A BIOCLIMATIC APPROACH TO PREDICT GLOBAL REGIONS WITH SUITABLE CLIMATE SPACE FOR *PUCCINA PSIDII*

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ABSTRACT

Puccinia psidii, the cause of eucalypt-guava-'ohi'a-myrtle rust, can infect diverse plants within the Myrtaceae, and this rust pathogen has the potential to threaten numerous forest ecosystems worldwide. Known occurrence records from Brazil, Uruguay, Paraguay, Costa Rica, USA (Hawaii, Florida, and Puerto Rico), and Japan were used to develop bioclimatic models for predicting suitable climate spaces of this rust on a global scale. Four separate models were developed to predict current distribution of suitable climate space for *P. psidii* : (1) sample points based on all rust occurrence points in our dataset (All model), (2) sample points based on our dataset for occurrences of the rust on guava (*Psidium guajava*) from South America only (Guava model), (3) sample points based on our data set for occurrences of the rust on eucalypt (*Eucalyptus* spp.) from South America only (Eucalypt model), and (4) sample points based on our dataset for occurrences of the rust from multiple hosts in Hawaii only (Hawaii model). The "All model" was also projected for the 2050s (based on years 2040-2069) using the A1B SRES (Special Report on Emission Scenarios) scenario and CCCMA-CGCM 3.1 (Canadian Centre for Climate Modeling and Analysis – third generation coupled global climate model). These models can help determine points of origin, evaluate potential pathways of spread, predict areas at risk for *P. psidii* introduction, and predict potential future risks for new introductions of *P. psidii* under climate-change scenarios.

BACKGROUND

Puccinia psidii is the cause of eucalypt /guava/'ohi'a/myrtle rust (hereafter referred to as eucalypt rust) disease of many host species in the Myrtaceae family, including guava (*Psidium* spp.), eucalypt (*Eucalyptus* spp.), rose apple (*Syzygium jambos*), and 'ohi'a (*Metrosideros polymorpha*) (Farr and Rossman 2010). First reported in 1884 on guava in Brazil (Winter 1884; MacLachlan 1938), the rust has since been detected in other South American countries (Argentina, Colombia, Paraguay, Uruguay and Venezuela), Central America (Costa Rica and Panama), Mexico, the Caribbean (Cuba, Dominica, Dominican Republic, Jamaica, Puerto Rico, Trinidad and Tobago, Virgin Islands), USA (Florida, California, Hawaii), and most recently Japan and Australia (Coutinho et al. 1998; Uchida et al. 2006; Kawanishi et al. 2009; Carnegie et al. 2010; Graça et al. 2011). Of present concern is the recent introduction of the rust pathogen to Hawaii, where it infects an endemic tree species known as 'ohi'a, the dominant tree species in Hawaii's remnant native forests. Recent analyses on the genetic diversity of *P. psidii* also

suggest several genetically distinct groups/races of this rust distributed throughout the world (Graça et al. 2011). Because only a single *P. psidii* genotype is known to exist in Hawaii (Graça et al. 2011), the introduction of additional rust genotypes or races could further threaten forests in Hawaii (Loope and La Rosa 2008). Eucalypt rust poses serious threats to several hosts in the Myrtaceae including *Eucalyptus*, a genus native to Australia and elsewhere, which is planted extensively in numerous tropical and subtropical countries (Coutinho et al. 1998; Graça et al. 2011). Previous climate-based studies have developed strong approaches for predicting areas at risk to *P. psidii* in Australia (Booth et al. 2000). Despite the potential threats to numerous forest ecosystems worldwide and the expanding geographic range of this disease, more information is needed about the potential global distribution of suitable climate space for this pathogen under present and changing climates. Bioclimatic modeling

methods to predict present and future suitable climate spaces for many tree species have already been developed (Rehfeldt et al. 2006). Similar approaches can be used to predict areas where the pathogen is climatically well-adapted for comparison with areas of host (Myrtaceae) adaptation and maladaptation.

