).

Recommendations made for the Greater Caribbean Region (Meissner et al. 2009) are similarly applicable to Hawai'i. These recommendations include:

- Develop a strategy to ensure that SWPM in both agricultural and nonagricultural commodities are adequately inspected, preferably by random selection and thorough inspection.
- Make the declaration of SWPM mandatory for all imports. (This would probably need to be done on a national level, however, and may be beyond state authority.)
- Increase regionwide inspection and identification expertise among inspectors. Educate inspectors on how to look for pests in SWPM and provide resources for pest identification.
- Allow entry of SWPM only if bark free. Solid wood products material that contains small patches of bark, permissible under ISPM 15, should be specifically targeted for inspection.
- Develop a communication network between HDOA, USDA-APHIS, and CBP inspectors to share pest interception data, inspection and diagnostic techniques, training materials, pest alerts, and other information.

6. Some pests not posing a risk to the mainland United States, or already present in the mainland, may be a potential threat to Hawai'i. The interstate movement of certain plant materials from Hawai'i to the mainland is restricted without treatment and certification. Similar restrictions on interstate movement into Hawai'i are not in place. For the most part, APHIS regulations do not discriminate between the mainland and islands of Hawai'i as far as potential threats. This includes some organisms that are native or commonly found on the mainland.

Invasive pests can be transported to Hawai'i either from domestic or foreign sources. Because most materials needed by people of Hawai'i are imported indicates the potential for unintentional introductions is substantial. Both domestic and foreign sources are under federal and state regulation and inspection. By regulation, HDOA has primary responsibility to prevent the introduction of pests that may be injurious to the agricultural industries and natural resources of the state (Hawai'i Revised Statutes §141). This section was amended in HRS §150A Section 3 to provide HDOA the authority to prohibit entry "...into the State*, from any or all foreign countries, or from other parts of the United States*, (italics added) or the shipment from one island within the State to another island therein, or the transportation from one part of locality of any island to another part or locality of the same island, of any specific article, substance, or object or class of articles, substances or objects, among those enumerated above in this section, which is diseased or infested with insects or likely to assist in the transmission or dissemination of any insect or plant disease injurious, harmful, or detrimental or likely to be injurious, harmful, or detrimental to the agricultural or horticultural industries, or the forests of the State, or which is or may be in itself injurious, harmful, or detrimental to the same."

The federal authority to regulate plant pest movement is within the Plant Protection Act of 2000 (Pub. L. 106–224, title IV, § 401, June 20, 2000, 114 Stat. 438). Specifically, this act states that "...no person shall import, enter, export, or move in *interstate commerce* (italics added) any plant pest, unless the importation, entry, exportation, or movement is authorized under general or specific permit and is in accordance with such regulations as the Secretary may issue to prevent the introduction of plant pests into the United States or the dissemination of plant pests within the United States."

The Plant Protection Act also states in §7756, "No State or political subdivision of a State may regulate in foreign commerce any article, means of conveyance, plant, biological control organism, plant pest, noxious weed, or plant product in order—(1) to control a plant pest or noxious weed; (2) to eradicate a plant pest or noxious weed; or (3) prevent the introduction or dissemination of a biological control organism, plant pest, or noxious weed." It goes on to state, "No State or political subdivision of a State may regulate the movement in interstate commerce of any article, means of conveyance, plant, biological control organism, plant pest, noxious weed, or plant product in order to control a plant pest or noxious weed, eradicate a plant pest or noxious weed, or prevent the introduction or dissemination of a biological control organism, plant pest, or noxious weed, if the Secretary has issued a regulation or order to prevent the dissemination of the biological control organism, plant pest, or noxious weed within the United States."

Department of Homeland Security, CBP, assumed foreign import inspection duties from APHIS, with the passage of the Homeland Security Act of 2002. This includes inspection of international passengers, luggage, cargo, and mail carrying nonpropagative material. Propagative material is still handled by APHIS.

Apparently, when state and federal regulations and statutes conflict, federal laws take precedence. Two exceptions to the above restrictions on state regulations of interstate commerce are in the law. No exceptions are identified for foreign commerce. However, importation of new foreign commodities that may pose a risk are announced by APHIS with the opportunity for stakeholders, including states, to provide information to change, support, or cause the commodity not to be approved for importation into the United States or Hawai‘i, specifically. If the proposed regulations are consistent with federal regulations, "A State or a political subdivision of a State may impose prohibitions or restrictions upon the movement in interstate commerce of articles, means of conveyance, plants, biological control organisms, plant pests, noxious weeds, or plant products that are consistent with and do not exceed the regulations or orders issued by the Secretary." If the State demonstrates a special need, "A State or political subdivision of a State may impose prohibitions or restrictions upon the movement in interstate commerce of articles, means of conveyance, plants, plant products, biological control organisms, plant pests, or noxious weeds that are in addition to the prohibitions or restrictions imposed by the Secretary, if the State or political subdivision of a State demonstrates to the Secretary and the Secretary finds that there is a special need for additional prohibitions or restrictions *based on sound scientific data or a thorough risk assessment*." (italics added).

