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by

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Table of Contents

List of Tables

List of Figures

Abstract

Since its first documented introduction to Hawai‘i in 2005, the rust fungus *P. psidii* has already severely damaged *Syzygium jambos* (Indian rose apple) trees and the federally-endangered *Eugenia koolauensis* (nioi). Fortunately, the particular strain has yet to cause serious damage to ‘ōhi‘a, which comprises roughly 80% of the state’s native forests and covers 400,000 ha. Although the rust has affected less than 5% of Hawaii’s ‘ōhi‘a trees thus far, the introduction of more virulent strains and the genetic evolution of the current strain are still possible. Since the primary pathway of introduction is Myrtaceae plant material imported from outside the state, potential damage to ‘ohi‘a can be minimized by regulating those high-risk imports. We discuss the economic impact on the state’s florist, nursery, landscaping, and forest plantation industries of a proposed rule that would ban the import of non-seed Myrtaceae plant material and require a one-year quarantine of seeds. Our analysis suggests that the benefits to the forest plantation industry of a complete ban on non-seed material would likely outweigh the costs to other affected sectors, even without considering the reduction in risk to ‘ōhi‘a. Incorporating the value of ‘ōhi‘a protection would further increase the benefit-cost ratio in favor of an import ban.

1 Introduction

Movement of plants material between geographical areas by human activities has reached unprecedented levels worldwide (Brasier 2008). Fungi and insects that may have little impact in the plant communities where they have evolved in certain instances bring about negative effects when transported to new regions of the world where the native plants have little resistance (e.g., Brasier 2008). Dominant tree species are declining in many areas of the world and the introduction of pests and pathogens to new environments is a major contributing factor, resulting in disruption of fundamental ecosystem processes and changes in environments on which a variety of other species depend (Ellison and others 2005). This analysis is aimed at quantifying the economic benefits and costs of a policy designed to reduce the risk of introducing new strains of a potentially damaging rust fungus, *Puccina psidii*, to Hawai‘i.

Most rust fungi are highly host specific, but *Puccina psidii* has an extremely broad host range within the myrtle family (Myrtaceae, with about 5,000 species worldwide) and gained notoriety with a host jump in its native Brazil from common guava (*Psidium guajava*) to commercial *Eucalyptus* (originally from Australia) plantations (Coutinho and others 1998). When detected in Hawai‘i in April 2005 (Killgore and Heu 2005, Uchida and others 2006)—the first invasion outside the Neotropics/subtropics—there was immediate concern for ‘ōhi‘a (*Metrosideros polymorpha*). ‘Ōhi‘a comprises 80% of native forest statewide, providing stable watersheds and habitat for most Hawaiian forest birds and plants. Within months, rust spores spread statewide on wind currents, but ʻōhiʻa was found to be only a minor host, showing very light damage. The primary host was non-native rose apple (*Syzygium jambos*), which was severely affected at a landscape scale. The massive production of rust spores subsided as rose apple was largely defoliated or killed within several years (Uchida and Loope 2009, Starr and Starr 2005-2011).

Although ʻōhiʻa was spared from significant rust damage following the 2005 outbreak, concerns remained about both a possible host jump and future introductions of more virulent *P. psidii* strains. To address those concerns, Hawaii's Coordinating Group on Alien Pest Species, (CGAPS, www.hawaiiinvasivespecies.org/cgaps) began to explore regulatory possibilities. However, national and international quarantine standards involving strains or other taxonomic categories below the species level require strong scientific justification, which was lacking at the time. Since then, results from several studies have built a strong case for *P. psidii* regulation. Kadooka (2010) reported the lack of genetic variation in standard genetic markers across analyzed rust samples from Hawaiʻi (indicating that they were all of a single strain). A 2011 study undertaken in conjunction with the USDA Forest Service confirmed the lack of detectable genetic variation in the Hawaiʻi populations and found that genetic variation of *P. psidii* in its home range is in fact substantial, and host species strongly influences rust population structure.[1] In other words, the likelihood that ʻōhiʻa will be susceptible to an introduced or mutated rust strain in the future is non-trivial.

In order to prevent introduction of new *P. psidii* strains, Hawaiʻi Department of

[1] Appendix I provides additional background information, including detailed findings from the 2011 genetic study. See also Loope (2010) and Loope and La Rosa (2008) for a preliminary assessment of the risks associated with introducing new *P. psidii* strains to Hawaiʻi.

Agriculture is proposing to move ahead with establishing stringent measures that restrict entry of Myrtaceae into Hawai‘i. The purpose of this report is to assess the economic implications of such a restriction. Specifically, the analysis estimates the expected policy-induced benefits and costs that would accrue to several sectors in Hawaii’s economy: florists, nurseries, and plantations.

2 Need for Economic Analysis of the Proposed Rule

The University of Hawai‘i Economic Research Organization (UHERO) received the task of evaluating the likely economic impact of Hawai‘i Department of Agriculture’s Proposed Rule intended to prevent establishment of new genetic strains of *Puccinia psidii* that would threaten Hawaii’s ‘ōhi‘a and other Myrtaceae.

In general, though standards for international and national phytosanitary regulation are geared toward protecting free trade to the extent feasible (Heather and Hallman 2008), they do not require economic analysis of options; the standards dictate that political entities are justified in providing the phytosanitary protection they deem necessary based on criteria of technical justification (sound science allowing accurate assessment of pest risk within the framework of the International Plant Protection Convention), involving environmental concerns as well as concerns for economic considerations (Hedley 2004, IPPC Secretariat 2008). However, Hawai‘i State Law requires that any new departmental regulation be evaluated for its impact on small business and subjected to public review and comment.[2]

[2] Regulation based on a particular strain rather than a species sets a new precedent for quarantine rules.

As mentioned above, from August 2007 to August 2008, an interim rule prohibited the importation of any Myrtaceae plants or parts from specified infected areas – designated as South America, California and Florida – except for treated seeds and tissue cultures certified to be *P. psidii*-free. Additionally, Myrtaceae imported from any other non-infected area required a certificate of origin. The interim rule was imposed to prevent the "introduction of additional and possibly more virulent strains" of *P. psidii* (State of Hawai‘i, Department of Agriculture, 8/28/07). However, with authorization for an interim rule limited to 12 months by Hawai‘i State Law the rule expired in August 2008. Currently, Myrtaceae can be imported to Hawai‘i from any region, but shipments are subject to inspection by HDOA agricultural inspectors and are released to the receiving party only if there is no visible evidence of *P. psidii*. (This policy is consistent with existing legislation and rules, but deemed ineffective since inspection capacity and latent (asymptomatic) infections limit the ability to detect the rust.)

Hawai‘i Department of Agriculture now judges that there is fully adequate scientific justification to support the urgency of a policy change and to support a sufficiently rigorous rule that has a good chance of preventing arrival and establishment of new strains of *Puccinia psidii*.

The following proposed (draft version, August 2011) Myrtaceae import rule is targeted for implementation in 2012:[3]

SUBCHAPTER 18

[3] Given that a major conference in Brazil in November 2011 aimed to assess best practices for assuring maximum safety in moving germplasm of Eucalyptus between locations, there may be some refinements in the eventual rule, which in any event will undergo Hawai‘i Board of Agriculture's public review process.

RESTRICTION OF INTRODUCTION OF MYRTACEAE (FOR PROTECTION OF OHIA)

§4-70-6 Duration of quarantine. Unless otherwise specified for specific plants in subsequent subchapters, the duration of quarantine shall be one year provided that the board may exempt or shorten the period of quarantine under certain conditions of importation or propagation procedure.

(Auth: HRS §§141-2, 150A-9) (Imp: HRS §150A-5)

§4-70-64 Notice of quarantine. The board has determined that there exists serious danger to all Metrosideros spp. and the forests of Hawaiʻi from the introduction of new strains of the ʻōhiʻa rust, Puccinia psidii, and other disease pathogens and insects not now established in Hawaiʻi.

(Auth: HRS §§141-2, 150A-9) (Imp: HRS §150A-5)

§4-70-65 Prohibited introduction. The introduction of any plant, plant part, or seed from any species of the family Myrtaceae into Hawaiʻi is prohibited except:

1) Dried non-living plant materials;
2) Tissue cultured plants grown in sterile media and is in a completely enclosed sterile glass flask or other similar container; and
3) By approved permit pursuant to section 4-70-66.

(Auth: HRS §§141-2, 150A-9) (Imp: HRS §150A-5)

§4-70-66 Permits. Upon written request, a permit may be issued by the chief authorizing the importation of a limited quantity of plants in the family Myrtaceae for propagation under the branch's supervision in a strictly enforced quarantine pursuant to section 4-70-3, 4-70-3.1, 4-70-4, 4-70-5, 4-70-6, and 4-70-6.1.