OBJECTIVES

The objectives of this study are to 1) determine the distribution of suitable climate space and potential sources for *P. psidii*; 2) predict future distributions of suitable climate space for *P. psidii* under climate-change scenarios; and 3) evaluate possible pathways of pathogen spread, and areas at risk for *P. psidii* establishment. Information from this approach will also be used to predict potential future areas at risk for *P. psidii* establishment under climate-change scenarios.
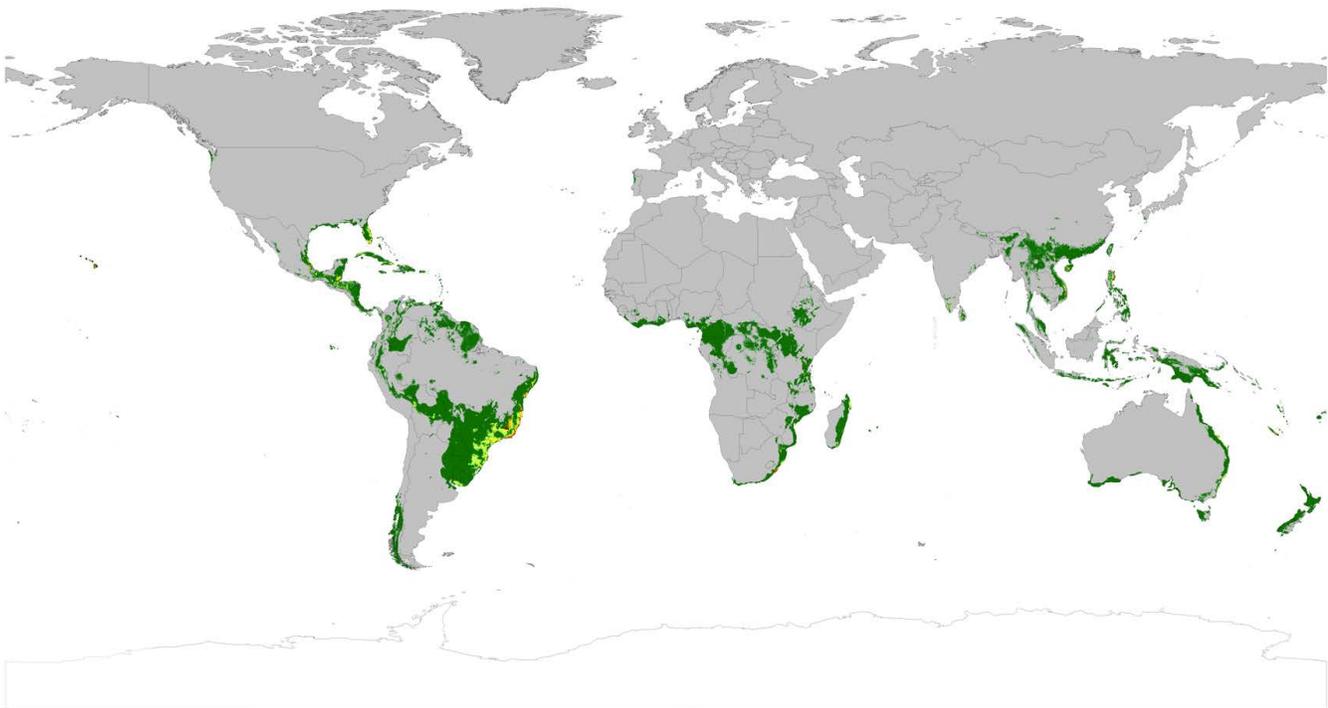

Figure 1: Global prediction of current (based on data from 1950-2000) suitable climate space for *Puccinia psidii* using 327 geo-referenced occurrence records from Brazil, Uruguay, Argentina, Paraguay, United States, Japan, and Costa Rica.