Several recommendations are provided:

- APHIS, in collaboration with HDOA, should consider the development of quarantine regulations specific to Hawai‘i and their unique situation to limit the potential for introduction of potential pests from foreign and domestic sources. This should also include intrastate movement between islands of Hawai‘i.
- Manifests of goods from mainland United States to Hawai‘i should indicate whether they are of foreign or domestic origin and, if foreign, the port of origination.
- When inspecting goods on the mainland United States destined for Hawai‘i, CPB inspectors should be familiar with those pests that may pose a unique threat to Hawai‘i.

- When APHIS announces draft regulations on potential quarantines for proposed imports, HDOA should provide a response with specific information that supports the need for specific restrictions on such importation to Hawai'i.
- HDOA should intensify its inspection of goods from mainland U.S. and foreign sources. Detailed analysis of the APHIS PestID (formerly Port Information Network 309) database and other import data sources may provide assistance in setting priorities. Unfortunately, the team was not able to access the PestID data and cannot provide any analysis.
- In addition to coordinated inspections, monitoring for potential newly introduced pests should be initiated/continued around likely points of entry.

Additional Issues and Findings

In addition to the six priority findings discussed above, numerous other findings were made and are presented for consideration. We have attempted to group these findings under similar topic areas.

General

- The broad range of commodities/hosts and countries for potential introductions makes it extremely difficult to accurately characterize pest risk to various hosts of concern.

One of the complexities of qualitative pest risk assessments is the uncertainty of which potential pests could be introduced to new hosts and ecosystems. This analysis attempted to identify pests and pathogens from other parts of the world that would endanger 13 species and genera of native Hawaiian plants. This is an impossible task to do completely and thoroughly; our efforts were directed at providing enough information and data to guide the state of Hawai'i in developing acceptable regulations and restrictions to limit such introductions.

- Although an invasive insect or pathogen may exist in a location, it should not be considered low risk once established, given that strains may exist that are exotic with different levels of virulence (Palm and Rossman 2003).

Regulations are usually based on restricting the entry of invasive organisms at the species level. However, genetic diversity in fungi and other plant pathogens often results in the identification of strains, biovars, pathovars, form species, and others. These may differ in their virulence, host range, mating type, and infectiveness. Although species like *Puccinia psidii* are present in Hawai'i, the potential for introduction of new strains that may be more damaging should not be ignored.

- Be aware of infestations by new species on the mainland.

The mainland United States is a major source of introduced pests to Hawai'i. It is suspected that myoporum thrips arrived from California. Similarly, daylily rust (*Puccinia hemerocallidis* Thuem.) had been identified in the southeast United States several years prior to being found in Hawai'i. Staying aware of new pests on the mainland can increase inspection effectiveness and possibly limit introductions.

- Do not attempt to develop a *comprehensive* list of pest threats to the entire state.

Most invasive pests are not considered significant in their home environment. Trying to identify a list of pest threats would be of little benefit and could provide a false sense of security. A more effective approach is to utilize data and information from accurate and up-to-date databases of interception records and pest surveys. Nonproprietary data need to be shared with stakeholders to better focus inspection efforts. This also benefits early inspection, rapid response, and public outreach.

- Do not base risk estimates on port interception data alone.

Port interception records are useful for exploring pest risk; however, it is erroneous to assume that a low number of interceptions is equivalent to low risk.

- Strive for transparency in all decisions and analyses.

Most decisions concerning safeguarding (e.g., level of inspection, inspection methodology, whether something should be considered high or low risk, and others) are made by some committee or group, either formally or informally.

All decisions have to be reevaluated periodically as situations change or new information becomes available. If the reasoning behind a decision is not clearly documented, it becomes impossible to evaluate the decision's validity. For the sake of continuous improvement and to reduce the possibility of errors, the reasoning behind all decisions should be clearly explained and documented, and this information should be available.

- Provide for greater transparency and sharing of pest interception data between all regulatory agencies involved in port inspections.

State and federal agencies both perform inspections of visitors and imported goods to identify potential pests and locate commodities not permitted to enter the state. A coordinated database of all agencies involved in these efforts that includes data on interceptions could increase everyone's ability in identifying commodities and pathways to target for increased inspection efforts. Limited sharing or delay in sharing these data decreases the efficiency and efficacy of efforts by all.

