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Climate Modelling to Determine the Impacts of *Phytophthora cinnamomi* under Future Climate Scenarios

FINAL REPORT

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Executive Summary

Phytophthora cinnamomi is listed as a 'Key Threatening Process to Australia's Biodiversity' and has had considerable impact on many plant communities throughout much of Australia. However, how the distribution and impact of *P. cinnamomi* will change with future climate change is unknown. This study used existing datasets on *P. cinnamomi* distribution together with strategic soil surveys from regions outside the pathogen's known distribution range and used CLIMEX modeling to determine its likely distribution in 2070 based on the CSIRO-Mk3.0 global climate model. The modeling demonstrates that in the future, areas with previously unfavourable conditions, particularly at altitudes above 700 m may result in an increase in disease incidence, as these regions become warmer over time. In addition, in areas where rainfall is predicted to decrease, disease incidence is likely to decline. This is the most comprehensive study of *P. cinnamomi* distribution undertaken to date. The information will be useful to managers and policy makers involved in ensuring the spread and impact of *P. cinnamomi* is contained in the future

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Introduction

Phytophthora cinnamomi is widespread throughout much of the high rainfall areas along the eastern seaboard, most of Tasmania and the south-west of Western Australia. It has been mapped based largely on the symptoms (plant deaths) it produces in susceptible plant species and plant communities. In addition, to mapping based on the death of indicator species, soil baiting and the plating of necrotic tissues onto *Phytophthora* selective agar is also used to confirm the presence of *P. cinnamomi* as the cause of the plant deaths. Although frequently, due to the costs and time required to bait and plate, this step is not undertaken and diagnosis in many landscapes relies on the mapping of susceptible 'indicator' plant species. In urban areas and other artificial environments (e.g. plant nurseries and horticultural crops) records are numerous, but do not reflect where the pathogen is in the natural environment. Consequently, while the pathogen is widespread in Australia, the overall quality of mapping both presence and absence in the natural environment is poor and this will affect development of a species distribution model.

Due to the ability of *P. cinnamomi* to be vectored by anthropogenic activities (e.g. vehicle and heavy machinery carrying infested soil, poor nursery hygiene spreading the pathogen in container plants for out-planting, bushwalkers, and apiarists to name a few) it is likely that the pathogen if far more widely distributed than has been mapped based on disease symptoms. There are a number of reasons as to why plant communities/ecosystems are not succumbing to the pathogen despite its presence including non-conducive climatic conditions (too cold, too dry), disease suppressive soils or resistant plant species/communities.

Recent work in our laboratory has shown that *P. cinnamomi* can survive as a biotroph and/or endophyte on native annuals and herbaceous perennial species in the absence of disease symptoms (Crone et al. 2012, 2013). Therefore, in the future it is possible with climate change that these 'symptomless' areas will start to express disease as conditions come more conducive to the pathogen and more adverse to the plant species/communities.

By modelling the distribution of *Phytophthora cinnamomi* we can assess its potential to spread, both under current and future climates. Modelling the distribution may also identify hypotheses that explain the limits to the distribution. These hypotheses can be tested. Broadly, the distribution of any organism is limited by climate. It is within the climate "envelop" that other factors, such as edaphic, can be identified for the role they might play in determining the observed distribution.

CLIMEX has been used previously to model potential distribution and relative disease risk of important plant pathogens on both continental (Scherm, 1999; Venette, 2006; Pinkard, 2010) and global scales (Watt, 2009; Yonow, 2004). CLIMEX has been used previously for *P. cinnamomi* (Brasier and Scott, 1994; Desprez-Loustau et al. 2007) and to model *P. ramorum* and its projected range in the US (Venette and Cohen, 2006; Ireland et al. 2013). In this project we developed a CLIMEX model based on information on the environmental factors suitable for growth and use the distribution records to fine tune and test the fit of the model. We then compare with existing models and identify areas where further research will lead to improved distribution models of *P. cinnamomi*.

Methodology

Data sources for presence and absence of *P. cinnamomi* in Australia

Data sources for the presence (and absence if available) of *P. cinnamomi* were obtained from around Australia (Table 1). Initially the data were downloaded, transferred or entered into Excel spreadsheets (except one WA dataset which was supplied as a shape file). In the data cleaning process, data were checked for formatting, various degree, minute, second formats were converted to decimal degrees, the zone determined for eastings and northings values, missing hemisphere signs corrected, and absent, impossible and obviously incorrect and zero grid data removed. Many duplicates were removed although not all may have been detected. The data were then imported into GIS to enable the detection of other obvious errors such as extra planetary records and biologically impossible records such as in oceans. At a finer scale, records were removed if they were in the ocean, adjacent to valid records. Once cleaned, the data were converted into shapefiles and decimal degrees values added for cases were only easting and northings were available, so that data sets could be combined.

World data sources

When assessing biosecurity risks it is desirable to have information from the entire range of the species because different parts of the world may demonstrate different aspects of the climatic conditions that determine a species distribution. For example a species may be susceptible to cold stress and this will determine the northern limit to the distribution in North America or Eurasia, but this may not be shown in Australia because the continent does not go far enough to the south.

In stark contrast to the records from Australia, it proved impossible to obtain accurate point source data for *P. cinnamomi* from elsewhere in the world despite extensive searches and contacts overseas. Point source data were not obtained for regions outside of Australia, except for Papua New Guinea (Table 1). International data aggregators (e.g. GBIF) do not include *P. cinnamomi* in their datasets and to obtain datasets for individual regions or countries (and the extensive negotiation required) was beyond the resources available to this project. No published datasets were found during a review of online literature sources. The world distribution is summarised as presence/absence for countries in EPPO/CABI 1998. Undoubtedly such databases exist and obtaining access will take more time than is available for this project.

New collections (2013)

The two regions with the most new collections made in 2013 were Tasmania and Western Australia. In the original proposal we had intended to sample soils in all states of Australia, However, based on climate predictions and available data on the presence and absence of *P. cinnamomi*, we decided to focus our sampling to alpine areas above 700m. Of particular interest to us were altitude transects which began at a lower altitude in areas known to harbour *P. cinnamomi*. Such transects were available from Tasmania and New South Wales (Appendix 1). Additional sampling was made in Victoria from regions poorly sampled previously (Appendix 1). Sampling in Western Australia covered areas where the impact of *P. cinnamomi* is considered low or in regions where it is not commonly isolated (Appendix 1)

Sampling and molecular identification

Environmental samples

Soils were sampled during summer and autumn in 2013 (Appendix 1). At each sampling site between 8-12 scoops of soil (approx 150 g) were taken at random within a 5 m radius. Each soil sample (up to 2 kg) was air-dried, homogenized by sieving (2-mm mesh size), and a portion (60-80 g) was crushed to a fine powder by using the TissueLyser LT (Qiagen). All samples were stored frozen after disruption.