(Auth: HRS §§141-2, 150A-9) (Imp: HRS §150A-5)

Any plants in the Myrtaceae family will be immediately confiscated and destroyed, regardless of the visual presence of rust. Seeds will be quarantined in one of the HDOA's existing facilities. If the seeds show no sign of infection after the one year period, they will be distributed to the importers. Otherwise, they will be destroyed. Importers will be allowed to apply to the Hawai'i Board of Agriculture for shorter quarantine periods with provision for scientifically sound safeguards establishing that the mitigative efforts (e.g. sterilization, genetic testing, tissue culture) are as effective as the one-year quarantine. Once a permit is granted for a specific treatment, that type of treatment need not be approved again. The HDOA is planning to work with leaders in the forestry industry to explore potential protocols for expedited seed entry. Although information is currently sparse on what treatments may be effective, it is foreseen that increased international research on this topic will likely be forthcoming in the near future.

The choice of one year for the quarantine period is based on the collective knowledge of the state's experts on *P. psidii* and anecdotal evidence from other countries. The rust fungus' thick walls that resist desiccation and pigments that reduce UV damage allow spores to remain viable for at least 90 days in favorable conditions (references summarized by Glen and others 2007). The rust has proven robust to harsher conditions as well; it was reported that spores on timber, plastic wrapping, and the outside of a shipping container survived a sea journey from Brazil to Australia (Grgurinovic and others 2006).

To ease the transition for current importers, the HDOA is planning to develop an *Import Replacement Program*. The program would assist by locating local sources of Myrtaceae and providing outreach during the transitional period, including presentations throughout the state to educate florists and nurseries about possible alternatives to Myrtaceae products. In addition, the HDOA is pushing for a bill to establish inspection stations at all ports of entry. This would discourage strategic avoidance measures by buyers, i.e. deliberately shipping to understaffed ports to decrease the likelihood of the shipment being searched thoroughly.

2.1 Direct Cost of the Proposed Rule

Since seeds require a relatively small quarantine area, no new capital expenditures will be required for the quarantine program. Moreover, all ongoing costs of maintenance will be paid for by HDOA, primarily out of the Import Replacement Program's $200,000 budget.

3 Survey of Local Industries: Florists, Nurseries, and Plantations

Any policy that bans or otherwise restricts the importation of Myrtaceae plant material will have an impact on primarily three sectors of Hawaii's economy: the floral industry (including florists, retail/landscaping/fruit tree nurseries), forest nurseries, and industrial plantations. To provide a basis for estimating the economic impact of the proposed rule, we surveyed and interviewed as many businesses in those industries as were willing to work with us. Presented below are summaries of each sector's self-assessed expected impact of a policy change regarding imported Myrtaceae.

3.1 The Floral Industry

Foliage or flowers from several Myrtaceae genera—including *Eucalyptus*, *Chamelaucium* (waxflower), and *Myrtus* (myrtle)—are commonly used as “fillers” in floral arrangements because they possess several desirable properties: the high-quality greens/flowers are consistently available from mainland and international growers, are durable and long-lasting to withstand the transit time from non-local grower to market in Hawaiʻi, are substantial in volume to give arrangements a “full” appearance, and are reasonably priced. While some of these fillers are grown locally, in-state growers do not currently produce enough to meet local Myrtaceae demand. Thus, the impact to the local floral industry will result mainly from any change in policy regarding imports of *cut* Myrtaceae. There are currently about 250 florists in Hawaiʻi, down from about 400 in the mid- to late-1990s. This decline is believed to be the result of three trends: the increased presence of “big box” department stores—typically, mainland-based supercenters—that have floral departments; the increased popularity of convenient internet-based floral delivery companies; and the lack of interest of younger generations to take over family-owned floral shops (M. Pereira, Watanabe Floral, personal communication). In the discussion that follows, businesses in the floral industry are classified into one of three groups: 1) superstores; 2) florists; 3) retail and commercial nurseries.

3.1.1 Superstores

Superstores buy large volumes of products from their distributors to sell at their many locations to the mass market and are thus able to offer products at lower prices than regular retail stores. This practice is also true of their floral departments, which, in Hawaiʻi, sell large quantities of potted plants, lei, bundled flowers and mixed bouquets.

The superstores' floral suppliers often fill mixed bouquets with eucalyptus, myrtle and waxflower because these plants create a quality bouquet and satisfy the desired price point. Due to the large volume, most floral packing for the mass market is done at the farm or wholesaler (see Loope 2010, p. 16) level on an assembly line for faster delivery to store and to provide a uniform product nationwide.

In the past, the floral department at Sam's Club Hawaiʻi was supplied by the company's mainland floral distributor. However, about five years ago, the company switched to a local vendor for all its floral products. A regional buyer suggested that the switch was made mainly to provide the freshest and highest quality floral products possible (M. Kalina, Wal-Mart, personal communication). Since the move, the floral department has grown, and is now moving a larger volume and an increased variety of products. The composition of mixed bouquets is at the sole discretion of the local vendor. Sam's Club sets a price point and requests a certain "perceived value" of the arrangement, while the vendor selects the flowers and fillers and assembles the bouquet based on product availability, quality and price. Thus, while Sam's Club Hawaiʻi has sold mixed bouquets containing Myrtaceae in the past, they do not order arrangements specifying its use as filler.

When asked about the expected impact of a policy affecting Myrtaceae imports, M. Kalina noted that the floral department represents a very small share of total revenue for any given store, and that because the local vendor selects the contents of the bouquets sold by Sam's Club, the burden of finding a filler substitute would fall on the vendor. Furthermore, since mixed bouquets currently sold at Sam's Club do not contain Myrtaceae, M. Kalina is certain that substitutes are already available at their desired price point and does not anticipate that the proposed rule would have any impact on her company's sales or revenues.

Wal-Mart, the sister company of Sam's Club, contracts with the same local vendor for its floral products (M. Kalina, personal communication). However, Wal-Mart carries a much smaller volume of floral products and often does not offer mixed arrangements. Therefore, Wal-Mart is in the same position as Sam's Club and would be essentially unaffected by a change in policy.

Costco Hawaiʻi does not currently use eucalyptus, myrtle or waxflower as fillers in mixed bouquets (D. Evans, Costco Hawaiʻi Regional Manager, personal communication). Corporate suppliers of Costco are of the understanding that Myrtaceae is still banned in accordance with the 2007 interim rule, and they have thus substituted away from Myrtaceae fillers for mixed bouquets. Consequently, there will be no impact on Costco's floral sales as a result of any change in Myrtaceae policy.

Safeway stores nationwide receive bulk floral shipments from Safeway Corporate, and each floral department within a store follows a uniform "recipe" for pre-made arrangements and mixed bouquets using these shipments. In the past, Hawaiʻi stores received the same shipments and recipes as all other mainland stores. However, about five years ago, prior to the interim rule, the Hawaiʻi Department of Agriculture (HDOA) began to confiscate boxes containing Myrtaceae, which were commonly used in the uniform recipes. Consequently, Safeway Corporate developed new Hawaiʻi-specific recipes and modified their shipments of floral products to Hawaiʻi stores accordingly (L. Areola, Safeway Kapahulu Floral Manager, personal communication). While Hawaiʻi Safeway stores imported large quantities of Myrtaceae in the past to use as filler, they have since stopped and now import alternative mixed greens to avoid potential loss of product altogether. Thus, any ban on imported Myrtaceae would have no impact on Safeway Hawai‘i floral sales. Moreover, there would be no transition period for the company because they already made the switch to Myrtaceae substitutes years ago and have since fully adjusted. When asked about using locally-grown Myrtaceae, L. Areola indicated that local growers would need to obtain a vendor contract with Safeway Corporate and have the ability to consistently supply all Safeway stores in the state to ensure uniform availability.

Based on the information gathered from our interviews, we believe that any change in policy regarding imported Myrtaceae—whether an outright ban, a ban based on origin or a ban of uncertified products—would not impact the superstores currently present in Hawai‘i.

3.1.2 Florists

A phone survey was conducted between August and December 2010 of all florists in the state whose contact information was available. Respondents were asked if they sell eucalyptus, myrtle or waxflower. The results from this survey are summarized in the table below.

