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The Threat of the Non-native Neotropical Rust *Puccinia psidii* to Hawaiian Biodiversity and Native Ecosystems: A Case Example of the Need for Prevention

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Introduction

The threat of invasive species to natural areas presents enormous challenges, but there are opportunities for working toward solutions, often in conjunction with agricultural and forestry perspectives. There is a growing awareness of the danger to botanical biodiversity and conservation from "emerging infectious diseases" that have increased in incidence, geographical distribution, or host range/pathogenicity; have newly evolved characteristics; and/or have been newly discovered (Anderson et al. 2004). There is a heightened concern for forest health due to accelerating worldwide movement of plant pathogens (e.g., with ineffective quarantine measures) that negatively affect both biodiversity and commercial forestry (Wingfield 2003). An important related concept is that of the ability of fungi to jump to new hosts following anthropogenic introduction. Native hosts are exposed to pathogens with no coevolved recognition or defense mechanism, and microevolution toward increased virulence of introduced pathogens can result (Wingfield 2003; Slippers et al. 2005). The rust fungus *Puccinia psidii* (Basidiomycota, Uredinales: Pucciniaceae), a species first documented to have jumped from native guava *(Psidium guajava*, Myrtaceae) to introduced *Eucalyptus* spp. (Myrtaceae) in Brazil in 1912 (Coutinho et al. 1998) is an extremely important example of this phenomenon (Wingfield 2003; Slippers et al. 2005). Such threats have typically been underestimated by quarantine authorities worldwide, largely due to a lack of understanding of the taxonomy and ecology of the fungi involved (Wingfield 2003). For example, Coutinho et al. (1998) stated: "A detailed taxonomic study is needed to determine the host range and geographical distribution of *P. psidii*. It is still not certain whether more than one species of *Puccinia* is capable of infecting members of the Myrtaceae. Comparisons at the molecular level would be particularly useful in this regard."

To protect a dominant Hawaiian tree species (*Metrosideros polymorpha*, Myrtaceae) and an associated large segment of Hawaii's terrestrial biodiversity, we must work closely with the Hawaii Department of Agriculture to block entry pathways for new strains of the rust pathogen, *Puccinia psidii,* from entering the state. This is a clear need and can serve as an important example of ecosystem protection by preventative measures.

Overview of the issue

Introduction of additional strains of the rust *Puccinia psidii* could pose a major threat to *'ohi'a (Metrosideros polymorpha)* forests, watershed health, and Hawaii's unique plants

and animals. Potential damage from the introduction of a strain of rust that kills or significantly damages *'ohi'a,* a tree species that dominates 80% of Hawaii's remaining forests, cannot be overstated. In April 2005, the rust was found in Hawaii, the first time it had been found to occur outside the Neotropics, and within a few months had spread throughout the main Hawaiian Islands. Effects have been highly dramatic on the endangered endemic plant *Eugenia koolauensis* and introduced rose apple *(Syzygium jambos).* The rust strain currently established in Hawaii damages leaves of *'ohi'a* in some instances, mostly on potted plants and in wet environments, but currently appears to cause minor though not yet fully defined damage to *'ohi'a* populations and ecosystems.

The rust is believed to have reached Hawaii through the live plant or foliage trade (Darcy Oishi, Hawaii Department of Agriculture, pers. comm., 2006). Well-known potential sources of infected Myrtaceae are in South and Central America, the Caribbean, and Florida. Plants from all infected areas would likely pass through the continental U.S. and arrive in Hawaii as domestic shipments (Dorothy Alontaga, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, pers. comm., 2006). The rust was recently discovered on myrtle in California (Mellano 2006), a state that exports a significant amount of Myrtaceae plant and foliage material to Hawaii (Darcy Oishi, pers. comm., 2006).

Background

The rust *Puccinia psidii* is a pathogen with a very broad host range in the myrtle family (Myrtaceae). It was first described from common guava *(Psidium guajava)* in Brazil in the 1880s, and it causes severe damage to introduced *Eucalyptus* plantations in Brazil. *Puccinia psidii* is "regarded as the most significant quarantine risk to the cultivation of *Eucalyptus* spp. as well as to related plants. In Brazil it is severely limiting to the growth of highly susceptible species and provenances" (Ciesla et al. 1996). Pathogens such as the guava rust, which has developed strong pathogenicity in Brazil on introduced eucalyptus, will be devastating if these new strains are introduced back into the geographic areas where eucalyptus evolved without the rust (Glen et al. 2007).