DNA extraction

DNA was extracted using the Mo Bio PowerSoil DNA isolation kit (M) (Carlsbad, CA), used according to the manufacturer's protocol, except for the first step where we replaced the buffer from the kit with 1 ml of saturated phosphate buffer (Na2HPO4; 0.12 M; pH 8) to the soil sample (500 mg), according to the methodology proposed by Taberlet et al. (2012) for extracellular DNA isolation. Final elutions were done in 60 µL of TE buffer. All DNA was stored frozen until used in the qPCR assay or for amplicon generation for next generation sequencing (NGS). All environmental DNA's were subjected to quantitative PCR for the template amount optimization.

Amplicon library generation, quantification and 454-pyrosequencing

Genomic DNAs from the soil samples were amplified separately in duplicate. Amplicon libraries were performed using a Nested PCR approach as described in Scibetta et al. (2012), with the *Phytophthora*-specific primers 18Ph2F and 5.8S-1R in the first PCR round. For the second PCR round, fusion primers were designed following the GS Junior System Guidelines for Amplicon Experimental Design, and the unidirectional sequencing protocol was selected (Lib-L chemistry for emPCR, 'One-Way Reads'). Forward fusion barcoded primers were based on the 5.8S-1R primer (5'-A-KEY-MID-5.8S-1R -3') and the universal ITS6 primer (Cooke et al., 2000) was used for amplification (5'-B-KEY-ITS6-3'), where A and B represents the NGS Lib-L adaptors, and the MID (1 to 37 from Roche's Technical Bulletin) was added for post sequencing sample identification. This allows us to pool 35 soil samples in a single run. 2 µl of the genomic DNA from soils and roots samples was used in the first PCR round. 2 µl of the PCR product from the first round was used as template for the second round.

PCR products were cleaned two times with AMPure XP Beads (Beckman Coulter Genomics) following the Short Fragment removal protocol according to manufacturers instructions. After purification, the amplicons were visualized in an ethidium bromide stained agarose gel (2%), and then pooled based on the intensity. The final pooling was diluted up to 1/5000 and then 50 µl of the dilution was again cleaned with AMPure XP Beads. The 1/5000 cleaned dilution was quantified following the methodology proposed for DNA by Bunce et al. (2012). The libraries were sequenced using Junior Genome Sequencer plates (454 Life Sciences/Roche Applied Biosystems, Nutley, NJ, USA). After the completion of the optimisation runs we tested all the soil samples for Western Australia. Simultaneously, the *Phytophthora cinnamomi* specific qPCR assay was also completed, this enabled us to compare results between the two methods.

Quantitative polymerase chain reaction (qPCR) for detection of Phytophthora cinnamomi

All DNA extracts from all soil samples that tested positive for the presence of *Phytophthora* were subjected to a *P. cinnamomi*-specific qPCR assay. This enabled us to cross check the results from this assay with the results from the 454 sequencing. After checking the first 50 samples we determined that the *P. cinnamomi*-specific assay correctly detected *P. cinnamomi* in all soil samples tested, and thereafter we used this more rapid technique (qPCR) for the detection of *P. cinnamomi* in the remaining soil samples.

CLIMEX parameters

Our aim was initially to build a species distribution model that reflected both the presence and true known absences of *Phytophthora cinnamomi*. To do this we developed a distribution model using the mechanistic niche model CLIMEX and methods outlined in previous studies (Michael et al. 2012, Webber et al. 2011). CLIMEX models the response of a species to climate based on the organism's physiology, biology, seasonal phenology and geographical distribution (Sutherst and Maywald 1985, Sutherst et al. 2007). The model is then projected to regions of the world using current climate (to test the model) and projected with a future climate scenario to account for climate change. It is an approach particularly suited to invasion and biosecurity issues (and detecting presence and absence in novel current and future climates), that which is not possible with standard correlation models (see Sutherst and Bourne 2009, Webber et al. 2011).

CLIMEX contains a parameter set of five meteorological variables, average minimum monthly temperature (Tmin), average maximum monthly temperature (Tmax), average monthly precipitation (Ptotal) and relative humidity at 09:00 h (H09:00) and 15:00 h (H15:00). These are used to define weekly and annual indices that determine the species response to temperature and soil moisture. CLIMEX calculates an annual growth index (GI) based on the growth of a species under favourable conditions of temperature, moisture and light. Stress indices (cold, hot, wet and dry) and their interactions may also be added to the model to indicate species restriction during unfavourable conditions. The Growth and Stress indices are combined to create the Ecoclimatic Index (EI), an annual measure of the favourableness of a particular location for the species.

The parameter values used in CLIMEX were initially determined from published sources (Table 2) or experiments (e.g. Desprez-Loustau et al. 2007). The distribution and annual phenology (where this information is available) are used to guide iteration of the parameter values so that a justifiable fit between the biology and distribution is obtained.

Climate datasets

We used the CliMond gridded world climate dataset (Kriticos et al. 2012, see http://www.climond.org/), for both projected current climate (recent historical data centred on 1975) and future climate change scenario models. For the future climate scenario, the CSIRO-Mk3.0 global climate model projected to 2070 was used, a time considered to provide a sufficient period to allow a different distribution for a short-lived and readily dispersed species such as *P. cinnamomi* to develop. The climate change scenario for 2070 is based on the IPCC emissions scenarios (the SRES scenarios or the Special Report on Emissions Scenarios) (Nakićenović and Swart 2000). We used the A1B scenario (IPPC 2007), which describes a future of very rapid economic growth, global populations that peak mid-century and decline thereafter and balanced for future technological changes in fossil intensive and non-fossil energy sources. It provides a set of near mid-range values for global warming. The observed global carbon dioxide emissions during the 2000 – 2006 period are in line with, but above the IPCC's A1B emission scenario (Raupach et al. 2007). The 2012 observations on emissions (Peters et al. 2012) continue to be in line with this scenario.