Table 1. Hawai‘i florist survey of Myrtaceae

	Total Responses	**Eucalyptus**		**Myrtle**		**Waxflower**		**At Least One**
		Available	Sell	Available	Sell	Available	Sell	Available
O‘ahu	119	23.5%	47.1%	13.4%	36.1%	21.0%	44.5%	31.1%
Big Island	35	20.0%	48.6%	5.9%	20.6%	5.7%	31.4%	25.7%
Maui	35	22.9%	37.1%	8.6%	34.3%	25.7%	42.9%	34.3%
Kaua‘i	16	6.3%	31.3%	0.0%	31.3%	0.0%	31.3%	6.3%

Of all the florists who responded, less than 35% on each island regularly stock at least one of the three types of plants (“available” in Table 1). Counting those who did not indicate immediate availability but offered the option of placing a special order with their supplier ("sell" above), the number of florists who sell any one of the three plants does not exceed 50% of the total on any island. While the florists themselves may opt to use these plants in special orders or pre-made arrangements, many florists who could provide these plants said it was very rare for customers to order arrangements made with these specific fillers. And although the number of florists who carry Myrtaceae is not insignificant, some florists acknowledged that these fillers comprise a very small percentage of total sales (less than 1% in some instances).

We interviewed willing florists in person to obtain more detailed information about the revenue share of these three plants, their anticipated impact of a policy change and their potential adjustment strategy to find alternate fillers in the event of a ban on imported Myrtaceae. Florists that were in existence during the interim rule of 2007, were further questioned about any changes they made and effects they experienced during that period. Based on these discussions, florists were divided into three categories.

The first category consists of florists that substituted away from Myrtaceae altogether during the interim rule, regardless of origin. From their perspective, the rule was implemented very quickly and without warning. They therefore lacked sufficient time to make appropriate adjustments without disruption to Myrtaceae-related sales. The buyers for these businesses sought other filler plants that have as many of the desired characteristics as possible and that would be immediately available for use to minimize loss of sales. In some cases, florists were forced to locate new suppliers for these alternate options. Whether or not these businesses reverted back to imported Myrtaceae from infected areas once the interim rule expired, they are in an ideal position among all florists in the event of a current policy change; they have already identified the best filler alternatives and have the experience of implementing this change. Thus, if given ample notification prior to any change in policy regarding imported Myrtaceae, the impact to florists in this group will likely be minimal.

The second category is comprised of florists that switched to imported Myrtaceae from uninfected areas—anywhere except the designated areas of South America, California and Florida. These florists may have done some initial research on alternative fillers, but found it most convenient and least disruptive to sales to simply switch Myrtaceae sources. Consequently, while these businesses would likely be unaffected by a ban on Myrtaceae from infected areas only, they may be affected for a temporary transition period following an outright ban on all imported Myrtaceae. The duration and magnitude of the impact resulting from a total ban will likely be smaller the larger the time gap between passage and implementation of the policy.

The final group is comprised of florists that did not exist during the interim rule. These businesses will need to identify the best substitutes for Myrtaceae and implement any adjustments to minimize impact on sales. However, with sufficiently early notification prior to imposition of a ban combined with outreach efforts by the HDOA's Import Replacement Program, even these businesses could realize negligible impact during their transition period.

We thus conclude, based on numerous conversations with both large importers who have already substituted away from Myrtaceae following the interim rule and smaller merchants who currently sell Myrtaceae and would need to substitute, that beyond a potential transition period during which alternative fillers are sought and/or buying practices are modified, there will likely be no significant lasting economic impact on individual florists as a result of a ban on Myrtaceae imports.

3.1.3 Retail and Commercial Nurseries

During the same time period, between August and December 2010, a phone survey of all retail and commercial nurseries in the state was also conducted. Respondents were asked if they sell eucalyptus, myrtle and waxflower. Results from this survey are summarized in Table 2 below. With the exception of myrtle on O‘ahu, less than 12 percent of nurseries on each island sell these plants.

Whether or not the proposed rule would increase demand for locally grown Myrtaceae remains to be seen, but discussions with buyers who were affected by the 2007 interim rule revealed that local nurseries were perceived unable to offer the product consistently, and therefore florists as a whole opted instead for mainland-supplied alternative fillers. Although local Myrtaceae production could expand if a longer-term policy were implemented, we expect that the response is more likely to follow behavior observed during the interim rule. And while the year-long seed quarantine may impose some costs to growers, the import ban would prevent both damages to the current stock of local Myrtaceae and mitigative costs that nurseries would face if a successful *P. psidii* invasion were to occur.

Table 2. Hawai‘i retail and commercial nursery survey of Myrtaceae

	Total Responses	**Eucalyptus**		**Myrtle**		**Waxflower**	
		Available	Sell	Available	Sell	Available	Sell
O‘ahu	44	4.7%	9.3%	20.0%	20.0%	0.0%	0.0%
Big Island	59	3.4%	5.1%	8.6%	8.6%	1.7%	1.7%
Maui	36	11.1%	11.1%	5.6%	5.6%	2.8%	2.8%
Kaua‘i	19	5.3%	5.3%	15.8%	15.8%	0.0%	0.0%

Note: At a late date, it has been suggested to us by colleagues that we should have asked retail, commercial, landscaping and fruit tree nurseries "what plants in the myrtle family do you sell and do you import any plants or propagative material of those?" If a lot of Myrtaceae nursery stock material (e.g., jaboticaba, various *Eugenia* spp., allspice) is brought from the U.S. mainland or foreign countries, there could be some additional significant economic disruption. Our general impression had been that this was not an important practice, but we could have been wrong about that. Last minute inquiries to a number of representative nurseries have suggested that it may not be an important practice (and those contacted generally felt that there are adequate local seed and parent material sources to supply industry in Hawaiʻi and they support the restriction to protect Myrtaceae), but this may not be the last word. Additional information may come out in the public review process.

3.2 Forest Nurseries

Forest nurseries differ from retail and commercial nurseries in that they produce forest tree seedlings in quantities sufficient for reforestation and restoration. There are about a dozen forest nurseries in the state, most of which are small part-time operations (Friday, 2010). While a few sell seedlings to individual homeowners, most forest nurseries grow quantities of seedlings to order for specific projects. Some also have lines of plants produced for sale to retailers for eventual use by homeowners.

Table 3. Hawaiʻi forest nursery survey of Myrtaceae

	Total Responses	Imports Myrtaceae Non-Seed Material	Imports Eucalyptus Seed Only
Oʻahu	1	0	0
Big Island	5	0	2
Maui	2	0	0

Kaua‘i	2	1	1

Of the ten forest nurseries we were able to successfully contact, only one reported importation of non-seed Myrtaceae plant material, while three reported importation of eucalyptus seeds. Three out of those four importers expect that a policy affecting Myrtaceae trade would have a non-negligible impact on their business. Inasmuch as the cost of obtaining phytosanitary certification and shipping from out-of-state is already high, importers suggest that any additional costs (e.g. genetic testing of seeds) could be prohibitive, especially for smaller businesses. Although buying seeds locally may be a lower cost alternative, the variety of species is limited. The proposed rule, however, does not require costly genetic testing. Rather, it offers testing as a possible alternative to the standard one-year quarantine for firms interested in expedited seed entry.

An import ban on Myrtaceae non-seed plant material combined with a requirement of testing or quarantining imported seeds could potentially reduce sales for 4 of 10 local forest nurseries (Table 3). The benefits resulting from the reduction in the risk of contaminating existing stock with *P. psidii*, however, would be enjoyed by the 9 of 10 forest nurseries that grow eucalyptus, ‘ōhi‘a, or both. While the extent of the damages would depend on how virulent the particular rust strain is, the types of host plants (susceptibility varies), and the mitigative strategies adopted by the particular nursery, anecdotal evidence suggests that an outbreak could be very costly. In 2007, Native Nursery, LLC on Maui (E. Romanchak, personal communication) experienced an 8-10% mortality rate for over 17,000 ‘ōhi‘a seedlings and young saplings, even with a monthly treatment of Puccinia-specific fungicide costing approximately $200 per application.

3.3 Plantations

There are currently four privately owned industrial forestry plantations in Hawai‘i. While the state manages scores of plantations, these are grouped into seven large management units called "timber management areas," for example the Waiākea Timber Management Area on windward Hawai‘i Island. While eucalyptus is the primary type of tree planted for many of the state plantations, the government has issued timber licenses for only one (Waiākea). The discussion that follows focuses primarily on the potential costs and benefits to private industrial plantations of the Myrtaceae import policy. Much of the information in this section was gathered from personal interviews with two property managers, whose primary duties include land management, market research, and day-to-day plantation operations.

In Hawai‘i, eucalyptus was harvested, chipped and shipped overseas in the 1970s to produce pulp for paper production. More recently, however, eucalyptus has only been harvested in relatively small quantities for "boutique" uses such as flooring, mushroom cultivation, and furniture construction. Despite over a decade of attempts to build a large-scale veneer mill, there is no local industry to process the logs into veneer. Potential markets for eucalyptus in the foreseeable future include liquid for biofuel and biomass for energy, the latter of which yields a significantly lower value per ton.[4] In the economic analysis that follows, we assume that eucalyptus will be used in the future as feedstock for biofuel production.

