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A preliminary assessment of high risk areas for *Puccinia psidii* (*Eucalyptus* rust) in the Neotropics and Australia

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Abstract

Puccinia psidii Winter, which causes both guava rust and eucalypt rust, is an important pathogen on eucalypts and other members of the Myrtaceae family in the Neotropics. If introduced into Australia it could represent a major potential threat to eucalypt plantations as well as native vegetation. Observations of the distribution of eucalypt rust epidemics in the Neotropics were analysed to develop a simple description of the species climatic requirements. Climatic mapping programs were used to generate maps showing high risk areas in the Neotropics and Australia. It is concluded that some northern parts of the Northern Territory as well as eastern coastal areas of northern New South Wales and Queensland are the regions most at risk to *P. psidii* in Australia. However, it is recognized that more detailed models and survey information are needed to provide better predictions of epidemic risks.

Keywords: Forestry; Pathology; *Puccinia psidii*; Temperature; Precipitation

1. Introduction

Puccinia psidii Winter is an important pathogen of eucalypts and other genera within the family Myrtaceae. It mainly affects young shoots and leaves. The pathogen is currently restricted in its distribution to Florida and the Neotropics including parts of Central America, South America and the Caribbean. It transferred to eucalypts from other species within Myrtaceae such as *Syzigium jambos,* which are indigenous to those regions. The pathogen is regarded as the most serious threat to eucalypt plantations worldwide (Coutinho et al., 1998) and could cause major damage to commercial and amenity plantings in many countries. The pathogen was first recognised on eucalypts in Brazil in the early 1940s and appears to be extending its range. For example, plantations in Sao Paulo State were first infected as late as 1992 and there are recent reports of the rust in Paraguay and northeastern Argentina (A.C. Alfenas, pers. commun.).

If the rust was introduced into Australia, native vegetation as well as commercial eucalypt plantations could be severely affected. The pathogen has shown a capacity for international dispersal and has been very damaging to industries based on susceptible crops. For example, oil refineries based on *Pimenta dioica* in Jamaica closed 2 years after the pathogen was first recorded on the island (Maclachlan, 1938).

The disease on eucalypts has been most studied in Brazil where a range of tropical and sub-tropical species has been exposed to the pathogen. The disease is particularly severe on seedlings, cuttings, young

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trees and coppice. Heavy infection of juvenile leaves and meristems causes plants to be stunted and multi-branched, markedly reducing their potential to develop into marketable trees. Very large differences in susceptibility among young trees established from seed have been observed in Sao Paulo State. Highly susceptible individuals (typically 10–20% of the stand) are grossly malformed and may be killed. Infection on 20–30% of canopies has been reported in some Brazilian plantations, enough to significantly affect growth rates and profitability.

Susceptibility to *P. psidii* varies among different species of eucalypts and closely related *Corymbia* species — *E. grandis*, *E. phaeotricha*, and *E. cloeziana* are susceptible and *E. citriodora* (syn. *Corymbia citriodora*), *E. pellita* and *E. urophylla* are more resistant (Carvalho et al., 1998). There is also provenance variation in disease susceptibility and strong evidence of host specialisation in the pathogen with isolates from one host genus not necessarily infecting other host genera. In addition to eucalypts and guava, 15 genera and 30 species of Myrtaceae are recorded hosts of the fungus.

P. psidii could have serious effects on native plant communities as the Myrtaceae is a large and important southern hemisphere family comprising about 3600 species in 155 genera. At least 52 of these genera are native or endemic to Australia where they are significant components of many communities. Many Australian ecosystems are dominated by the genus *Eucalyptus*, which includes approximately 850 species and subspecies (Boland et al., 1984; Flora of Australia, 1988). Members of the Myrtaceae family are also significant elements of heath and other vegetation (e.g. *Leptospermum*, *Callistemon*, *Corymbia*, *Kunzea*, *Melaleuca*, *Micromyrtus*, *Verticordia*).