Findings

Distribution of *P. cinnamomi*

The Australian records of *P. cinnamomi* include 13,830 for presence (Figure 1) and 20,890 for absence (Figure 2) in Australia. The sampling is most comprehensive in south-west Western Australia and in Tasmania. The relative lack of sample points in South Australia, Victoria and Queensland is more a reflection of the data sources obtained than lack of actual samples. For example, we excluded a Victorian data source (Marks et al. 1975) with 720 data records (380 present, but circa 410 mapped into two broad areas, of presence and absence) because the original data set was apparently not available and the data points in the publication were difficult to interpret. In addition, some known potential data sources have yet to be added to the national map (e.g. Gibson et al. 2002).

The world distribution is summarised as presence/absence for countries in Figure 3. In addition there are 18 positive records for Papua New Guinea (Table 1, not shown on Figure 3).

CLIMEX models

The original distribution model for Australia (Brasier and Scott, 1994) was based on the known biology of *P. cinnamomi* and did not include any assessment against presence and absence data because it was not available at the time (Table 2). Being a parameter-based mechanistic model, it is possible to re-visit the distribution models and incorporate new knowledge. Subsequently three other models have been published, one with the CLIMEX program material (Sutherst et al. 1999) and two models for the French distribution of *P. cinnamomi* (Desprez-Loustau et al. 2007). Two further models were produced for this project, one attempting to model the distribution of the disease the other the distribution of the pathogen.

Table 3 lists the parameters and their values for each of the six CLIMEX models. The six world distributions for each model are shown in Appendix 2. The original model (Brasier and Scott 1994) did not have an Australian distribution as a guide and yet it gives a reasonable approximation to the observed distribution covering 89% of data points (Table 4). The Sutherst et al. (1999) model has a similar result (Table 4). However, the models based on French material (Desprez-Loustau et al. 2007) are even better at predicting the Australian distribution (sensitivity = 91 and 99%) (Table 4). The revised pathogen model used as its starting point the Desprez-Loustau et al. 2007 model for *P. cinnamomi* on roots and changed two aspects, the moisture index, so that wet tropical areas were included (see Appendix 2), and slight changes to the hot stress accumulation rate to better define the distribution in south-west Western Australia. This revised model also covers 99% of Australian records while making a slight improvement in Prevalence (Table 4, Figure 4). Model specificity, the proportion of true absences occurring in climatically unsuitable areas, was not calculated because a new method will need to be developed to analyse the large number of records of both true presence and true absences both within the climatically suitable and unsuitable areas.

The ten Australian pixels with positive records that were not included in the model (Table 4) required further investigation. There was one pixel in south-west Western Australia (at Lake Magenta) with five records that may be an easting and northing zone misclassification. A second and third pixel (with one and two points) are beside the South Coast Highway near the Fitzgerald NP and would likely be included in the modelled area, but for the scale of the pixel used in this study (Figure 5). Similarly for the one missed record in central Tasmania (Figure 6). Four missed records in Vic and NSW were associated with horticultural situations (potting mix, avocado, peach, and protea) (Figure 7). In Queensland one record was associated with horticulture and the other lacked details.

The negative values support the model distribution in south-west Western Australia (Figure 5) in particular at the northern and inland edges of the distribution. The model in Tasmania has a lack of positive records in the centre (Figure 6) and negative records are present. The remainder of Australia lacks in negative records that occur separate from positive records, hence are not informative.

qPCR results

The 88 positive and 279 negative samples of qPCR are plotted in Figure 8 along with the EI. These values bring into question part of the extensive information gathered by classical means. Positive qPCR records were found outside of the model (and the records of presence) in the south-west (Figure 9), the Australian Alps and Tasmania (Figure 10). Even so, the negative values help confirm the northern and eastern extent in south-west Western Australia (Figure 9).

Comparison to earlier models

Twenty years ago one of us published a distribution model for the major plant pathogen, *Phytophthora cinnamomi*, accompanied by a climate change projection for Europe (Brasier and Scott 1994). Since then there has been improvements in modelling techniques and understanding of the types of models that are applicable for biosecurity and climate change situations. Considerably more data have also been collected on both the presence and absence of the soil pathogen, including evidence of further spread, enabling the early model to be tested and the development of a revised model.

Climate change scenario

Figure 11 shows the projection to 2070 of the “pathogen” model. Overall, the climate change model shows a retreat from dryer regions in the south west and south east while the Kimberly and most of the northern parts of the Northern Territory and inland Queensland become unsuitable. Despite this, most areas currently susceptible to *P. cinnamomi* will remain susceptible. Increases in favourability were observed in the Australian Alps and central Tasmania.

Western Australia: decrease favourability in the Kimberley and a contraction of the favourable range in the south west of Western Australia toward the coast

Northern Territory: dramatic reduction in suitability of the region for the survival of *Phytophthora cinnamomi*

Queensland: contraction of suitable region toward the coast with a marked decreased in the suitability inland from the region between Rockhampton and Townsville (the Far North and Northern Regions).

New South Wales: contraction toward the coast, but still highly susceptible in Clarence River and Coffs Harbour region and the costal regions bordering with southern Queensland (including the Gondwana rainforest), Additionally there will be an increase in suitability in the Australia Alps.

Victoria: Contraction toward the coast, marked decrease in most regions with the most suitable range shrinking toward Wilson Promontory and around Croajinolong NP. However, suitability in all but the higher elavations of the Australian Alps will increase.

South Australia: there will be decreased suitability in most regions contracting toward Talisker NP and Kangaroo Island

Tasmania: sutibality remains the same or increase throughout Tasmania, the central plateau which was unsuitable in the earlier models will become suitable.

Concluding remarks

This is the most comprehensive study of *P. cinnamomi* distribution undertaken to date. The model generated fits very well with the known presence of the disease. However, the pathogen appears to be present but not actively causing disease in other areas. In a changing climate, previously unfavourable conditions, especially at altitudes above 700 m, may result in an increase in disease incidence. Concurrently, a reduction of rainfall in other areas may results in decreased disease incidence.

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Tables

Table 1. Sources of locality data for *P. cinnamomi* and locality data that were negative for *P. cinnamomi* in Australia and Papua New Guinea.