[4] Two reviewers questioned the likelihood of whether Eucalyptus will be used as a biofuel in Hawai‘i. We agree that the future of the biofuel industry is uncertain and have noted some of our own qualms about the assumption in Appendix II, most notably the worldwide lag in technology for lignocellulosic conversion of plant tissue to biofuels and problems of scale in Hawai‘i for local refinery capacity. However, we feel that biofuel production in Hawai‘i will likely become a reality (some time in the future) given the Hawai‘i Clean Energy Initiative goals for 2030 (explained in footnote 14).

The current seed importation process takes roughly half a year from start to finish. The importer must obtain a permit from USDA-APHIS, request a phytosanitary certificate from the shipper, send the import permit to the shipper, have the seeds shipped (80% of seeds are currently obtained from South Africa), then wait for approval upon the seeds' arrival in Honolulu. The proposed Myrtaceae import policy would require an additional year of quarantine, but the perceived cost is fairly low, provided that permits can be eventually granted for expedited seed entry. Many existing plantations are likely to regenerate harvested stands via coppicing (i.e. growing sprouts from stumps) for up to two harvest cycles, which should provide ample time for the Hawaiʻi Board of Agriculture to consider alternatives to the one-year seed quarantine, such as sterilization or genetic testing.

The expected benefit of the import policy to plantation owners is determined primarily by the value of damages and costs avoided. If a successful *P. psidii* invasion were to occur, a portion of existing stands would be lost (given the conditions in Hawaiʻi, especially in rainforest climates, with leaf wetness as discussed below) and regeneration of stands would be significantly hampered. While the actual percentage cannot be perfectly predicted, previous experience in Brazil, where extensive Eucalyptus plantations have been established, beginning in the 1940-1960s and accelerating in the 1970s, indicates that the infection rate could be potentially high. For example, plantations in Brazil reported infection rates of 20-30% of the canopies of young trees (Tommerup and others 2003). An Australian contingency planning document reported that "seedling and young plants are the most severely impacted although yield losses from the disease in plantations in Brazil have reached as much as 40% (Commonwealth of Australia, 2006).

Zauza and others (2010) have developed an explanation for why in a typical eucalyptus plantation situation in Brazil, eucalyptus plants taller than 3–4 m are not infected by the pathogen even when new, developing leaves are present. They found that microclimatic conditions above a height of 3 m favor neither pathogen establishment nor disease development. Rust incidence decreases as height increases. Rust incidence was negatively correlated with the height gradient and positively correlated with both hours with leaf wetness and the concentration of airborne urediniospores, greater near the ground.

Would a future situation in *P. psidii*-susceptible *Eucalyptus* stands in Hawaiʻi likely be similar to Brazil's? Anecdotally at least, the impact of the Hawaii's *P. psidii* strain on rose apple (*Syzygium jambos*) has been greater than that observed elsewhere in the world, perhaps because of more consistent leaf wetness and more persistent trade winds, so that it might not be unrealistic to expect potentially greater impact on *Eucalyptus* in Hawaiʻi, especially in the Hāmākua area on the windward side of Hawaiʻi island that has a very wet climate and is where most of the plantations are located.

To combat a successful outbreak, plantation owners would need to select and breed for *P. psidii* resistance, which is a difficult and expensive process. Several types of resistant eucalyptus would need to be planted simultaneously, and even then, resistance to a particular strain of the rust does not guarantee resistance to newly introduced or mutated strains. Alternatively, non-susceptible, non-Myrtaceae feedstocks could be substituted for eucalyptus. However, if the target end-market is biofuels, substitution could be costly because alternative forestry feedstocks likely have a lower growth potential than eucalyptus, may be invasive in nature, and may require more water and/or land to grow.

Appendix II is provided to attempt to give a slightly broader view of the potential future importance of *Eucalyptus* forestry to Hawai‘i (beyond biomass and ethanol).

4 Economic Analysis: Costs and Benefits of the Import Policy

Using available information about Myrtaceae plant imports, sales data for Hawaii's floral industry, expected damages to plantations from *P. psidii*, the approximate value of current eucalyptus stands based on biofuel end-use, and estimated transition costs to current importers, we compare the benefits and costs for which monetary values are apparent. Section 4.1 discusses the costs of the proposed rule, and Section 4.2 details the potential benefits, including, in particular, avoided damages. In Section 4.3, we calculate the present value of the policy for a range of parameter values.

Present value (PV) is a concept used to compare dollar amounts from different time periods. The PV of a dollar amount in the future is the amount that would be needed today, given available interest rates, to produce that future amount (Mankiw, 2003). Thus, the PV of X dollars received at some point T years into the future is $X/(1+r)^T$ if interest is compounded annually at rate r, and Xe^{-rT} if interest is compounded continuously. Policies and projects tend to generate a stream of benefits and costs over time rather than a single amount, however, which must be discounted appropriately before being added or compared. If a project generates X dollars every year from now until year T, then the PV of the project is simply the sum of the present values for each X, i.e. $\int_{t=0}^{T} Xe^{-rt}\,dt$, where time zero denotes the current period. The *net present value* (NPV) is the PV of benefits net of project costs. While the discount rate (*r*) sometimes refers to the risk-free interest rate, there are often risks involved in any project, so *r* may incorporate a risk premium. In the calculations that follow, we assume a discount rate of 2%.[5]

4.1 Costs

The primary cost to importers of adapting to the policy is the time spent finding suitable Myrtaceae substitutes. We assume that the length of time (*h*) required per florist business to research and locate sellers of the desired substitute is 80 hours and that the hourly wage (*w*) of a representative florist is $30 per hour.[6] Given that the total number of florists (*N*) in the state currently selling Myrtaceae is estimated at 59, the total cost of searching for Myrtaceae substitutes (C_u), defined as the product $h * w * N$, is equal to $141,600.

Florists will also experience some lost sales during the transition period. In 2007, sales (*S*) in Hawaii's retail floral industry totaled $44 million (U.S. Census Bureau, 2010). Products containing Myrtaceae plant material comprise a very small percentage of total sales in the sector. One of the biggest florists on O'ahu, for example, estimated that Myrtaceae products make up less than 1% of their total sales (L. Watanabe, personal communication). We assume that the percentage of sales (θ) from Myrtaceae products is

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[5] Although economists are not in consensus on all of the issues surrounding intergenerational discounting, the consumption rate of interest can be used as a starting point for benefit-cost analysis (US EPA, 2010). Based on returns to government-backed securities, current estimates of the discount rate are in the 2-3% range. We also calculate the NPV for the White House Office of Management and Budget's recommended 7% rate for the opportunity cost of private capital, as well as the discount rate for which the policy breaks even, i.e. for which NPV=0.

[6] As discussed in Section 3.1, Myrtaceae is used as a filler in products that comprise a very small fraction of total sales (detailed further in the current section). In addition, the proposed Import Replacement Program (IRP) would assist florists with finding suitable substitutes. Given that florists were able to transition relatively quickly in response the 2007 interim rule, even without advanced notice or an IRP, we feel that 80 hours of search time is a reasonable assumption.

roughly the same for all florists and equal to 1%. Since this follows the observation from a large florist, the 1% can be viewed as an upper bound on θ. Given that the proportion (m) of florists in the state who sell any type of Myrtaceae is 29%, and assuming that the period of losses continues for no more than one year following the implementation of the policy, the cost to florists in terms of lost sales (C_s),[7] defined as the product $S * m * \theta$ is equal to \$126,332. The total cost of the policy, is therefore, $TC \equiv C_u + C_s \approx \$268{,}000$.

While nurseries and plantations will also face costs in adjusting to the proposed rule, those costs may be small relative to the benefits to all local growers who currently maintain stocks of Myrtaceae and ‘ōhi‘a. As can be seen in Table 2, very few of the nurseries we contacted have Myrtaceae readily available for sale (at most 25% for any given island). And based on discussions with people in the industry, most do not import saplings or seedlings. The main costs, therefore, would involve adjustments in planning to account for the one-year quarantine of imported seeds and/or searching for local seed suppliers. Similarly in the forest plantation industry, few import non-seed Myrtaceae plant material (1 of 10), while nearly all (9 of 10) grow rust-susceptible eucalyptus and/or ‘ōhi‘a (Table 3). Given the relatively small proportion of growers potentially affected by the policy and the fact that most growers import seeds in favor of plant material which presumably means local propagation is feasible using seeds from existing plants or other local sources, excluding policy-induced costs to growers should not affect the overall conclusions drawn from the net present value calculations. Although the total transition cost to florists and nurseries is at least \$268,000, the \$200,000 budget for HDOA’s Import Replacement Program would be used largely to reduce that burden.

