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An economic approach to assessing import policies designed to prevent the arrival of invasive species: the case of *Puccinia psidii* in Hawai'i

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ABSTRACT

Since its first documented introduction to Hawai'i in 2005, the rust fungus *Puccinia 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 *Metrosideros polymorpha* ('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 'ōhi'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 1-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 plant 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 et al., 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, *Puccinia psidii*, to Hawai'i.

Most rust fungi are highly host specific, but *P. psidii* has an extremely broad host range within the myrtle family (Myrtaceae, with about 5000 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 et al., 1998). When detected in Hawai'i in April 2005 (Killgore and Heu, 2005; Uchida et al., 2006)—the first invasion outside the Neotropics/subtropics—there was immediate concern for 'ōhi'a (*Metrosideros polymorpha*), a native species

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within the Myrtaceae family. ʻŌhiʻa comprises 80% of native forests throughout the state, 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.[1] 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.[2] 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, the Hawaiʻi Department of Agriculture is proposing to move ahead with establishing stringent measures that restrict entry of Myrtaceae into Hawaiʻi. The purpose of this paper 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 purpose of this paper is to evaluate the likely economic impact of the Hawaiʻi Department of Agriculture's Proposed Rule intended to prevent establishment of new genetic strains of *P. psidii* that would threaten Hawaii's ʻōhiʻa and other Myrtaceae.

In general, standards for international and national phytosanitary regulation are geared toward protecting free trade to the extent feasible (Heather and Hallman, 2008) but 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; IPPC Secretariat, 2001). However, Hawaiʻi State Law requires that any new departmental regulation be evaluated for its impact on small business and subjected to public review and comment.[3]

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 Hawaiʻi, Department of Agriculture, 8/28/07). However, with authorization for an interim rule limited to 12 months by Hawaiʻi State Law the rule expired in August 2008. Currently, Myrtaceae can be imported to Hawaiʻi 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.)

Hawaiʻi 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 *P. psidii*.

The following proposed (draft version, August 2011) Myrtaceae import rule is targeted for implementation in 2012. 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 1 year period, they will be distributed to the importers. Otherwise, they will be destroyed. Importers will be allowed to apply to the Hawaiʻi 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 1-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.

The choice of 1 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

[1] Less than 5% of ʻōhiʻa individuals were lightly affected: less than 5% of leaves on affected trees had rust pustules, but with no apparent deleterious effects on reduced survival, growth, or reproduction of mature individuals. Much more significant damage to ʻōhiʻa seedlings occurred during the period (2006–2008) of very high spore inoculum from rose apple, however.

[2] See Cannon et al. (2009), Loope (2010), and Loope and La Rosa (2008) for a preliminary assessment of the risks associated with introducing new *P. psidii* strains to Hawaiʻi.

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

UV damage allow spores to remain viable for at least 90 days in favorable conditions (references summarized by Glen et al., 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 et al., 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.

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: they 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 Hawai'i, 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 Hawai'i. 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 Hawai'i, 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.

In some cases, the superstore sets a price point and requests a ''perceived value'' of the floral arrangements, meaning that the burden of finding a Myrtaceae substitute (including search costs) would fall primarily on the supplier. In other cases, bulk floral shipments are received from a corporate headquarters on the mainland, and changing the ''recipe'' for pre-made arrangements being sent to Hawai'i could be costly. However, information gathered from personal interviews with buyers suggests that most superstores have continued to use Myrtaceae substitutes even after the 2007 Interim Rule lapsed. Thus, a policy affecting Myrtaceae imports would not have a significant impact on sales and there would be no transition period for companies who already found suitable substitutes in 2007.

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.

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

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%

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 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% 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.

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.

Of the 10 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

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%

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 1-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, ʻōhiʻa, 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 ʻōhiʻa seedlings and young saplings, even with a monthly treatment of Puccinia-specific fungicide costing approximately $200 per application.

3.3. *Plantations*

While the state manages scores of plantations, grouped into seven large management units, timber licenses have been issued for only one (the Waiākea Timber Management Area on Hawaiʻi Island). The discussion that follows focuses primarily on the potential costs and benefits of the Myrtaceae import policy to the four privately owned industrial plantations in Hawaiʻi. 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 Hawaiʻi, 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] A legitimate concern is the uncertainty surrounding the future of biofuels in Hawaiʻi, notably the worldwide lag in technology for lignocellulosic conversion of plant tissue to biofuels and problems of scale in Hawaiʻi for local refinery capacity (see Appendix II in Burnett et al., 2012 for a detailed discussion). However, we feel that biofuel production in Hawaiʻi will likely become a reality (some time in the future) given the Hawaiʻi Clean Energy Initiative goals for 2030 (explained in footnote 12).

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 1-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, 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 et al., 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).

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 (*S. 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 bioenergy, 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.

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.

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 h and that the hourly wage (w) of a representative florist is $30 per hour.[5] 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 $h \times w \times N$, 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 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 1 year following the implementation of the policy, the cost to florists in terms of lost sales (C_s),[6] defined as the product $S \times m \times \theta$ 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 1-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.

Table 3 – Hawai'i forest nursery survey of Myrtaceae.

	Total responses	Imports Myrtaceae non-seed material	Imports eucalyptus seed only
O'ahu	1	0	0
Big Island	5	0	2
Maui	2	0	0
Kaua'i	2	1	1

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 retail, commercial, and forest nurseries. At the same time, however, the future of biofuels in Hawai'i is largely uncertain. 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

$$\phi(T) = \beta e^{-\beta T}, \quad (1)$$

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

[5] 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 h of search time is a reasonable assumption.