Bioclimatic Modeling

We used a maximum entropy approach with 327 geo-referenced occurrence records of *P. psidii* from Brazil, Uruguay, Paraguay, Costa Rica, USA and Japan. MaxEnt (Maximum Entropy Species Distribution Modeling) version 3.3.3e (Phillips et al. 2006) was used to predict the current distribution of *P. psidii* using high-resolution (30second = 1km) climate surfaces of 19 bioclimatic variables (e.g., annual mean temperature, annual precipitation, precipitation coldest quarter, etc.). These data were obtained from WorldClim (worldclim.org) and are based on interpolations of observed data from 1950-2000 (Hijmans et al. 2005). The future prediction model was then projected onto statistically downscaled (delta method) future climate surfaces for the 2050s (years 2040-2069) using the A1B SRES (Special Report on Emission Scenarios) scenario and CCCMA-CGCM 3.1 (Canadian Centre for Climate Modeling and Analysis – third generation coupled global climate model; Ramirez and Jarvis 2010). Four separate models were developed to predict current distribution of *P. psidii* based on (1) sample points of all occurrences of eucalypt rust in our data set (All model), (2) sample points of our occurrence data for eucalypt rust on guava (*Psidium guajava*) in South America only (Guava model), (3) sample points of our occurrence data for eucalypt rust on eucalypt (*Eucalyptus* spp.) from South America only (Eucalypt model), and (4) sample points of our occurrence data for eucalypt rust from multiple hosts in Hawaii only (Hawaii model).

Bioclimatic Prediction Maps

Predicted current global distribution of suitable climate space for *P. psidii* based on "All model" is shown in Figure 1. The predicted current global distribution map shows several geographic areas that may be at risk for *P. psidii* establishment, including parts of Africa, Australia, and Southeast Asia (Figure 1). Current distribution of suitable climate space for *P. psidii* in Hawaii based on the "All model" (Figure 2a) shows more areas with suitable climate space for *P. psidii* compared to predicted distribution based on the "Hawaii model" (Figure 2c). Projections of the "Eucalypt model" and "Guava model" on Hawaii show an almost inverse distribution compared to the "Hawaii model" (Figure 2c, 2d, and 2e).
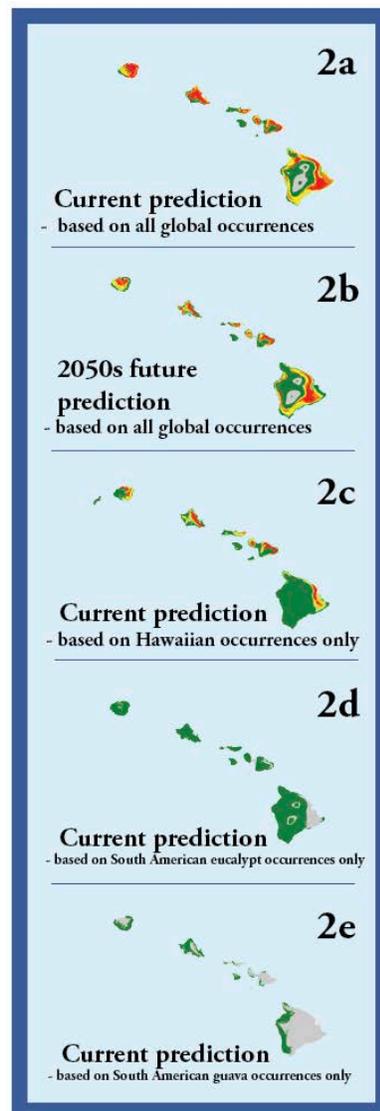

Figure 2a-e: Hawaiian *Puccinia psidii* predictions. Figure 2a: Detail of Figure 1. Figure 2b: Projected future suitable climate space for *P. psidii* using statistically downscaled (delta method) future climate surfaces for the 2050s (years 2040-2069), using CCCMA-CGCM 3.1 global circulation model, and the A1B SRES scenario. Figure 2c: Prediction of current suitable climate space for *P. psidii* based on 94 occurrence records from Hawaii (multiple host species). Figure 2d: Prediction of current suitable climate space for *P. psidii* based on 82 occurrence records from *Eucalyptus* spp. in South America. Figure 2e: Prediction of current suitable climate space for *P. psidii* based on 63 occurrence records on guava (*Psidium guajava*) in South America.