Area covered by the data	Time span of data	Number of presence data points	Number of absence data points	Total (number used)	Data owner/source
New South Wales (Royal National Park)	2001 - 2002	35		35 (35)	Keith et al. 2012
New South Wales (south east)	No date	17	5	22 (22)	Keith McDougall (Office of Environment and Heritage) pers. com.
NSW, Sydney Metropolitan Catchment Management Authority area (includes Garigal and Lane Cove National Park	2005-2008	201	472	673 (671)	Suddaby 2008
NSW, Garigal National Park	April-May 2007	2	67	69	
NSW, Lane Cove National Park	April-May 2007	10	80	90	
NSW, Berrowra	June 2007	1	19	20	Ed Liew pers. com.
NSW northern tablelands: Dorrigo, Gibraltar Range, Mummel Gulf, New England, Nightcap, Oxley Wild River, Werrikimbe, National Parks	May 2007	0	242	242	Craig Wall and Ed Liew pers. com.
NSW, Smoky Mouse sites near Eden	April 2013	31	60	91	Linda Broome and Ed Liew pers. com.
NSW (northern) and Qld (southern) Gondwana Rainforests of eastern Australia	2004-2007	360	1366	1726	Rosalie Daniel, David Guest and Thomas Bishop pers. com. 2013, Bishop et al. 2012
Victoria (Grampians and Wilsons Promontory National Parks)	April 2012	45	17	63 (45)	Scott-Walker and Francis 2012
Victoria (Warby Ovens National Park)	2011-2012	6		10 (6)	David Cahill pers. com.
Western Australia (south west)	1982 - 2012	9,962	17,106	28,742 (27,068)	Mike Stukely (Western Australian Department of Parks and Wildlife) pers. com.
Tasmania (whole state)	1972 - 2012	1,199	640	1839 (1829)	Tim Rudman (Department of Primary Industries, Parks, Water and the Environment) pers. com.
Queensland (Wet Tropics World Heritage area, and MacKay region)	1975 - 1982	104	209	646 sites[1]	Brown 1999

Area covered by the data	**Time span of data**	**Number of presence data points**	**Number of absence data points**	**Total (number used)**	**Data owner/source**
Australia	1965 - 2012	2,048		2,092 (2,048)[2]	Atlas of Living Australia (http://www.ala.org.au/)
Australia	1947 - 2007	1,003		1,065 (1,003)	Australian Plant Disease Database (Shivas et al. 2006)
Papua New Guinea	1975- 1980			17	Frans Arentz pers. com. 2013; Arentz 1985; Old et al. 1984

[1]646 sites had *P. cinnamomi* present. Figures 3 and 4 in Brown (1999), showing 1 km^2 grids with presences (104) and absences (209), were digitize to include in the database.
[2]Note: considerable overlap with records from Tasmania.

Table 2. Information sources used to initiate the CLIMEX modelling process in various models. The parameter set in Sutherst et al. (1999) is undocumented.

Index	Information informing parameter values	Source	Model informed
Temperature	Absolute lower limit known for growth is 5°C	Zentmyer 1980	All models
	Growth occurs between 5 and 35°C with an optimum between 28 and 30°C	Grant and Byrt 1984	All models
	Growth of Australian isolates was between 5 and 35°C with an optimum between 25 to 30°C	Phillips and Weste 1985	Revised pathogen model
	Cardinal temperatures of minimum 5-16°C, optimum 20-32.5°C and maximum 30-36°C based on growth in laboratory culture of 187 isolates from 24 countries and 59 hosts.	Zentmyer et al. 1976	All models
	Gametangia were formed from 9 to 33°C, and oospores from 12 to 30°C. The optimum temperatures ranged from 15 to 24°C	Zentmyer et al. 1979	Revised pathogen model
	Temperature range was based on daily linear growth over a range of temperatures (see Table 3)	Desprez-Loustau et al. 2007	Revised pathogen model
	Growth on avocado was greatest between 21 to 27°C, some disease occurred at 15°C and the pathogen did not cause disease at 33°C, indicating the upper value in the temperature range	Zentmyer 1981	Revised disease model
	Optimum temperatures for infection were between 15 to 25°C in soil	Shew and Benson 1983	Revised disease model
Moisture	The distribution of jarrah, *Eucalyptus marginata,* was used to indicate starting values for the moisture index	Abbott and Loneragan 1986	Brasier and Scott 1994
	The maximum numbers of sporangia were produced on the soil surface under flooded and saturated conditions indicating that SM2 and SM3 values should be well above 1	Gisi et al. 1980	Revised pathogen model
	Disease in avocados is evident when soil is near to saturation (MI = 1)	Sterne et al. 1977	Desprez-Loustau et al. 2007, Revised disease model
	Fitted to geographical distribution and seasonal variation data in France	Desprez-Loustau et al. 2007	Desprez-Loustau et al. 2007
Cold stress	*P. cinnamomi* does not survive in soil below zero degrees	Benson 1982	Desprez-Loustau et al. 2007, Revised pathogen model
	Frost (0°C) limits the presence of *P. cinnamomi* in France	Marcais et al. 2004	Desprez-Loustau et al. 2007, Revised pathogen model
Heat stress	The values for heat stress were retained from Desprez-Loustau et al. 2007, as the parameter contributes to reducing the projected distribution in northern Australia	Desprez-Loustau et al. 2007	Revised pathogen model

Dry stress	The northern extent of records in south west Australia was used to define dry stress using the parameter values in Desprez-Loustau et al. 2007 as a starting point	Desprez-Loustau et al. 2007	Revised pathogen model
Distribution databases used to train the model	The distribution of *P. cinnamomi* in south western Australia	Shearer and Tippett 1989	Brasier and Scott 1994
	World distribution based on presence or absence in countries or regions as given in CABI map 302	CABI 1991	Desprez-Loustau et al. 2007
	Distribution records for Australia World distribution based on presence or absence in countries or regions	EPPO/CABI 1998	Revised pathogen model

Table 3. CLIMEX parameters values used for modelling the distribution of *Phytophthora cinnamomi* based on the temperature and moisture requirements for development, the Australian and world distribution. Note that parameters without units are a dimensionless index of available soil moisture scaled from 0 (oven dry) to 1.0 (field capacity).