[6] 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.

$$\phi'(T) = (\beta - \tilde{\beta})e^{-(\beta-\tilde{\beta})T}. \tag{2}$$

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

$$P(T) = \phi(T) - \phi'(T) = \beta e^{-\beta T} - (\beta - \tilde{\beta})e^{-(\beta-\tilde{\beta})T}. \tag{3}$$

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 1 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.[7] 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.[8]

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 et al. (2011) estimate that a refinery that processes 453,592 metric tons per year (Mg/year) would yield profits of roughly $21.7 million/year.[9] And given current refining technology, every Mg of eucalyptus biomass can be converted to 369.3 L (97.6 gal) 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.[10] 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/gal (USDA, 2011) is $0.49.

Eucalyptus yield estimates are taken from a Hawai'i study by Tran et al. (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/gal), and the total gallons of biofuel producible annually by existing eucalyptus 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 50 year time horizon is[11]:

$$B = \int_{T=10}^{50} \left[P(T) \int_{t=T}^{50} (L \times \pi \times G)e^{-rt} \right] dT. \tag{4}$$

Losses can potentially accrue starting from year 10 when it is assumed that the biofuel sector would begin producing benefits.[12] 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:

$$NPV = \int_{T=10}^{50} \left[P(T) \int_{t=T}^{50} (L \times \pi \times G)e^{-rt} \right] dT - h \times w \times N - S \times m \times \theta. \tag{5}$$

Given the baseline parameter values summarized in Table 4, the net present value of the proposed rule is $14.3 million.

[7] 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. For example, illegal importations, mistakes during the inspection process, and other alternative pathways of introduction can contribute to a lower efficacy and hence NPV of the policy.

[8] Discussions with resource managers, scientists, and other local *P. psidii* experts (including early reviewers of the paper) have provided guidance in determining that 0.01–0.2 is a reasonable range of values for β. Furthermore, preliminary results from ongoing experimental research by P. Andrade at Brazil's Federal University of Viçosa indicate that three out of five common *P. psidii* strains are highly pathogenic on ʻōhiʻa, which further supports the assumption that the risk of introducing a virulent strain to Hawai'i is nontrivial.

[9] 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 startup 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).

[10] 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 Hāmākua 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.

[11] 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.

[12] 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.

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%
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/year
h	Hours of labor required to adjust to policy per firm	80 h
N	Number of florists that sell Myrtaceae	59
w	Hourly wage of florists	$30/h
τ	Length of transition period	1 year
S	Total florist sales in Hawai'i per year	$44 M/year
m	Percentage of florists that sell Myrtaceae	29%
θ	Percentage of sales from Myrtaceae products	1%

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 1-year quarantine into production plan[e]	C_1
Plantations	
Finding local seed suppliers, switching to local propagation, and/or building 1-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 'ōhi'a 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.

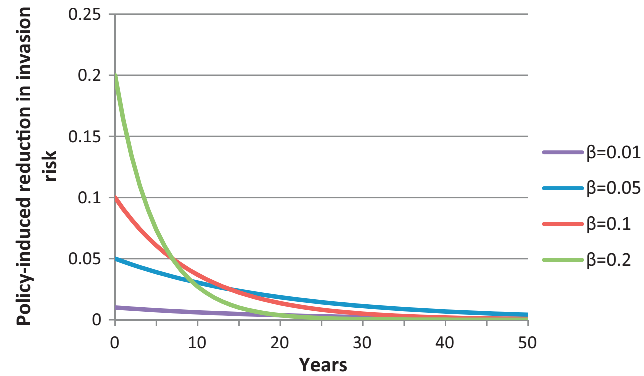

Fig. 1 – P(T) curves for different values of β.

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 1-year seed quarantine into production plans.

The NPV is also calculated for alternative parameter values. With the exception of the case where $\beta = 0.01$, 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 Fig. 1 for a comparison of $P(T)$ curves under different assumptions about β). If the conditional probability of invasion starts low and remains relatively constant over time (e.g. when $\beta = 0.01$), then per-period expected losses are always relatively low, regardless of the timing of biofuel production. 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 loss scenario, the NPV is almost $800,000. If a particularly virulent strain is likely to arrive, conditions in Hawai'i 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.

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.

In all scenarios, the NPV is positive, and the estimates would be even higher if we could quantify the avoided damage

Table 6 – Sensitivity analysis—conditional probability and yield loss.

	L = 5% (very low)	L = 10% (low)	L = 30% (baseline)	L = 50% (high)
$\beta = 0.01$ (very low)	$1.0 million	$2.4 million	$7.6 million	$12.8 million
$\beta = 0.05$ (low)	$2.7 million	$5.6 million	$17.3 million	$29.0 million
$\beta = 0.10$ (baseline)	$2.2 million	$4.6 million	$14.3 million	$24.0 million
$\beta = 0.20$ (high)	$0.8 million	$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.

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.

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 et al. (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. Potential unintended consequences

Any new policy will have a myriad of unintended consequences, and the proposed policy is no exception. For example, plants used to replace the formerly imported Myrtaceae could carry novel diseases, potentially even more damaging than *P. psidii*. Another concern is that since the policy increases the costs of importing seeds, it may induce some businesses to import seeds illegally. This could put compliant growers at a disadvantage and potentially increase the risk of rust introduction. Thus, while the intent of this report is to estimate as accurately as possible the net present value of an import ban on Myrtaceae material, it is important to keep many of these caveats in mind when interpreting the results.

6. Conclusion

The objective of this paper was to calculate the net present value of a potential policy that would ban imports of Myrtaceae (non-seed) plant material to Hawaiʻi and require a 1-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 ʻōhiʻa, as well as avoided damages to ʻōhiʻa 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 1-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 ʻōhiʻa 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 $800,000. 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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