Australian quarantine regulations have been imposed on plants and seeds of susceptible genera (Navaratnam, 1986), but there is no information on the extent of areas which might possibly be affected if the disease were introduced into Australia. The purpose of this paper is to provide a preliminary assessment of areas in Australia which experience similar climatic conditions to those where the pathogen is already causing problems. This study is a first output from a two-and-a-half year study of *P. psidii* which will collect more information on the disease's distribution and also develop more detailed models of disease risk.

2. Materials and methods

The method used here follows a similar procedure used for *Cylindrocladium quinqueseptatum* Boedijn and Reitsma leaf blight (CqLB), a disease found on eucalypts in various tropical and sub-tropical parts of the world (Booth et al., 2000). A simple model was developed for CqLB describing temperature and precipitation conditions where the disease is commonly found in South East Asia. Climatic mapping programs were then used to identify other areas in different parts of the world, which would be expected to have a high risk for CqLB. The simple model successfully identified some areas in the world where the disease was already a problem as well as other areas where the disease was not yet present. Some of these areas, such as parts of the Congo and Costa Rica have commercial plantations or farm forestry plantings of susceptible host eucalypt species.

Once again climatic mapping programs, which were originally developed to map where particular tree species can be grown, were used in this study. They are PC-based programs, which make use of interpolated data sets developed for thousands of locations. Booth et al. (1989) described the development of the first climatic mapping program and Booth (1996a) includes descriptions of programs for several different regions and countries. The programs make use of interpolation methods (Hutchinson et al., 1984) which allow mean monthly climatic conditions to be reliably estimated for most locations around the world.

The first step in the analysis of *P. psidii* was to carry out a literature review. A total of 24 relevant references were found in the Commonwealth Agricultural Bureau International (CABI) abstracts. These included some useful overall reviews (Ferreira, 1983; Coutinho et al., 1998) which provided references to other material, as well as papers providing information on specific occurrences (e.g. Dianese et al., 1984; Carvalho et al., 1994). Further information was obtained from personal discussions, particularly by one of us (KMO) with Prof. A.C. Alfenas (Department of Plant Pathology, Federal University of Vicosa, Brazil).

Information on the known distribution of eucalypt rust was converted into a simple description of climatic requirements based on the range of conditions estimated for six climatic factors. The simple description was then input into a climatic mapping program for the Neotropics (Booth and Jones, 1998) to show the likely extent of the current distribution and into a climatic mapping program for Australia (Booth, 1996b) to map potentially vulnerable areas.

3. Results

Table 1 lists the main locations where *P. psidii* is currently associated with severe epidemics of *Eucalyptus* rust. The locations were derived from the literature review and discussions with experts. Information on occurrences on other species, such as on *P. dioica* in south Florida, was not used (e.g. Marlatt and Kimbrough, 1979). Locations where there was doubt about the causal organism were excluded. Information about possible occurrences in Equador and the Dominican Republic were also not used because the locational data were too vague. The locations are only given to the nearest decimal degree as affected areas are normally spread over several kilometres. The values given approximate the centres of these occurrences. The climatic values given in Table 1 were estimated from data in a climatic mapping program for the Neotropics (Booth and Jones, 1998) as well as from meteorological stations (FAO, 1985). Ranges determined for each factor are shown in Table 1.

The description of the range of climatic conditions derived from Table 1 was input into a climatic mapping program for the Neotropics (Fig. 1). This included areas of Tropical and South America as well as the countries of the Greater Antilles, such as Cuba, Jamaica, Haiti and the Dominican Republic and the Lesser Antilles, such as Barbados and Grenada. Only three states of Australia such as Queensland, New South Wales and the Northern Territory, included high risk climatic conditions for *P. psidii*. Climatic mapping outputs for these states are shown in Figs. 2–4.