Ecology

- Outdoor recreation and ecotourism in Hawai‘i increase the chance of introductions and spread of pests, especially pathogens, because of direct exposure from visitors. Limit access to very sensitive sites.

A major draw of tourists to Hawai‘i is its natural environment. Direct access by recreationists to natural areas significantly increases the risk of introducing invasive pests on their equipment and clothing. Educating visitors and guides to this potential and how they can reduce the risk will aid in reducing the possibility of introduction and spread of new and existing invasive species. Pristine natural areas may be considered for closure to recreational use because of extreme threat of exposure.

- The numerous nonnative plant species that are present (planted around airports, ports, and other areas) serve to harbor pests that can move to the native species.

Some nonnative host species may be highly susceptible to invasive pests and provide a means for pest establishment and rapid population increase around ports of entry. This may increase the possibility of transfer and spread onto native species. This is a difficult balance between aesthetic landscaping around ports and the possible increased likelihood of pest establishment. Nonnative hosts could be useful detection sentinels if closely monitored, but could also become avenues of spread to native environments. Monitoring efforts need to be increased if these hosts are identified as detection sentinels.

Detection Surveys

- Get more involved with the USDA's Cooperative Agriculture Pest Survey (CAPS) program to expand beyond agricultural pests to include forestry pests.

The HDOA is a participant in CAPS program designed for the early detection of significant plant pests: add Hawai‘i Division of Forestry and Wildlife as a participant to increase awareness of and attention to forest pests.

- Maintain current awareness of the literature for reports of new pests (or outbreaks or rises in pest populations) in other countries that could potentially infest/infect the 13 priority species and other native species.

New invasive insects and pathogens are constantly identified and reported on commodities in other countries. Many of these pests could just as easily be transported to Hawai‘i. Awareness of these new identifications can increase vigilance for them during inspection. Maintaining good contacts and access to databases with other countries pest regulatory authorities, especially those in Asia-Pacific, can improve the state's ability to intercept potential pests.

- Early detection can be increased, particularly for species where traps/lures have been identified.

Early detection is emphasized as a way to limit spread of introduced exotics. It is often difficult to achieve, however, because of the lack of efficacious attractants and traps. When individual pests of concern are identified that have a high likelihood of introduction, opportunities for detection trapping should be assessed. If detection tools are available, they should be implemented around likely places of introduction, including military installations and training sites. Also, vegetation around ports should be monitored at least annually to determine if any exotic pest may have been introduced.

- Develop surveillance systems for the early detection of pests.

Surveillance programs for the early detection of exotic species should be implemented. Decisions will need to be made regarding which pests to survey for and which areas to survey. The USDA CAPS Program has developed a process for making these decisions using the analytical hierarchy process. Hobby entomologists and botanists, gardeners, nursery professionals, and others (e.g., Invasive Species Councils), may be important and competent contributors to a regional surveillance system.

- Implement surveys to determine the distribution of pests commonly associated with SWPM outside of their native range.

Collaborate with state and federal forest management agencies, not-for-profit organizations (e.g., Centre for Agricultural Bioscience International [CABI] and the CAPS Program. Involve the public. Use the help of hobby biologists. Do not exclude countries that are enforcing ISPM 15 from these survey efforts.

- Develop an effective integrated biosurveillance and pest information system, also to be used as a mechanism for official pest reporting

Both safeguarding against and responding to pest introductions depend strongly on the availability of current pest information. Of special importance is information on distribution, host range, trapping and identification tools, control methods, and port interception records. The sheer amount of pest information available throughout the world and the fast pace at which new information appears make it impossible for any individual to stay abreast of it. The collection, analysis, dissemination, and storage of pest information must occur in an efficient and organized manner. An on-line database is indispensable. One example of an existing biosurveillance system is the Exotic Pest Information Collection and Analysis of USDA APHIS-Plant Protection and Quarantine. Examples of initiatives that deal with pest information management are the Global Pest and Disease Database and the Off-Shore Pest Information Program of USDA APHIS, as well as the Hawai‘i Biodiversity Information Network Early Detection Network, the Global Invasive Species Database of the Invasive Species Specialist Group, and the Invasive Species Compendium of CABI. The potential usefulness and applicability of these and other projects should be evaluated and collaborations should be developed as appropriate.

- Increase the use of detector dogs wherever feasible.

Resources will never allow a thorough inspection of all pathways by human inspectors. Detector dogs make it possible to reliably scan a larger number of items than humans given the same amount of time. Dogs can be used to increase efficacy of checking incoming mail, luggage, and cargo.