4.2 *Expected Benefits (Avoided Costs)*

The expected benefit calculations that follow are fairly conservative in that we consider primarily the avoided losses to the eucalyptus industry alone. If data were more readily available, the same techniques could be applied to measure potential benefits for

[7] The measure likely overestimates losses to florists since it ignores the fact that profits are only a fraction of revenues and that florists would substitute other products for Myrtaceae.

retail, commercial, and forest nurseries. At the same time, however, the future of biofuels in Hawai‘i is largely uncertain (see Appendix II). We calculate the expected benefits for a certain stream of profits generated by eucalyptus and incorporate uncertainty only with regard to the unknown time of rust invasion. If we had more confidence in the distribution of possible future outcomes for the eucalyptus industry, that aspect of uncertainty could be directly integrated into the model.

While the exact time of a successful future rust invasion (*T*) is unknown, the expected net benefit with and without the policy could be calculated if we could parameterize a hazard function for each scenario. The hazard function is a measure of the tendency to fail (in this case, failure constitutes a successful invasion); the greater its value, the greater the probability of impending failure. Therefore, a policy restricting the import of Myrtaceae would reduce the hazard rate, or the probability of successful rust invasion in any given period. If β represents the status quo annual rate of invasion conditional on invasion not having yet occurred, then the policy-free time-dependent rate of invasion is

$$\phi(T) = \beta e^{-\beta T},$$

where the conditional probability β is discounted by the likelihood that invasion has already occurred by time *T*. Supposing that the policy reduces the annual conditional probability of invasion by $\tilde{\beta} < \beta$, the time-dependent invasion rate under the policy is

$$\phi'(T) = (\beta - \tilde{\beta})e^{-(\beta - \tilde{\beta})T}.$$

The change in invasion risk can then be calculated as the difference

$$P(T) = \phi(T) - \phi'(T) = \beta e^{-\beta T} - (\beta - \tilde{\beta})e^{-(\beta - \tilde{\beta})T}.$$

Although we do not know the exact status quo probability of invasion, through discussions with local *P. psidii* experts, we have constructed estimates for the change in the annual conditional probability of invasion induced by the policy ($\tilde{\beta}$). Given that Myrtaceae trade is the primary pathway of *P. psidii* invasion and that a ban on importing plant material and a one year seed quarantine are fairly stringent requirements, we assume that $\tilde{\beta} \approx \beta$, i.e. the policy effectively eliminates the threat of invasion once implemented.[8] It follows that $\phi'(T) \approx 0$ and the change in risk invasion is approximate by the function $P(T) = \phi(T) = \beta e^{-\beta T}$. The parameter β can be interpreted as both the status quo conditional probability of invasion and the policy-induced reduction in the conditional probability of invasion.. In our baseline scenario, we assume that β is equal to 0.1.[9]

In order to estimate the avoided damages, one also needs to determine the profit per gallon of biofuel, the gallons of biofuel producible annually from existing eucalyptus stands, and the expected yield losses of eucalyptus in plantations if a successful rust invasion were to occur. Although capital expenditures are likely to be substantial for a processing facility, they would be sunk costs, meaning that the presence of *P. psidii* would not change existing capital expenditures. It would, however, change the revenue generated annually, which is the focus of the subsequent calculations. In a biofuel feasibility study for the southern United States, Gonzalez and others (2011)[10] estimate

[8] In reality the threat of invasion is not completely eliminated, which means that results based on the assumption of complete elimination biases the NPV calculations upward.
[9] Discussions with resource managers, scientists, and other local *P. psidii* experts (including early reviewers of the report) have provided guidance in determining that 0.05-0.2 is a reasonable range of values for β.
[10] The corresponding numbers in Hawai‘i could be different, although the lack of a current market for ethanol makes a quantitative assessment quite difficult. Generally if input prices are higher and output

that a refinery that processes 453,592 metric tons per year (Mg/yr) would yield profits of roughly $21.7 million/yr.[11] And given current refining technology, every Mg of eucalyptus biomass can be converted to 369.3 liters (97.6 gallons) of biofuel. At the price of $0.66/L ($2.50/gal), each Mg of eucalyptus generates revenues of $243.74. The study estimates that feedstock costs of $66.1/Mg account for roughly 33% of the total costs (not including capital expenditures). Thus, total production cost is $198.30/Mg, and net profit is $243.74 - $198.30 = $45.44/Mg.[12] The profit margin, therefore, is $45.44/$243.74 = 18.6%, and the per gallon profit (π) based on the current ethanol price of $2.64/gallon (USDA, 2011) is $0.49.

Eucalyptus yield estimates are taken from a Hawai‘i study by Tran and others (2011). The authors report that eucalyptus yields 7.8 tons of biomass/acre/year, based on a 10-year harvesting cycle. Multiplying that figure by the approximately 24,700 acres of planted eucalyptus (J.B. Friday, personal communication), gives a total of 192,660 tons (174,778 Mg) of biomass producible per year, and consequently the total volume of ethanol producible from eucalyptus per year (*G*) is approximately 17 million gallons.

The policy-induced decrease in potential losses for a given year are determined by the reduction in probability of invasion (*P*), the yield loss rate (*L*) of eucalyptus in plantations (assumed to be 30% in the baseline case); the profit per gallon of biofuel ($0.49/gallon), and the total gallons of biofuel producible annually by existing eucalyptus

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prices are lower in Hawai‘i, then the NPV calculations will be biased upward, i.e. potential benefits and hence avoided losses will be overestimated.

[11] They calculate a negative net present value (NPV) for ethanol production, assuming a discount rate of 12%. However, the study finds that as long as investors have a discount rate less than 11.4%, they will be willing to foot the large start up costs. This may already be the case in Hawai‘i, given current plans for Hu Honua’s 24 MW bioenergy facility (http://www.huhonua.com).

[12] The total cost includes a freight charge of $9.8/Mg to cover a distance of 48.3 km. The distance between eucalyptus stands on the Hamakua coast on the Big Island and Hu Honua’s planned 24 MW bioenergy facility in Pepeekeo is also roughly 50 km, so we do not adjust the freight estimate.

stands (17 million gallons). Inasmuch as profits will be accruing in the future, however, the present value (PV) of benefits should be calculated to reflect the time value of money. The PV of benefits from the proposed import policy over a fifty year time horizon is:[13]

$$B = \int_{T=10}^{50} \left[P(T) \int_{t=T}^{50} (L \times \pi \times G) e^{-rt} \right] dT.$$

Losses can potentially accrue starting from year 10 when it is assumed that the biofuel sector would begin producing benefits.[14] The reduction in probability of a successful invasion at year *T* is accounted for by the function *P(T)*. The total expected benefit is calculated by integrating over all values of *T* for which benefits potentially accrue, i.e. from year 10 to 50, and discounting to the present at rate *r*=2%.

4.3 Net Present Value of the Import Policy

The net present value of the import policy is calculated according to the following equation:

$$NPV = \int_{T=10}^{50} \left[P(T) \int_{t=T}^{50} (L \times \pi \times G) e^{-rt} \right] dT - h \times w \times N - S \times m \times \theta$$

Table 4. Summary of parameters and values

Symbol	Description	Baseline Value
T	Time at which a virulent rust strain is introduced	N/A
P(T)	Policy induced change in invasion risk	N/A
β	Annual conditional probability of invasion with the policy in place	0.10
t	Index of time (years)	N/A
L	Expected yield loss for eucalyptus in plantations	30%

[13] Although a 50 year time horizon is assumed for practical planning purposes, the benefits of the policy would technically accrue in perpetuity, i.e. the time horizon should be infinite. The implications of relaxing the finite horizon assumption are discussed in Section 4.3.
[14] Given the Hawai‘i Clean Energy Initiative’s goal of achieving 70% clean energy by 2030 with 30% coming from efficiency measures and 40% coming from locally generated renewable sources (www.hawaiicleanenergyinitiative.org), we feel that biofuel production could start producing benefits within the decade.

π	Profit per gallon of biofuel	\$0.49/gal
r	Discount rate	2%
G	Total gallons of biofuel from eucalyptus per year	17 M gal/yr
h	Hours of labor required to adjust to policy per firm	80 hrs
N	Number of florists that sell Myrtaceae	59
w	Hourly wage of florists	\$30/hr
τ	Length of transition period	1 yr
S	Total florist sales in Hawai'i per year	\$44 M/yr
m	Percentage of florists that sell Myrtaceae	29%
θ	Percentage of sales from Myrtaceae products	1%

Given the baseline parameter values summarized in Table 4, the net present value of the proposed rule is \$14.3 million. Table 5 includes a list of both monetized and non-monetized benefits and costs expected to be generated from the policy. Benefits absent from the NPV calculation include avoided damages to nursery growers of Myrtaceae and avoided damages to ‘ōhi‘a, while non-monetized costs borne by florists and nurseries included those related to finding local seed suppliers, switching to local propagation of Myrtaceae and/or building the one-year seed quarantine into production plans.