Index	Parameter	CLIMEX model						
		Brasier and Scott 1994	Sutherst et al. 1999	Desprez-Loustau et al. 2007 (in roots)	Desprez-Loustau et al. 2007 (in stems)	Revised 2013 (Pathogen)	Revised 2013 (Disease)	Units
Temperature	DV0 = lower threshold	15	5	8	8	8	15	°C
	DV1 = lower optimum temperature	22	23	22	22	22	22	°C
	DV2 = upper optimum temperature	27	28	32	32	32	27	°C
	DV3 = upper threshold	31	32	34	34	34	31	°C
Moisture	SM0 = lower soil moisture threshold	0.5	0.4	0.4	0.4	0.4	0.6	
	SM1 = lower optimum soil moisture	0.6	0.7	0.7	0.7	0.7	0.75	
	SM2 = upper optimum soil moisture	1.3	1.3	1.3	1.3	3	3	
	SM3 = upper soil moisture threshold	2	3.0	3.0	3.0	4	4	
Cold stress	TTCS = cold stress temperature threshold	5		0	2	0	5	°C
	THCS = cold stress temperature rate	0.001		0.005	0.100	0.005	0.001	
	DTCS = cold stress degree day threshold		10	10	10	10		
	DHCS = cold stress degree day rate		0.0007	0.0001	0.0001	0.0001		
Heat stress	TTHS = temperature threshold		30	34	34	34		°C
	THHS = heat stress accumulation rate		0.005	0.002	0.002	0.002		$Week^{-1}$
Dry stress	SMDS = dry stress threshold		0.10	0.10	0.10	0.10		
	HDS = dry stress rate		0.05	0.05	0.05	0.055		
Hot dry stress	TTHD = hot dry temperature threshold		32					
	MTHD = hot dry moisture threshold		0.05					
	PHD = hot dry stress accumulation rate		0.005					

Note: Empty cells indicate unused values (not all parameters need to be included in CLIMEX).

Table 4. Numbers of pixels (10x10’) within six CLIMEX models with and without records of *P. cinnamomi* presence in Australia. Model sensitivity is the percentage of known distribution records in Australia covered by the model values of EI > 0 and model prevalence is the proportion of the model universe (Australia) estimated to be climatically suitable. The total pixels in Australia is 25,339. The total number of pixels with positive records of *P. cinnamomi* is 672.

	Pixels without records	Records within unsuitable area	Pixels within suitable area without records	Records within suitable area	Sensitivity (%)	Prevalence
EI values of pixels	EI=0	EI=0	EI>0	EI>0		
Numbers of pixels with/without presence records	Records=0	Records>0	Records=0	Records>0		
Brasier and Scott 1994	22604	74	2063	598	89%	0.11
Sutherst et al. 1999	21943	107	2724	565	84%	0.13
Desprez-Loustau et al. 2007 roots	21145	10	3522	662	99%	0.17
Desprez-Loustau et al. 2007 stems	21635	60	3032	612	91%	0.14
Current model based on disease	22976	105	1691	567	84%	0.09
Current model based on pathogen	21329	10	3338	662	99%	0.16

Figures

Figure 1. Positive records of *Phytophthora cinnamomi* in Australia based on data sources given in Table 1.

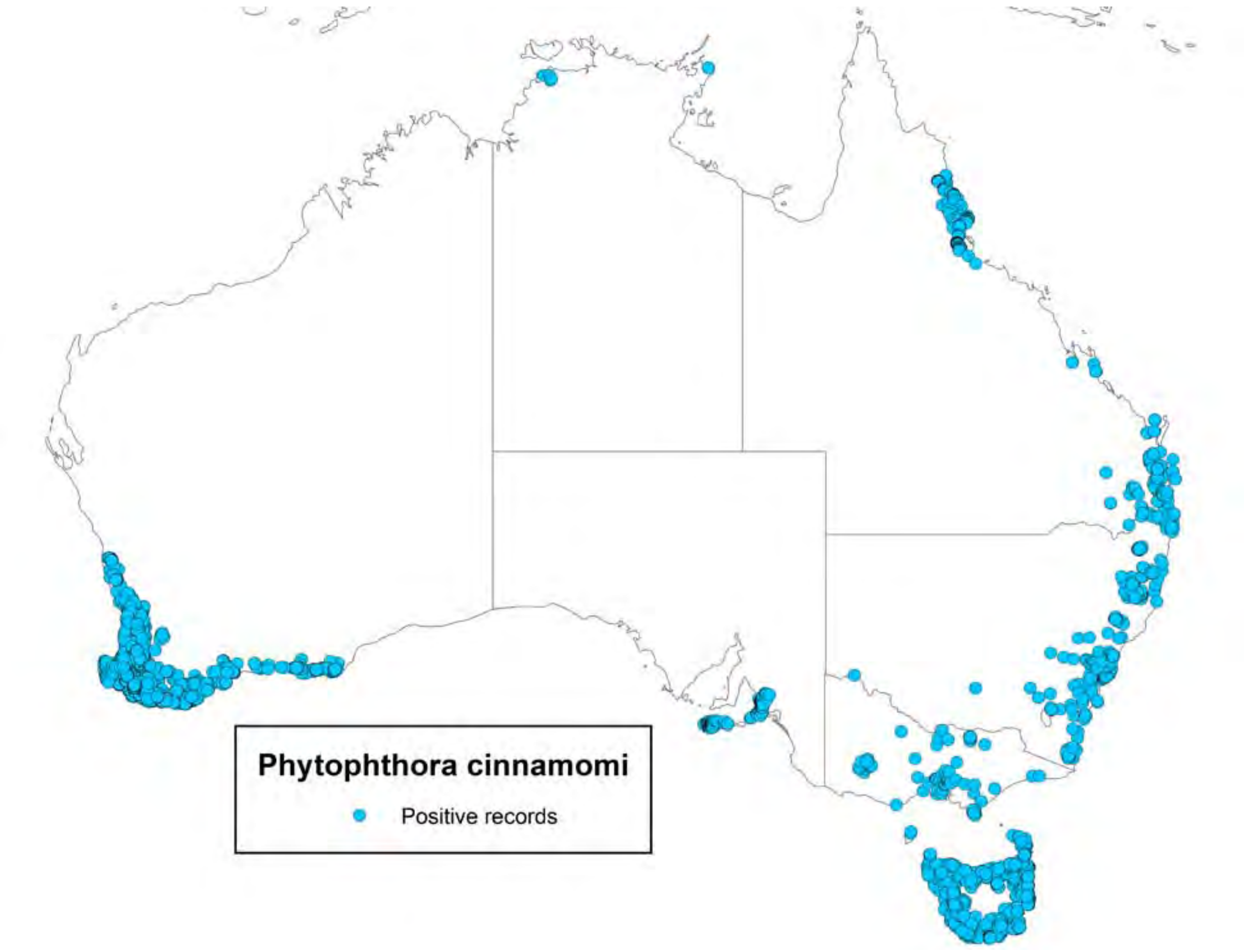


Figure 2. Negative records of *Phytophthora cinnamomi* in Australia based on data sources given in Table 1.