4. Discussion

As *P. psidii* has not spread as widely around the world as CqLB it was not possible to validate the description of suitable conditions for epidemics of *P. psidii* by comparing observed and predicted results for other parts of the world in the same way as the CqLB study (Booth et al., 2000). However, comparison with the Commonwealth Mycological Institute (1987) map for *P. psidii* provides some limited validation. This shows the general distribution of *P. psidii* as eight circled areas. Although Table 1 did not include geocoded locational data for Mexico, Cuba, Guatemala, Colombia or Venezuela the climatic anal-

Table 1
Mean climatic conditions at *P. psidii* (*Eucalyptus* rust) sites[a]

Location	Latitude (°)	Longitude (°)	MAP (mm)	Regime	Dry	MaxT (°)	MinT (°)	MAT (°)
Brazil								
Teixeira Defreitas	18.1S	40.1W	1440	Summer	0	30	16	23
Belo Horizonte	19.8S	43.9W	1560	Summer	4	28	13	21
Espirito Santo	18.1S	41.1W	1210	Summer	5	29	14	22
Rio de Janeiro	22.9S	43.2W	1090	Summer	0	29	17	23
Other locations								
Trinidad	11.2N	60.8W	1420	Uniform	1	32	24	27
Puerto Rico	18.4N	66.0W	1530	Uniform	0	30	21	26
Uruguay	31.4S	58.0W	1330	Uniform	0	32	7	18
Paraguay	24.5S	57.0W	1450	Uniform	0	32	13	22
Argentina	27.4S	56.1W	1670	Uniform	0	33	10	21
Range								
Low			1090		0	28	7	18
High			1670		5	33	24	27

[a] MAP: mean annual precipitation; regime: rainfall regime; dry: dry season length (number of consecutive months $<$ 40 mm); MaxT: mean maximum temperature of the hottest month; MinT: mean minimum temperature of the coldest month; MAT: mean annual temperature.

Fig. 1. Dark shaded areas indicate predicted high risk areas for *P. psidii* (*Eucalyptus* rust) in the Neotropics.

ysis correctly identified these countries as having areas at risk to *P. psidii* epidemics (see Fig. 1).

The North Coast area of New South Wales was identified as a high risk area in Australia (Fig. 3). It is a major area for commercial forestry with over 30 000 ha of eucalypt plantations (National Forest Inventory, 1997) and hundreds of thousands of hectares of managed native forest. The coastal areas of Queensland, which were also shown to be at high risk (Fig. 2) are less important for eucalypt plantation forestry with only about 1100 ha in the south-east region and less than 500 ha in northern coastal areas (National Forest Inventory, 1997). However, this area of coastal Queensland is close to the Great Barrier Reef and is one of the most important areas for tourism in Australia. Damage to native ecosystems in this area might have some impact on the appeal of the region for tourists. However, it is difficult to predict the amount of visual impact until more is known about how many native species are susceptible. Australian authorities are keen to avoid the introduction of the disease to avoid negative impacts on biodiversity as well as the visual appearance of landscapes. Damage to native ecosystems would also be the major concern in the Northern Territory (Fig. 4). The high risk areas include parts of Melville Island, where the major forest plantations include pine species and so would not be vulnerable. On the mainland the vulnerable area is part

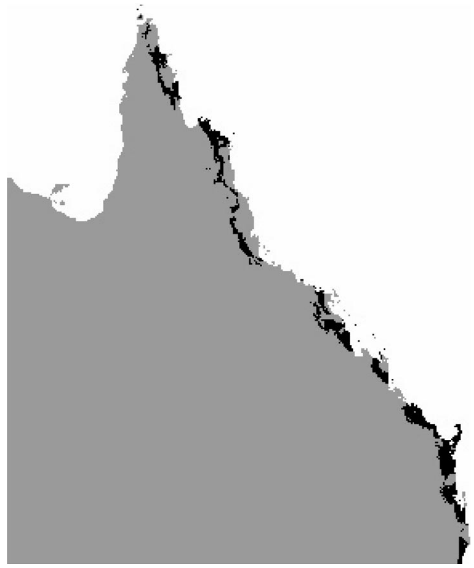

Fig. 2. Dark shaded areas indicate predicted high risk areas for *P. psidii* (*Eucalyptus* rust) in Qld, Australia.

of the eight million hectare Arnhem Land Aboriginal Reserve.