Table 5. Benefits and costs of the proposed policy (baseline scenario)

Benefits	
Nurseries	
Avoided damages to Myrtaceae products[a]	B_1
Plantations	
Avoided damages to Eucalyptus[b]	\$14.3 million
All residents of the state	
Avoided damages to ‘ōhi‘a[c]	B_2
Costs	
Florists	
Finding Myrtaceae substitutes (C_u)	\$141,600
Lost profits during transitional period (C_s)[d]	\$126,332
Nurseries	
Finding local seed suppliers, switching to local propagation, and/or building one-year quarantine into production plan[e]	C_1
Plantations	
Finding local seed suppliers, switching to local propagation, and/or building one-year quarantine into production plan	C_2
Net benefits	\$14 million + $B_1 + B_2 - C_1 - C_2$

[a]90% of forest nurseries grow Eucalyptus and or ʻōhiʻa so this value could be substantial.
[b]Assumes biofuel end-use. Value will be lower if Eucalyptus is used for flooring, furniture, etc.
[c]Other valuation studies suggest that this value is significant (see Section 4.4).
[d]Calculated using sales instead of profit data so should be viewed as an upper bound.
[e]Only a small proportion of growers import Myrtaceae so this value is not expected to be large.

The NPV is also calculated for alternative parameter values. The NPV is lower when β is higher because delayed production in the biofuel sector creates opportunities for larger avoided losses if the risk reduction *P(T)* start low but decline more slowly over time (see Figure 1 for a comparison of *P(T)* curves under different assumptions about β). On the other hand, NPV is higher when *L* is higher, i.e. the eucalyptus yield loss resulting from a virulent rust strain is higher. Even in the most conservative scenario, the NPV is almost $2 million. If a particularly virulent strain is likely to arrive, conditions in Hawaiʻi are more favorable for *P. psidii* to thrive than in Brazil, and the proposed policy is effective, the NPV could be upwards of $30 million. The results are summarized in Table 6.

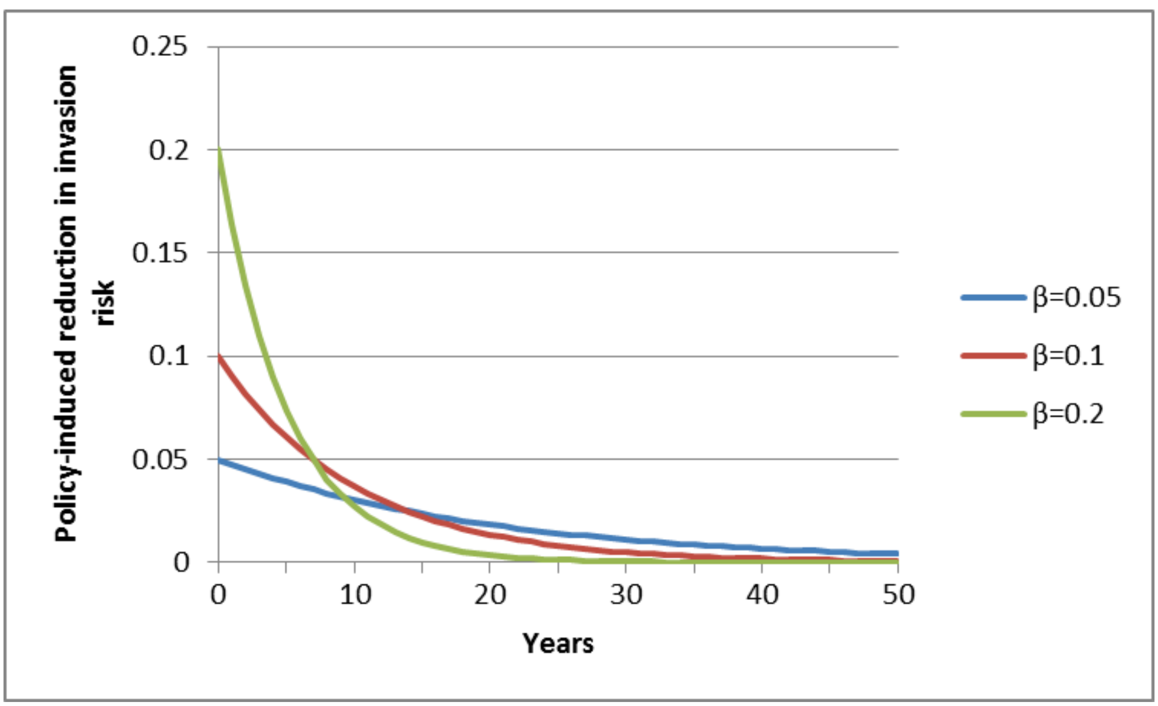

Figure 1. ***P(T)*** **curves for different values of** β

Table 6. Sensitivity analysis – conditional probability and yield loss

	L = 10% (Low)	L = 30% (Baseline)	L = 50% (High)
$\beta = 0.05$ (Low)	$5.6 million	$17.3 million	$29.0 million
$\beta = 0.10$ (Baseline)	$4.6 million	$14.3 million	$24.0 million
$\beta = 0.20$ (High)	$1.9 million	$6.1 million	$10.4 million
β: annual conditional probability of invasion with the policy in place L: yield loss to eucalyptus plantations if a virulent strain of rust is successfully introduced			

The NPV calculations will also largely depend on the selected discount rate and time horizon (Table 7). Increasing the discount rate to 7% reduces the NPV of the policy by over $10 million from $14.3 to $3.2 million in the baseline case because a higher discount rate places a lower value on future benefits. Increasing the time horizon from 50 years to infinity has a large impact when the discount rate is low (NPV rises from $14.3 to $31.2 million for $r = 0.02$) because benefits accruing far into the future are valued highly in the present. The effect is much smaller for higher discount rates, however. In fact, when the discount rate is sufficiently high, the time horizon has no discernible effect on the NPV; for $r = 18.5\%$, the NPV is zero for both a 50 year and an infinite time horizon. As the interest rate increases, the time at which NPV approaches zero increases. If the present value of future benefits is lower, the horizon must be longer to allow enough of the expected benefits to accumulate to offset the costs.

Table 7. Sensitivity analysis – discount rate and time horizon

	Horizon = 50 years (Baseline)	Horizon = infinite	Break-even time
r = 0.02 (Baseline)	$14.3 million	$31.2 million	12.8 years
r = 0.07 (High)	$3.2 million	$3.6 million	14 years
Break-even rate	0.185	0.185	-
Note: all calculations are based on baseline parameter values described in Table 6.			

In all scenarios, the NPV is positive, and the estimates would be even higher if we could quantify the avoided damage to ʻōhiʻa, as well as mitigation and adaptation costs (e.g. fungicidal treatment and/or selecting for rust-resistant species) faced by eucalyptus plantation owners. In addition, although we have focused on privately owned plantations, eucalyptus and ʻōhiʻa are present on state-owned land, so including the value of those additional stands would further increase the benefits of the proposed import policy.

4.4 Value of ʻōhiʻa

We do not measure the value of ʻōhiʻa directly in this exercise, but the avoided damages to the native forest are expected to be substantial and likely higher than avoided damages to the affected industries. For example, Kaiser and others (2000) estimated the total PV of ecosystem services generated by the Koʻolau Watershed on Oʻahu — of which ʻōhiʻa is a principal component — to be in the range of $7-14 billion. More specifically, the healthy forest structure increases fresh groundwater recharge and provides habitat provision for many iconic, endemic and endangered species. Although the ecosystem services provided by the watershed cannot be attributed entirely to the presence of ʻōhiʻa, the total benefits are underestimated, inasmuch as cultural value is not included in the calculation. Moreover, the estimated PV is for a single watershed, whereas the proposed rule would prevent reductions in ecosystem service provision for multiple watersheds on all islands throughout the state. If the import restriction prevented the loss of even 1% of the lower estimated value of $7 billion in our baseline scenario, then the NPV of $14.3 million should be adjusted upward by $70 million. If the value of ʻōhiʻa is higher and/or the policy-induced avoided losses larger, then the net present value would be even greater.

5 Conclusion

The objective of this report was to calculate the net present value of a potential policy that would ban imports of Myrtaceae (non-seed) plant material to Hawai‘i and require a one-year quarantine for imported seeds. Benefits to plantation owners in the form of avoided *P. psidii* damage were calculated under the assumption that eucalyptus would be used primarily as feedstock for biofuel in the future. Other benefits not monetized in the analysis include avoided damages to growers of Mytaceae and ‘ōhi‘a, as well as avoided damages to ‘ōhi‘a forests, which provide many important ecosystem goods and services to local residents. The primary costs quantified would accrue to florists and include both the lost profits during the transition period and the resources required to find suitable Myrtaceae substitutes. The costs to nurseries and plantations of finding local seed suppliers, switching to local propagation, and/or building the one-year quarantine into production plans were not quantified, although the relative size of those costs is expected to be small in comparison to the total NPV.