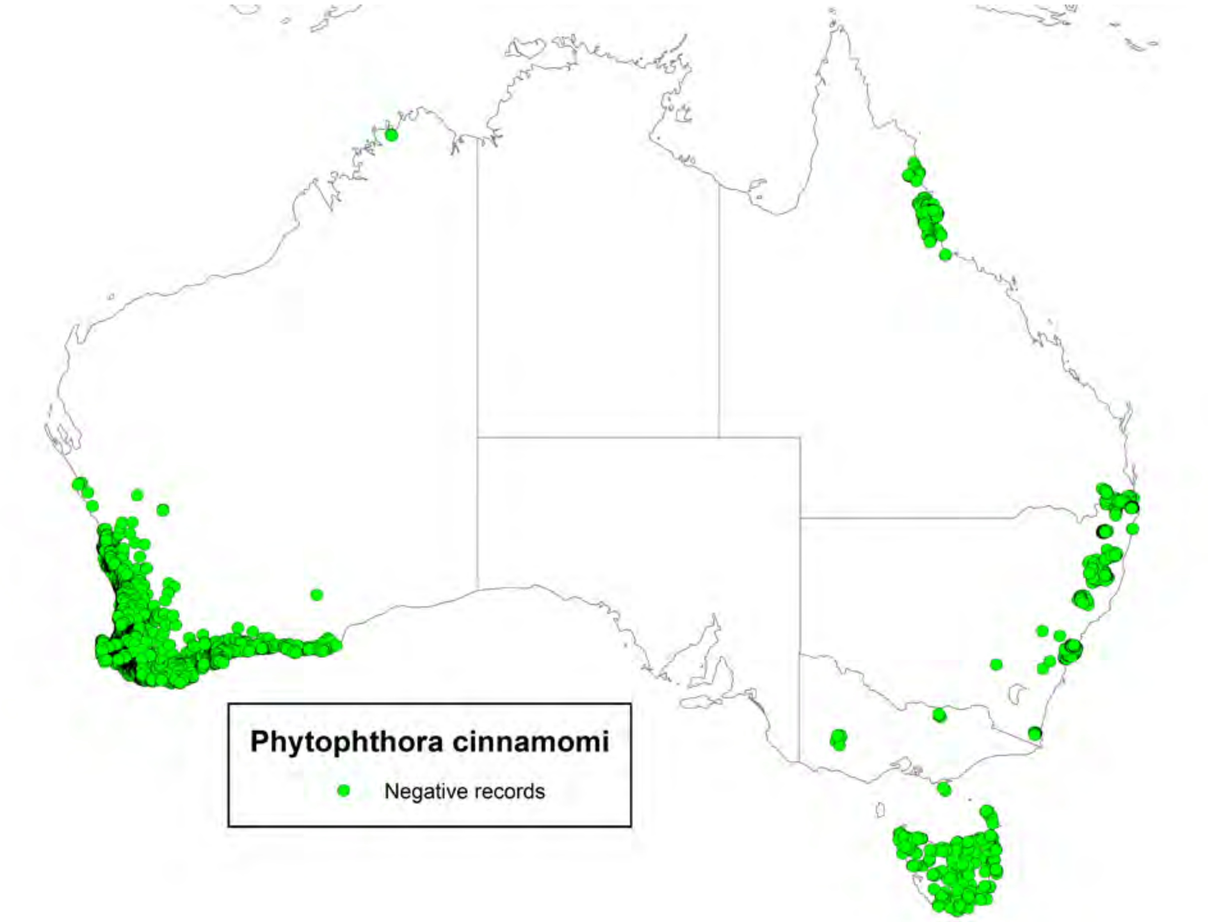


Figure 3. World distribution of *Phytophthora cinnamomi* based on country or region presence or absence based on EPPO/CABI (1998).