When considering that the *P. psidii* genotype in Hawaii has not been found on eucalypt or guava, these projections further indicate that introductions of new *P. psidii* genotypes from eucalypt and guava from South America or elsewhere pose an additional risk to potential hosts and new geographic areas of the Hawaiian Islands. The "Hawaii model" predictions of geographic areas with suitable climate for the single-genotype, Hawaiian *P. psidii* race (Graça *et al.* 2011) can provide insights into potential origins of the Hawaiian *P. psidii* race, especially when compared to the "Eucalypt model" and "Guava model" (Figure 3a, 3b, and 3c).
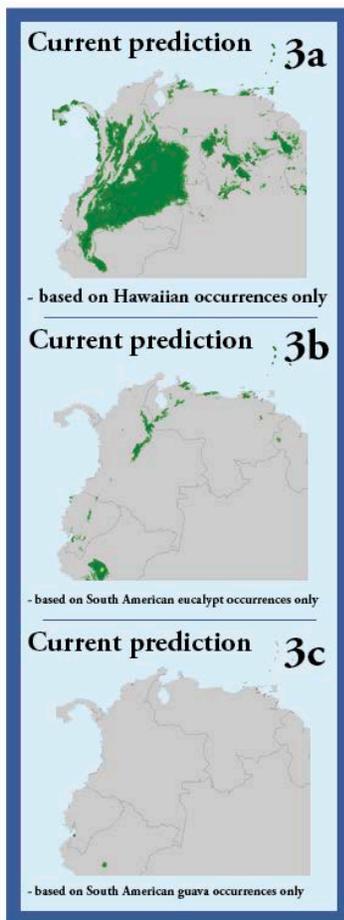

Figure 3a-c: *Puccinia psidii* predictions for northwestern South America. Figure 3a: Prediction of current suitable climate space for *P. psidii* based on 94 occurrence records from Hawaii (multiple host species). Figure 3b: Prediction of current suitable climate space for *P. psidii* based on 82 occurrence records from *Eucalyptus* spp. in South America. Figure 3c: Prediction of current suitable climate space for *P. psidii* based on 63 occurrence records of guava (*Psidium guajava*) in South America.

Figure 4: 2050s prediction of suitable climate space for *Puccinia psidii* in Brazil (using the same methods as Figure 2b).
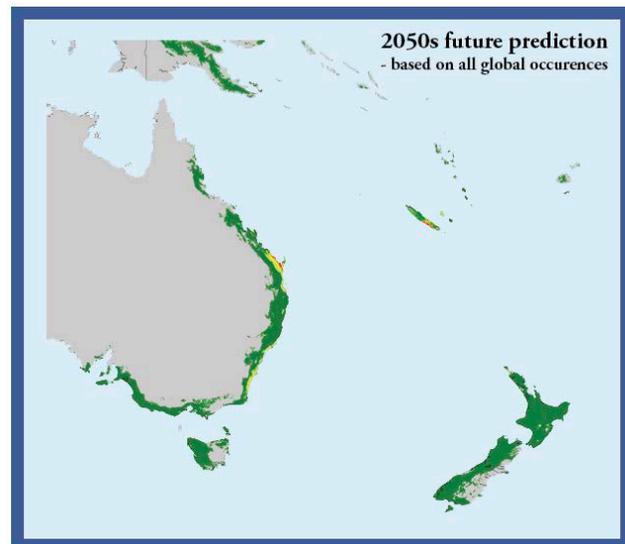

Figure 5: 2050s prediction of suitable climate space for *Puccinia psidii* in eastern Australia and New Zealand (using the same methods as Figure 2b).