A hazard function was parameterized based on discussions with *P. psidii* experts to incorporate uncertainty about the arrival of new *P. psidii* strains, given the proposed policy. In the baseline scenario—assuming a discount rate of 2%, a 50 year time horizon, a policy-induced reduction in the likelihood of a successful rust invasion starting at 10% and declining over time, and yield losses to eucalyptus plantations of 30%—the NPV was estimated at $14.3 million, which suggests that benefits of the proposed import policy largely outweigh the costs, even when potential damages to native ‘ōhi‘a forests are not directly accounted for. In the most conservative scenario (flatter invasion risk curve, lower yield losses), the NPV was still positive and equal to $1.9 million. If the time horizon is at least 50 years, any discount rate less than 18.5% yields a positive NPV. This follows from the fact that costs are accrued immediately, while large expected benefits are only generated following year 10. The break even time horizon (i.e. when NPV=0) occurs at 12.8 and 14 years for discount rates of 2% and 7% respectively. In other words, the policy must be enforced for at least 12.8 years to ensure a positive NPV if the benefits to ʻōhiʻa forests are not accounted for.

In reality, however, the benefits of protection are enjoyed by ʻōhiʻa from the moment the policy is implemented, and those benefits could be substantial. Previous studies have estimated that the ecosystem benefits provided by the state's watersheds, which are comprised largely of ʻōhiʻa forests, are upwards of $7 billion. Thus, if a successful *P. psidii* invasion were to reduce that present value by as little as 1%, avoided damages would be at least $70 million. Therefore, even if avoided losses are overestimated for the eucalyptus industry given the uncertainty about the feasibility of commercial biofuel production in the future, the ecosystem benefits provided by ʻōhiʻa are of at least a similar magnitude.

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Appendix I. Background on the earlier interim rule and recent genetic findings

In response to a preliminary evaluation of the risk posed by additional strains of this pathogen species (Loope and La Rosa 2008), Hawaii's Board of Agriculture approved a 12-month interim rule to stringently regulate incoming plants and plant parts in the family Myrtaceae from "infested areas". However, this rule expired in August 2008 after the 12-month period authorized by Hawai'i State Law for interim rules for plant quarantine. Leadership of Hawai'i Department of Agriculture felt at that time that they lacked an adequate basis in sound science for a long-term rule, given that there was little available knowledge of the genetics of *P. psidii* in relation to its utilization of diverse hosts.

This situation involving a perceived deficit of sound science has quickly changed, however, based on results of research underway by a team comprised of collaborating individuals, primarily with University of Viçosa in Brazil and the USDA Forest Service (Cannon and others 2009, Western Wildland Environmental Threat Assessment Center 2011).

The important results from the recent genetic studies were summarized in a letter from N.B. Klopfenstein of the USDA Forest Service to C. Okada of HDOA (7/15/2011):

> It has come to my attention that your agency and others require information about the known genetic diversity of *Puccinia psidii* in comparison to that which presently exists in Hawaii. The most definitive study to date was performed by Dr. Rodrigo Neves Graça as a part of his Ph.D. research with Prof. Acelino

Couto Alfenas at the Universidade Federal de Viçosa in Brazil. I served on Rodrigo's Ph.D. committee, I am a collaborator on some of these studies, and much of this research was performed in our USDA Forest Service laboratory. For this reason I can vouch for the quality of this research and the validity of the results. This information is published in Rodrigo's dissertation, and is in preparation for journal publication.

The aforementioned genetic studies used microsatellite markers to genotype diverse sources of *P. psidii*, derived from diverse locations and hosts. These studies determined the following: 1) Only one *P. psidii* genotype has been found on the Hawaiian Islands, and this genotype is capable of infecting multiple hosts. This unique genotype was also found in California, but it was not found in sampled populations from Brazil, Uruguay, or Paraguay; 2) Another distinct 25 *P. psidii* genotypes were characterized in South America, and these genotypes were host-specific on seven different myrtaceous species, including *Eucalyptus* spp., *Syzygium jambos*, *S. cumini*, *Psidium araca*, *P. guajava*, *Myrciaria cauliflora*, and *Eugenia uniflora*.

In short, multiple genotypes of *P. psidii* are known to exist, and these genotypes have different host specificity. **Because only one *P. psidii* genotype is known to exist in Hawaii, the introduction of additional *P. psidii* genotypes represents an additional risk or threat to myrtaceous species in Hawaii.**

Additional studies relating to the pathogenicity of some of the more common Brazilian genetic strains of *P. psidii* to Hawaii's ʻōhiʻa were described by P. Cannon of the USDA Forest Service in a presentation at the Hawaiʻi Conservation Conference on

August 3, 2011. The research presented by Cannon was designed to address the question of whether the Brazilian strains were likely to be pathogenic to ‘ōhi‘a:

> [They] wanted to ask the question, are any of these other strains of *Puccinia psidii* likely to be highly pathogenic on ‘ōhi‘a? To get an answer to this question a fairly elaborate and comprehensive experiment was set up. It took over three years to complete this experiment.
>
> First of all, Rob Hauff [State of Hawai‘i DLNR DOFAW] organized a collection of seed from many different families of ‘ōhi‘a from all over the Hawaiian Islands. This seed was shipped to Viçosa, Brazil where seedlings were produced from each family lot.
>
> Then, in a well replicated (six blocks) split plot experiment, each of five of the different *Puccinia psidii* strains was inoculated, using equal aliquots of inoculums and under very carefully controlled conditions, onto each of 11 different families of ‘ōhi‘a. Most of this inoculation work was done by Pedro Andrade but all under the supervision and with plenty of guidance from both Acelino Alfenas and Rodrigo Graça.
>
> The results of this large experiment clearly show that three of the five strains of *Puccinia psidii* (the Eucalypt, Rose Apple and Jaboticaba strains) are each very highly pathogenic on ‘ōhi‘a, while two of them (the Guava and the Araca strains) have virtually no impact at all.

The early but definitive results capsulized above are partly “in press” (e.g., Graça and others 2011 in press) with more definitive articles based on chapters in Graça’s Ph.D. dissertation (successfully defended in January 2011) proceeding toward publication.

Pedro Andrade (also a graduate student of Prof. Acelino Alfenas at U. of Viçosa) will also complete a thesis including more comprehensive analysis of impacts of various strains of the rust on ‘ōhi‘a. The research underway on the genetics of *P. psidii* promises to develop into major international collaboration now that this pathogen is spreading to other countries (e.g., Australia, where a variant of *P. psidii* arrived in April 2010, Carnegie and others 2010).

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Appendix II. Background on Hawaii's forest industry and *Eucalyptus*

Substantial public-private investment has gone into development of the basis for a *Eucalyptus*-based industry in Hawai‘i, primarily motivated by the recognition of potential for bioenergy (e.g., Whitesell and others 1992, Phillips and others 1995, 1997). A 10-year research and development program was conducted in the 1980s by the BioEnergy Development Corporation, USDA Forest Service, and U.S. Department of Energy on the island of Hawai‘i, where nearly 230,000 acres were considered suitable for growing biomass in short-rotation *Eucalyptus* plantations (Whitesell and others 1992). Planting 20,000 acres of *Eucalyptus* on former sugar lands at establishment costs of ca. $1000/acre pumped $20 million into the local economy at a vulnerable time following collapse of the sugar industry. However, relatively inexpensive oil allowed Hawai‘i to cope economically with use of petroleum for production of electrical energy. That situation is drastically changing for Hawai‘i, and the world energy paradigm is changing from one based on petroleum to one based on a mixture of energy platforms (e.g., Johnson and others 2007). However, technology for lignocellulosic conversion of plant tissue to biofuels has lagged – progress is being made but we may still be 5-10 years away from an economically viable process for ethanol production from cellulose (Gnansounou and Dauriat 2010).

Furthermore, Johnson and others (2007) bring to the forefront the issues that cellulosic ethanol production will raise -- concerns over “competing uses for crop or crop products, co-products, competition for land base, and management strategies to protect soil, water, and climate resources. As the energy paradigm shifts, the balance among competing needs will be critical to achieve sustainable food, fiber, and energy while protecting the soil resource and the environment." And Hawaiʻi has special vulnerability of its endemic biota and native ecosystems to biological invasions, dramatized by the fact that the state has well over 300 federally listed endangered species (Loope 2011). Can the seemingly substantial promise for using *Eucalyptus* be achieved in an economically viable way to assist Hawaiʻi in meeting its energy needs while protecting its environment? Though not without challenges, we believe that goal may be achievable if wisely approached through a public-private partnership of the type advocated by Sheppard and others (2011) to facilitate a condition with beneficial biofuel supply with acceptable environmental impacts. *Eucalyptus* forestry provides potential for energy, economic and possibly environmental gains for Hawaiʻi. We will attempt here to articulate an abbreviated vision of what might be entailed.