The Neotropical species in the Myrtaceae recorded by Simpson et al. (2006) as having been attacked by the pathogen *P. psidii* are in the genera *Acca* (1), *Campomanesia* (2), *Eugenia* (10), *Marlierea* (1), *Myrcia* (3), *Myrcianthes* (2), *Myrciaria* (3), *Pimenta* (2), and *Psidium* (4). The other-than-Neotropical species exposed through cultivation/naturalization and attacked are in the genera *Angophora* (1), *Callistemon* (3), *Corymbia* (3), *Eucalyptus* (20), *Eugenia* (2), *Heteropyxis* (1), *Kunzea* (1), *Melaleuca* (6), *Metrosideros* (1), *Myrtus* (1), *Syncarpia* (1), and *Syzygium* (5) (Simpson et al. 2006). The large genus *Eugenia* (ca. 1,000 spp.) is the only genus that occurs both within and outside the Neotropics. The 26 species recorded as attacked comprise 2.3% of the 1,131 Neotropical species in the myrtle family. The 45 non-Neotropical species documented as susceptible comprise a small percentage of the ca. 3,400 (naïve) species in the myrtle family that grow outside the Neotropics, although most of the latter have never been exposed to *P. psidii*. Susceptibility to *P. psidii* seems to be low among species of Myrtaceae from the Americas but more common among taxa from Asia, Australia, and the Pacific (Simpson et al. 2006). Glen et al. (2007) cite a collaborative Australian–Brazilian study in 1996 in which 58 Australian Myrtaceae species were exposed

to *P. psidii* in Brazil; 52 of those had some degree of susceptibility.

Lesions on susceptible hosts are produced by *P. psidii* on young, actively growing leaves and shoots, as well as on fruits and sepals. Lesions are brown to gray with masses of bright yellow or orange yellow (asexual) urediniospores. It is considered an autoecious rust species, with all stages produced on the same myrtaceous host; and aecia with aeciospores are morphologically identical to uredinia and urediniospores (Glen et al. 2007).

Conditions optimal for growth and development of *P. psidii* have not been precisely defined, perhaps because of differences among strains, but most active spore production and germination occurs during periods of high humidity/leaf wetness and temperatures in the range of 15–24°C (Glen et al. 2007). Such conditions are normal in windward Hawaii along an elevational gradient for much of the year.

Hawaii's current situation

Although the rust was first discovered on Oahu on potted *'ohi'a* in April 2005 (Killgore and Heu 2007), it has been found to be primarily attacking non-native rose apple *(Syzygium jambos)*. Damage to rose apple has occurred at a landscape scale with very significant partial dieback of large rose apple stands (L. Loope and others, pers. obs.). In spite of large numbers of spores produced on rose apple, adjacent *'ohi'a*, bombarded by millions of wind-dispersed spores, have appeared relatively disease-free to date.

Three native and about a dozen non-native species have been observed as hosts of *P. psidii* in Hawaii, with the introduced rose apple *(Syzygium jambos)* being the most severely affected. The rust has been found statewide, attacking local Myrtaceae from sea level to about 1,200 m elevation in areas with mean annual rainfall ranging from 750–3,000 mm (Robert Anderson, U.S. Geological Survey, pers. comm.). The host distribution and DNA profile suggest that only one genotype is established in Hawaii (Zhong and Yang 2007).

Eugenia koolauensis, listed federally as an endangered plant species endemic to Hawaii, is significantly affected by the rust (Kapua Kawelo and Jane Beachy, U.S. Army Garrison, Hawaii, pers. comm., 2006).

According to the generally accepted taxonomic treatment, Hawaii has seven endemic species in the Myrtaceae: *Eugenia koolauensis*, *Eugenia* (*Syzygium*) *sandwicensis, Metrosideros macropus, Metrosideros polymorpha*, *Metrosideros rugosa, Metrosideros tremuloides,* and *Metrosideros waialealae*. There is a single indigenous species, *Eugenia reinwardtiana*, that is a host for *P. psidii*. Of special concern for damage by additional rust strains is *'ohi'a, Metrosideros polymorpha*, a major component of the native forest on all main islands of the Hawaiian archipelago. This single species overwhelmingly dominates approximately 80% of Hawaii's remaining native forest—about 965,000 acres (1,500 square miles). Significant damage to Hawaii's *'ohi'a* forests would have major impacts on Hawaiian birds, plants, and invertebrates.

Eighteen of 19 extant Hawaiian honeycreepers in the main Hawaiian islands, including 12 species listed as endangered by the U.S. Fish and Wildlife Service (as well as six not listed as endangered) inhabit *'ohi'a* or *'ohi'a/koa* forests. Significant degradation of Hawaii's *Metrosideros polymorpha* forest by *P. psidii* will negatively affect populations of endangered honeycreepers as well as populations of at least some of the non-endangered birds *(aniani-*

au, Kauai creeper, Maui creeper, and *i'iwi*), increasing the likelihood for these species to become endangered.

In addition to direct impacts on Hawaiian Myrtaceae, dozens of endemic Hawaiian plant and invertebrate species are also dependent upon *'ohi'a* or *'ohi'a/koa* forests. As with the birds, the loss of *'ohi'a* could have significant negative affects on these taxa as well.