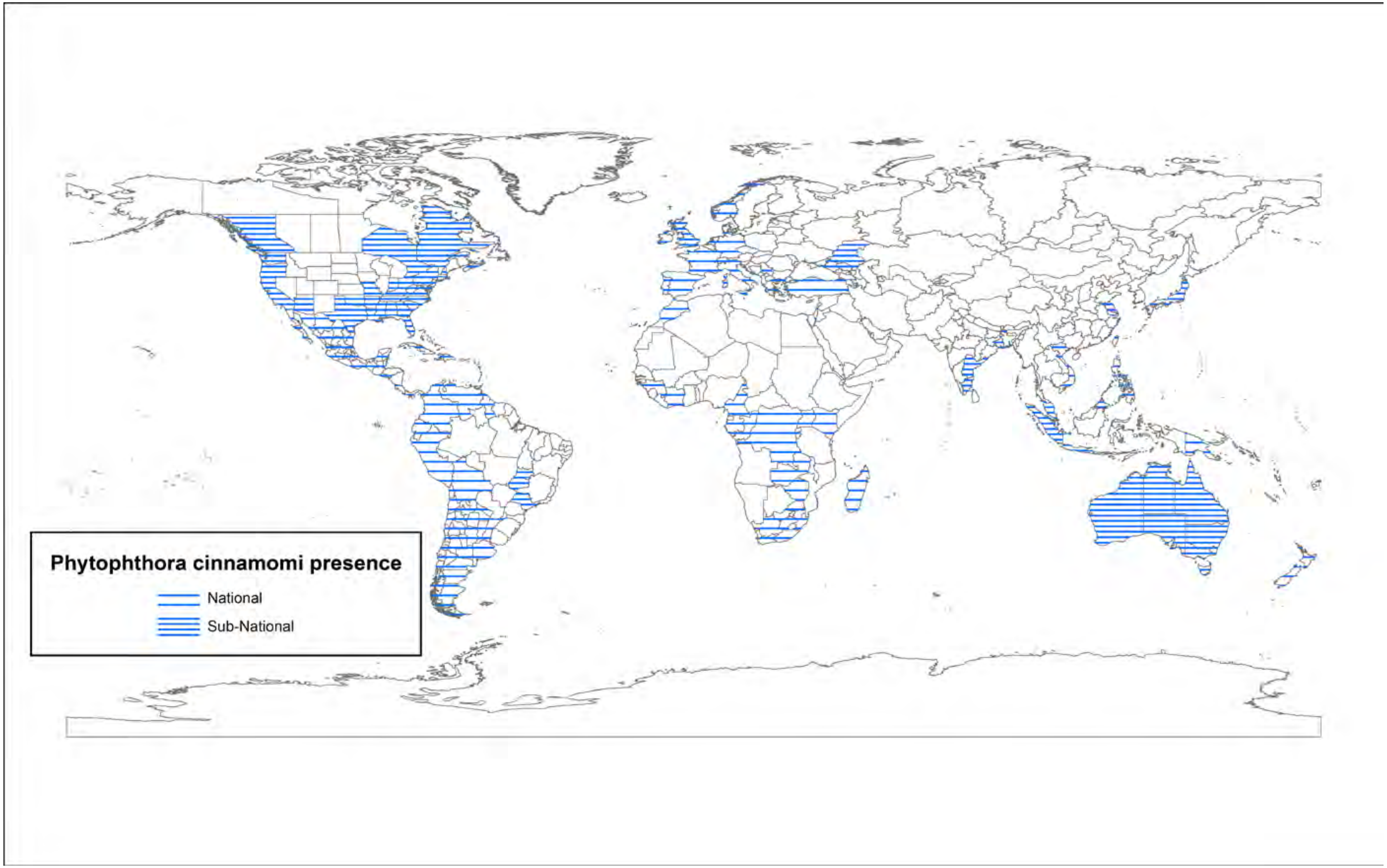


Figure 4. Historical climate suitability for *Phytophthora cinnamomi* ("pathogen" model) in Australia as indicated by the CLIMEX Ecoclimatic Index (EI).

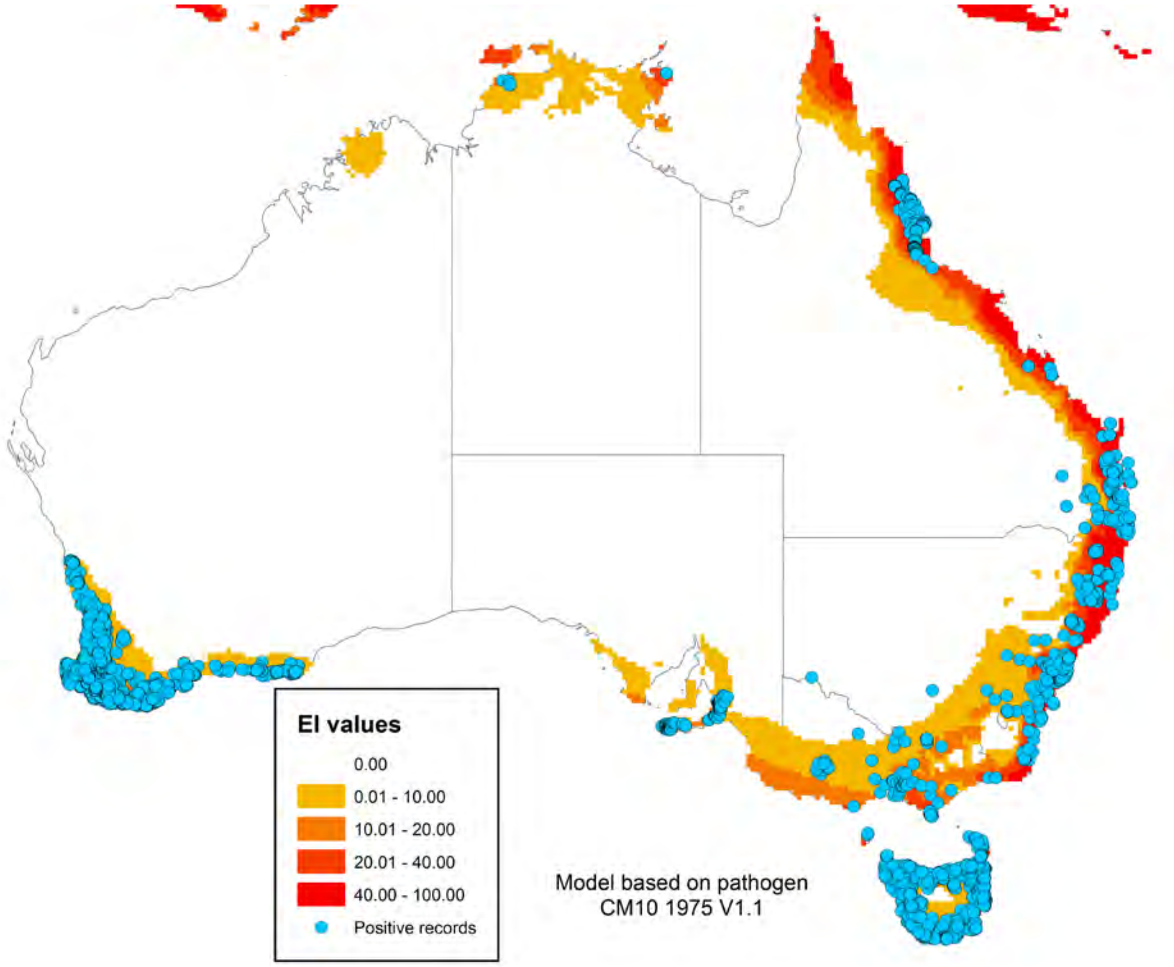


Figure 5. Historical climate suitability for *Phytophthora cinnamomi* (“pathogen” model) in south-west Western Australia.