Ideally climatic profiles for plant disease epidemics should be developed using hundreds of geocoded (i.e. latitude, longitude and elevation) records of disease occurrence. Unfortunately, such detailed data sets are rarely available. Management decisions, such as the decision to select a resistant but less productive plant to grow on a particular site, have to be made with limited information. The simple analysis presented here and the previous study of CqLB (Booth et al., 2000) show that limited data sets can be used to generate preliminary predictions of vulnerable areas. However, it is important to emphasize that these estimates are based on long-term mean climatic data. The analyses do not take short-term climatic variations into account, so regions outside the dark shaded areas may be at some risk if favourable conditions for the disease occur.

Fig. 3. Dark shaded areas indicate predicted high risk areas for *P. psidii* (*Eucalyptus* rust) in NSW, Australia.

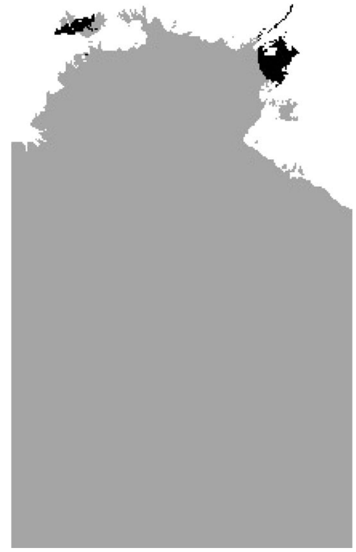

Fig. 4. Dark shaded areas indicate predicted high risk areas for *P. psidii* (*Eucalyptus* rust) in the NT, Australia.

More needs to be done to assess *P. psidii* risk to both plantations and native vegetation. More geocoded records of disease outbreaks should be compiled in order to validate and improve the preliminary predictions shown here. In addition, more work is needed to improve disease risk assessments. For eucalypt plantations it is known that *P. psidii* epidemics are related to periods of leaf wetness (Carvalho et al., 1994), so there is a need to develop databases which are both temporally and spatially more detailed, so that disease risk can be predicted more accurately. For native vegetation there is a need to assess which of the many species in the Myrtaceae family are vulnerable to infection. All these tasks are being undertaken as part of a collaborative Australian–Brazilian–South African research program supported by the Australian Centre for International Agricultural Research (ACIAR).

This analysis demonstrates the use of climatic mapping programs for one particular type of application, but they are suitable for applying in many situations where maps of climatic classifications (e.g. Köppen, 1918; Thornthwaite, 1948) have often been used in the past. As Wilcox (1968) noted in his review of the Köppen classification "since the machine makes it possible to sort the detailed record of original observations in the way best suited to the particular problem, every problem can be allowed to produce its own classification". PC-based climatic mapping programs now allow this potential to be realised for many agricultural, forestry and ecological problems where there is a need to identify regions experiencing similar conditions.

5. Conclusions

This preliminary analysis suggests that eucalypts growing in coastal areas of the Northern Territory, Queensland and northern New South Wales in Australia are at greatest risk of eucalypt rust, should the causative organism *P. psidii* be introduced into Australia.

Climatic mapping programs now provide ready access to summary climatic information for hundreds of thousands of locations across the world (e.g. Booth, 1996a; Booth and Jones, 1998). This analysis indicates that readily available information on disease distribution from published and unpublished sources can be used with these programs to develop hypotheses about the location of high risk areas for particular tree diseases. However, it is recognised that there is a need to gather more information to validate these predictions.

It is also desirable to develop more complex models of infection which make use of very detailed information (e.g. hourly or three hourly meteorological data). However, there are difficulties in applying such models over very broad areas and there are many pathogenic organisms that will never be studied in such detail. The method outlined here is not intended to replace detailed studies of weather–disease interactions, but to provide a quick, simple and cheap means to generate preliminary assessments of potentially vulnerable areas for tree diseases. It offers significant advantages over the hand drawn mapping methods used in the past (e.g. Commonwealth Mycological Institute, 1987). The CMI map provides only a crude representation of *P. psidii* distribution as eight broad regions. For example, the data presented in Table 1 suggest that eucalypt rust epidemics are associated with areas of relatively high rainfall, but the CMI map for *P. psidii* indicates all of Mexico, including many areas with mean annual rainfall below 450 mm, is vulnerable. The CMI map also provides no identification of potentially vulnerable areas in other parts of the world.

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