Rust strains

There is strong evidence of host specialization in this pathogen, with isolates from one host unable to infect certain other hosts. A rust population that consistently causes disease on a host species is termed a "strain" (= race or biotype). Each species of rust can have several or many strains.

Glen et al. (2007) summarize some of the findings to date on strains of *P. psidii*: "Several races or biotypes of *P. psidii* are known to exist; although in comparison with other rusts such as those of cereal crops, very little is known of these specialized forms." For example, two strains in Jamaica infected allspice (*Pimenta* spp.) and rose apple, respectively, but neither strain infected guava. The allspice strain was able to infect rose apple but did not sporulate. In Florida, the *Pimenta* (allspice) strain sporulated in rose apple, even though it took twice as long for maturation of urediniospores in rose apple than in allspice. In later tests, rose apple was considered immune to rust strains from *Melaleuca quinquenervia* (paperbark) and allspice (Rayachhetry et al. 2001).

In Florida, there seems to be good evidence that this rust has increased its host range since an outbreak on allspice *(Pimienta dioica)* was first detected 30 years ago, presumably through the importation of additional rust strains or development of new pathogenicities. The host range of *P. psidii* in Florida now includes about 20 species, most of which are introduced species. It has received special attention since an epiphytotic on invasive *Melaleuca quinquenervia* stands in South Florida in 1997 demonstrated explosive virulence (Rayachhetry et al. 2001), with the rust defoliating thousands of trees.

Although the rust in Hawaii was originally found on *'ohi'a*, the primary species damaged thus far is rose apple. To date, the *'ohi'a* forests have been minimally affected. Species such as the common guava, eucalyptus, and allspice are not affected by the strain currently in Hawaii, although they are substantially damaged by *P. psidii* elsewhere in the world.

The latest (though preliminary) information from DNA analysis is that there might exist only one strain or genotype of *P. psidii* in Hawaii (Zhong and Yang 2007), and the complete life cycle has not been found (Uchida 2007). In its first two years in Hawaii, the host preference behavior of *P. psidii* has been consistent among islands and locations on islands, and may indicate that only a single strain is present at this point (L. Loope and others, pers. obs.). This is in contrast to a substantial amount of variation found in the same rust species in Florida (Rayachhetry 2001; Zhong and Yang 2007).

Importance of excluding a sexual strain or strains of *P. psidii*

The apparent lack of the complete life cycle in the *P. psidii* strain already in Hawaii has enormous implications. Populations that undergo regular sexual reproduction are able to recombine genes in the population into new combinations, whereas populations with strict-

ly asexual reproduction possess a more limited number of different gene combinations (McDonald and McDermott 1993). Whereas an asexual strain may have less potential for evolution, a sexual strain would have enormous potential for increased virulence for *'ohi'a* and increased environmental tolerance (Janice Uchida, University of Hawaii, pers. comm., 2006). Introduction events present a window of evolutionary opportunity for a pathogen, with potential for novel or episodic selection in a new environment, leading to rapid evolution (Brasier 2001; Wingfield 2003; Slippers et al. 2003). Few, if any, other environments on earth have a single plant species dominant over such a broad environmental range as *'ohi'a* in Hawaii (Vitousek 2004). *'Ohi'a* has been in place in Hawaii for over 1 million years and has a great amount of genetic variation, but is nevertheless constrained in its genetic variation by within-species gene flow (Vitousek 2004). Given Hawaii's generally highly favorable environmental conditions for *P. psidii* and an abundant potential host in *'ohi'a*, the stage is set for rapid pathogen evolution. There are few, if any, more important achievable priorities for biodiversity conservation in Hawaii than exclusion of new strains of *P. psidii.*

Recommendations

Rapid establishment and spread of the rust *Puccinia psidii* in Hawaii demonstrates how quickly this organism can affect multiple species on multiple islands. Establishment of a strain damaging or lethal to *'ohi'a* would be catastrophic to Hawaiian ecosystems. Management and research organizations should work together to:

- Prevent the introduction of additional strains of eucalyptus rust *(Puccinia psidii)* into Hawaii. Because it is not possible to predict which strains might affect *'ohi'a* and other Hawaiian Myrtaceae, and because of the potential for adaptation and evolution once a new strain arrives in Hawaii, effective efforts should be undertaken to prevent all additional strains of this rust from reaching Hawaii.
- Monitor nursery stock and cut-vegetation products that are freshly imported from the U.S. mainland into Hawaii to determine whether stocks are infected.
- Complete baseline documentation of current conditions through a thorough host/effects assessment and DNA analysis for the *P. psidii* that is in Hawaii already, and periodically monitor for changes in the status quo.
- Monitor native Hawaiian Myrtaceae to continually assess the impact of the existing or future rust strain(s).
- Develop a management plan to mitigate the effects of the existing rust strain on native Myrtaceae species, especially *Eugenia koolauensis,* an endangered species.
- Work with Pacific Island/Asian countries to develop procedures aimed at minimizing the spread of the rust from Hawaii.

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