Addressing the serious threat of insect pests and pathogens

Early proponents of *Eucalyptus* understandably failed to grasp the severe threat of insect pests and fungal pathogens. Two decades ago, Whitesell and others (1992) reported that *Eucalyptus* plantations both in Hawaiʻi and worldwide exhibited "relative freedom from pest damage." That had been the case worldwide initially since *Eucalyptus* was introduced to far-flung locations over nearly a century as relatively small numbers of seeds (Wingfield and others 2001, Paine and others 2011). But that privileged status had already begun to change, especially in Brazil where (Australian) *Eucalyptus* plantations were affected severely by the native (to Brazil) rust fungus *Puccinia psidii*, but though pest problems were arising as *Eucalyptus* forestry expanded worldwide (Wingfield and others 2001), Hawai‘i was still largely problem-free. Liberalization of phytosanitary practices to encourage free trade started in the 1980s and went into full swing in the 1990s, adding horticulture as a major pathway for pests of *Eucalyptus* and Myrtaceae as well as virtually all other taxa (Campbell 2001, U.S. Department of Agriculture 2005, Brasier 2008).

Problems and potential problems with *Eucalyptus* epitomize the generic situation with huge risk and need for proceeding carefully for all biofuels policy (Sheppard and others 2011). The pest situation is potentially dire for the eucalypt industry worldwide, in the view of forest pathologist Michael Wingfield, Director of the Forest and Agricultural Biotechnology Institute at University of Pretoria, South Africa (Wingfield and others 2008):

> When eucalypts have been planted in areas where these trees or their close relatives are native, the impact of pests and pathogens emerged as a limiting factor very rapidly. Planting eucalypts as non-natives has provided outstanding opportunities to capitalise on the absence of pests and pathogens. This is a situation that is clearly changing and the costs relating to pest and pathogen management will certainly increase. It is likely that profits will coincidentally also drop and competition to produce fibre profitably will emerge as a driving force in plantation forestry.
>
> All available evidence suggests that *Eucalyptus* plantation forestry based on non-native species is likely to be increasingly threatened by pest and disease problems. New introductions are occurring increasingly more frequently and there is no reason to believe that this trend is likely to change. While we would

> not wish to be negative, our view is that successful forestry companies will be those that clearly recognise the reality of the situation and that plan accordingly.
>
> Resolution of pest and disease problems in *Eucalyptus* forestry already lies firmly in the implementation of modern technologies. As new problems emerge, new technologies will also follow. These should make it possible to deal with even the most complex pest and disease problems. However, the driving issue here is whether companies will have the vision to invest in these technological opportunities sufficiently rapidly to avoid levels of damage beyond the so-called 'point of no return'. Our belief is that companies failing to invest vigorously in disease and pest avoidance strategies, and to do so early, will be doomed to failure. This might appear as a strongly pessimistic view but there are sufficient examples of failure in forestry and agriculture due to pests and pathogens that the future appears relatively clear.

Fortunately, there is evidence that the Hawai'i Forest Industry Association and its members recognize the risks and are supportive of the public-private partnership concept in protecting native 'ōhi'a forest and *Eucalyptus* from *Puccinia psidii* and other pests of Myrtaceae (e.g. Lake 2011).

Issues of biodiversity conservation vs. *Eucalyptus* plantations in Hawai'i

The biodiversity conservation community in Hawai'i in general harbors resentment (B.H. Gagné, State of Hawai'i DLNR DOFAW, personal communication) toward past plantings of *Eucalyptus* in cases when native forest was bulldozed to clear sites in Forest Reserves for planting of *Eucalyptus* and other non-native forestry trees in the

1960s and 70s, most of which were never harvested.

Foster and Robinson (2007) described the history of part of their 54 ha (130 acre) study area in Makawao Forest Reserve, Maui, over four decades later:

> "Native forest was cleared in half of the study area in 1960. Roughly 5% of the native ohia (*Metrosideros polymorpha*) and koa (*Acacia koa* Gray) trees were left standing, based on aerial photos from 1965… The exotic canopy trees [tropical ash canopy (*Fraxinus uhdei*), with assorted *Eucalyptus* spp.] were planted from 1962 to 1964, 2–4 years after bulldozing of the native forest."

The following material from Loope and La Rosa (2010), mostly synopsized from Little and Skolmen (1989), gives a quick summary of Hawai'i's *Eucalyptus:*

> Very significant plantings of non-native Eucalyptus species were made in Hawai'i, primarily on degraded lands of the five main Hawaiian islands, with most planting activity in the 1930s and 1960s. Frequently, they are single-species plantings of *Eucalyptus robusta*, a tree with thick reddish brown bark; more than 2.3 million trees were planted by the Hawai'i Division of Forestry before 1960 and similar numbers were planted by private landowners (Little and Skolmen 1989). *E. saligna*, a tree with smooth bluish gray bark, is the only species that rivals *E. robusta* in quantity; 437,000 trees were planted prior to 1960 and one million trees after 1960 (Little and Skolmen 1989). Along highways at low elevation the most common other species seen are *E. citriodora* (now included in *Corymbia*), with gray dimpled bark, and *E. deglupta*, with pink and green scaly

bark. At higher elevations, the common species are *E. sideroxylon*, with black bark, and *E. camaldulensis*, with bark mottled gray and brown. Hawai‘i has more than 90 species of *Eucalyptus* as well as many closely related Australian Myrtaceae, and they are often found in mixed plantings. Additional common *Eucalyptus* spp. include: *E. botryoides, E. globulus, E. grandis*, *E. microcorys, E. paniculata*, *E. pilularis*, and *E. resinifera* (Little and Skolmen 1989).

During the 1980s, a research project was conducted in the Hāmākua and Ka‘u districts of the Big Island that developed guidelines for establishing and managing short-rotation (5 to 8 years) *Eucalyptus* plantations in Hawai‘i and explored whether woody biomass is a suitable source of bioenergy (Whitesell and others 1992). *Eucalyptus grandis* and *E. saligna* were found to be the best performers. Provenances, specific areas where seed should be obtained, were identified in Australia for those two species (Skolmen 1986).

In the decade after 1996, more than 20,000 acres of industrial eucalyptus plantations were established in Hāmākua, Ka‘u, and Waimea. Most of these were pure stands of *E. grandis.* An additional 2,000 acres of mixed *E. deglupta* and *Falcataria moluccana* stands have been established on Kaua‘i. These plantations are intended for commercial harvest, either for solid wood products or bioenergy (J.B. Friday, pers. comm.).

Although about one-third of the 90-plus eucalypt species present in Hawai‘i have been recorded as naturalized (Clyde Imada, Bishop Museum, pers. comm.), relatively few are significantly invasive. Though *Eucalyptus* is one of the most widely planted genera outside its native range in the world, “they have been orders of magnitude less successful as invaders than pines and several other widely planted trees... Where eucalypts have invaded, they have very seldom spread considerable distances from planting sites…" (Rejmanek and Richardson 2011).

Realistically, a situation has likely been reached where a majority of conservationists would agree that the greatest threat to native forest in Hawai'i may be the rust *Puccinia psidii,* though invasive plants such as miconia (*Miconia calvescens*), strawberry guava (*Psidium cattleianum*) and albizzia (*Falcataria moluccana*) compete for that dubious honor. Stands with *Eucalyptus* are generally very impoverished in native species (Ostertag and others 2008) and unlikely to be restored to native ecosystems. Conversely, it is unlikely that we will ever again see bulldozing of native ecosystems to plant *Eucalyptus* or other biofuels in Hawai'i.

Biodiversity conservationists and foresters clearly have a powerful common cause for preventing arrival of new strains of *Puccinia psidii.* Though trying to forecast the future has its hazards, there may eventually be opportunities for those groups and others to pull together for strategies to address some of Hawai'i's environmental needs, including energy self-sufficiency. There are undoubtedly more energy-rich biofuels than ethanol that may lend themselves to production from *Eucalyptus* in Hawai'i. For example, bio-oil, potentially produced from *Eucalyptus* by a pyrolysis process (Laird and others 2009) and refinable as an energy-rich liquid fuel for transportation, appears to be a strong candidate for a "next generation of biofuels" (e.g., Savage 2011, Fairly 2011); production of biochar as an important by-product might be feasible if its environmental benefits (carbon sequestration and soil improvement) and absence of significant negative impacts can be verified (Barrow 2012). Whether the critical mass of feedstock will exist in Hawai'i for pyrolysis and bio-oil refinery capacity also remains to be seen, as does whether *Eucalyptus* is an ideal feedstock with acceptable environmental side-effects. Nevertheless, it seems wise for Hawai'i to keep such options open for the future.

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