- Develop targeting strategies for inspection of airline passenger baggage.

Possible targeting criteria include origin of passenger, seasonality, and holidays. For this to be possible, a systematic data collection program has to be implemented.

- Conduct periodic data collection efforts (“blitzes”).

Carry out statistically sound data collection to answer specific questions. Consider regionwide coordination and sharing of resources with others in Asia-Pacific for carrying out blitzes. Share results regionwide.

- Foster collaboration between customs officials, agricultural officials, mail facility staff, and any other groups. With limited resources, all parties can benefit by sharing both resources and information.
- Monitor interisland trade via small vessels.

Any commodities that are reshipped to other islands should be monitored for the possible shipment of invasive species to reduce the risk of spread and establishment to additional locations.

Monitor areas on and near the perimeter of the ports regularly for introduced pests of particular interest (Robinson et al. 2008). To reduce costs, employ the help of amateur taxonomists, university students, and qualified volunteers.

Avoid attracting pests into the area (e.g., through lures, lights, others).

- Develop a strategy to ensure adequate inspection of SWPM on all agricultural and nonagricultural cargo.

Simply checking for treatment seals is not a sufficient inspection method. A certain percentage of SWPM should be randomly selected and thoroughly searched for pests, both on the surface and inside the wood. All pertinent information (type of cargo, origin of cargo, presence of treatment seal, types and number of pests found, and other) should be recorded and shared regionwide.

- Increase regionwide inspection and identification expertise on pests associated with SWPM.

Educate inspectors on how to look for pests on SWPM. Ensure that identifiers have the expertise and the necessary reference material to identify the pests that are found.

Regulations

- Require phytosanitary certificates for all imports of plant materials.

The certificate should include species and variety of imported plant, if applicable, and should certify that the material was pest free at the time of shipping based on specified inspection protocols and issued by appropriate officials. This includes both international and domestic sources of plant material.

- Preshipment pest inspections and treatments.

Prior to shipment from the country/state of origin, require that plant material be inspected for the presence of any invasive pest.

- Minimize pest contamination on containers by:
  - Minimizing time of container storage outdoors.
  - Avoiding container storage on soil and near vegetation.
  - Avoiding night-time lighting of outdoor storage areas.
  - Cleaning storage areas on a regular basis.
  - Cleaning inside and outside of containers after and before each use.

- Make the declaration of SWPM mandatory for all imports regardless of commodity.

The origin of SWPM usually cannot be determined. Having shippers identify the presence of SWPM may increase the effectiveness of inspection. This includes material as part of the shipment, as well as associated material, such as dunnage. Ensure that SWPM meets ISPM 15 standard. Inspection of SWPM should include looking for actual pests, boring holes, boring dust and frass, staining, and other indicators of pest presence.

- Record information on propagative material imported by plant species, with information on variety, type of material (roots, cuttings, other), country of origin, growing and inspection practices followed, date of importation, and amount imported in consistent units.

Education/Public Awareness

- Emphasize a statewide public awareness campaign on invasive species focused on transport and introduction from overseas.

Hawaiʻi has several active groups involved in invasive species management and public information distribution. The Hawaiʻi Invasive Species Council provides policy-level direction, coordination, and planning among state departments, federal agencies, and international and local initiatives for the control and eradication of harmful invasive species infestations through five working groups, including a group for public awareness. The Coordinating Group on Alien Pest Species is composed primarily of management-level staff from every major agency and organization involved in invasive species work, including federal, state, county, and private entities. They, too, provide information to the public on invasive species. These groups need to be maintained and encouraged in their efforts to inform the public on the threats of invasive species

- Develop voluntary codes of conduct for groups involved in the dispersion of and the prevention of the introduction of exotic species.

Draft a voluntary code of conduct for nurseries and landscaping businesses to limit spread of any newly introduced invasive species. Draft a voluntary code of conduct for local governments, resorts, hotels, and other entities that engage in large-scale landscaping. Draft a voluntary code of conduct for botanical gardens and arboreta. Develop a certification process.

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Two previous pest risk assessments provided important background and data for this report. The authors of this assessment take full responsibility for the contents, however.

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English Equivalents

When you know:	Multiply by:	To find
Micrometers (µm)	0.000039	Inches
Millimeters (mm)	0.039	Inches
Centimeters (cm)	0.394	Inches
Meters (m)	3.28	Feet
Kilometers (km)	0.6215	Miles
Hectares (ha)	2.47	Acres
Square kilometers (km^2)	0.386	Square miles
Kilograms (kg)	0.0011	Tons
Metric ton	1.102	Tons
Celsius (°C)	1.8 °C + 32	Fahrenheit

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