The future distribution (2050s) of *P. psidii* based on the "All model" shows little change in suitable climate space for Hawaii (Figure 2b), greatly decreasing suitable climate space for Brazil in as little as 40 years (Figure 4), and relatively unchanged or slightly increasing climate suitability for *P. psidii* in Australia (Figure 5). As demonstrated here, this approach can be used to model *P. psidii* by host or genetically distinct group/race to determine whether individual *P. psidii* groups require disparate

environmental conditions. Combining climate-based, species-distribution modeling with genetic data can yield powerful insights into future distribution and potential invasive spread of forest disease. Additionally, predictions of the present and future distribution of *P. psidii* can help guide forest managers to implement appropriate forest practices to manage eucalypt rust according to current and future climates. This study is of great relevance for one-half of the forested land area of the tropics and sub-tropics, where the 4,500 species of Myrtaceae grow naturally and/or are actively cultivated. This area includes all countries that have significant investments in eucalypt forestry. Thus, information from this study can help identify areas at risk for *P. psidii* establishment, based on climatic envelopes. This information can also be used to help prevent introductions of *P. psidii* to global populations of Myrtaceae within regions that are at risk for *P. psidii* establishment.

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REFERENCES

Booth, T.H., Old, K.M., Jovanovic, T. 2000. A preliminary assessment of high risk areas for *Puccinia psidii* (Eucalyptus rust) in the Neotropics and Australia. Agriculture Ecosystems & Environment. 82:295-301

Carnegie, A.J., Lidbetter, J.R., Walker. J., Horwood, M.A., Tesoriero, L., Glen, M., Priest, M. 2010. *Uredo rangelii*, a taxon in the guava rust complex, newly recorded on Myrtaceae in Australia. Austalasian Plant Pathology. 39:463-466.

Coutinho, T.A., Wingfield, M.J., Alfenas, A.C., Crous, P.W. 1998. Eucalyptus rust: A disease with the potential for serious international implications. Plant Disease. 82:819-825.

Farr, D.F., Rossman, A.Y. 2010. Fungal Databases, Systematic Mycology and Microbiology Laboratory, ARS, USDA. Retrieved 5/4/10 from http://nt.ars-grin.gov/fungaldatabases/.

Graça, R.N., Alfenas, A.C., Ross-Davis, A.L., Klopfenstein, N.B.,and others. 2011. Multilocus genotypes Indicate differentiation among *Puccinia psidii* populations from South America and Hawaii. Pages 131-134 In Fairweather, M.L. Comp. Proceedings of the 58th Annual Western International Forest Disease Work Conference; 2010 October 4-8; Valemount, BC. US Forest Service, AZ Zone Forest Health, Flagstaff, AZ.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A. 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology. 25:1965-1978.

Kawanishi, T., Uematsu, S., Kakishima, M., Kagiwada, S., Hamamoto, H., Horie, H., Namba, S. 2009. First report of rust disease on ohia and the causal fungus, *Puccinia psidii*, in Japan. Journal of General Plant Pathology. 75:428-431.

Loope, L., La Rosa, A.M. 2008. An analysis of the risk of introduction of additional strains of the rust *Puccinia psidii* (`Ohi´a rust) to Hawai´i. U.S. Geological Survey Open File Report 2008-1008, Reston, VA.

MacLachlan, J.D. 1938. A rust of pimento tree in Jamaica, B.W.I. Phytopathology. 28:157-170.

Phillips, S.J., Anderson, R.P., Schapire, R.E. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling. 190:231-259

Ramirez, J., Jarvis, A. 2010. Decision and Policy Analysis Working Paper No.1 Centro Internacional de Agricultura Tropical International Center for Tropical Agriculture. Cali, Colombia.

Rehfeldt, G.E., Crookston, N.L., Warwell, M.V., Evans, J.S. 2006. Empirical Analyses of Plant-Climate Relationships for the Western United States. International Journal of Plant Sciences. 167:1123-1150.

Uchida J.; Zhong, S.; Killgore, E. 2006. First report of a rust disease on Ohi'a caused by *Puccinia psidii* in Hawaii. Plant Disease. 90:524.

Winter, G. 1884. Repertorium. Rabenhorstii funi europaei et extraeuraopaei. Cent. XXXI et XXXII. Hedwigia. 23:164–172.

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