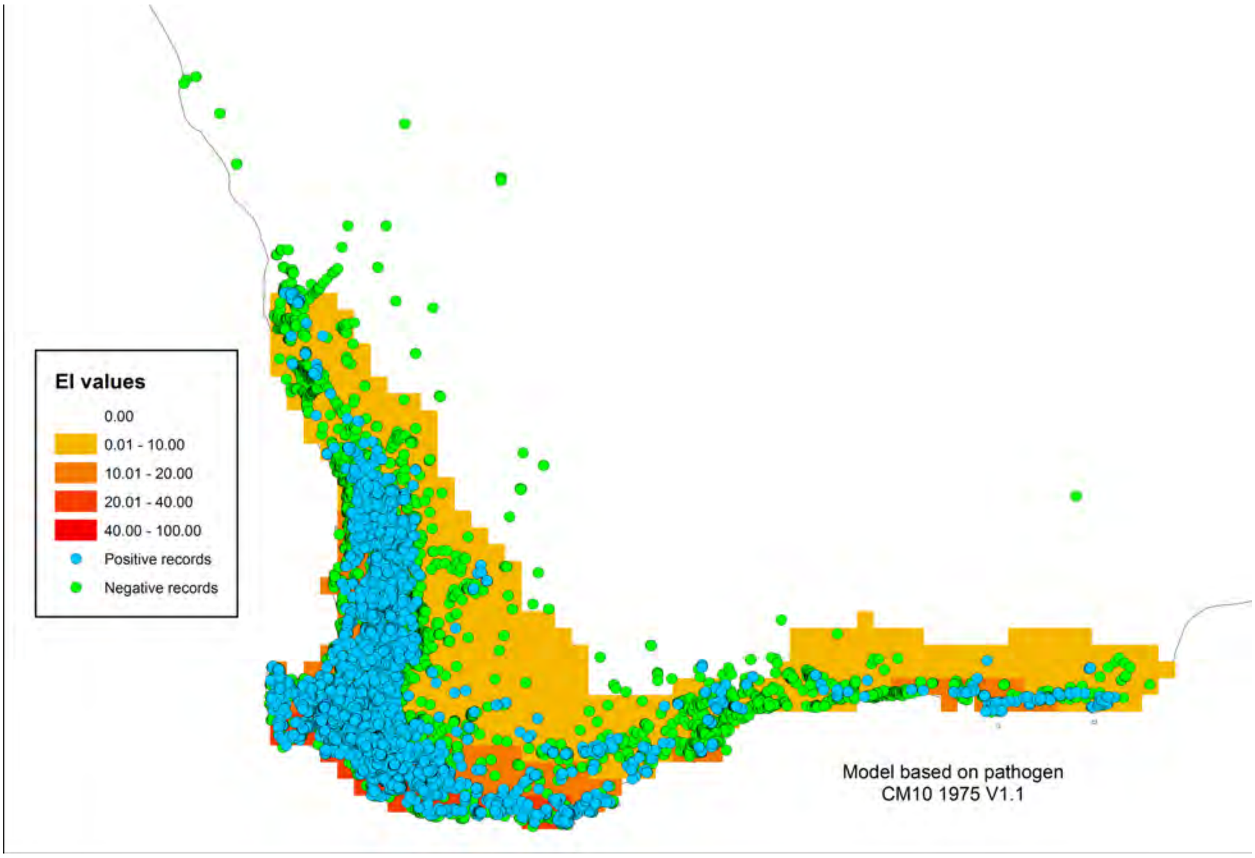


Figure 6. Historical climate suitability for *Phytophthora cinnamomi* (“pathogen” model) in Tasmania.

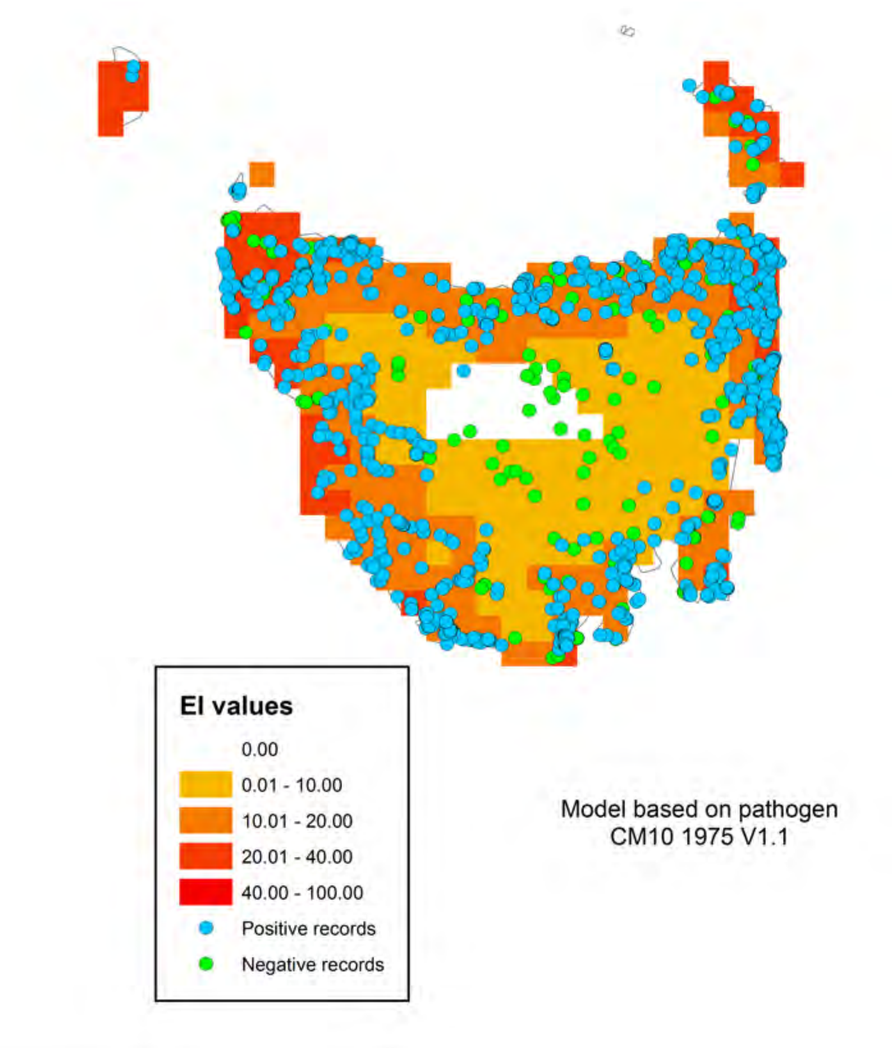


Figure 7. Historical climate suitability for *Phytophthora cinnamomi* (“pathogen” model) in Victoria and NSW.

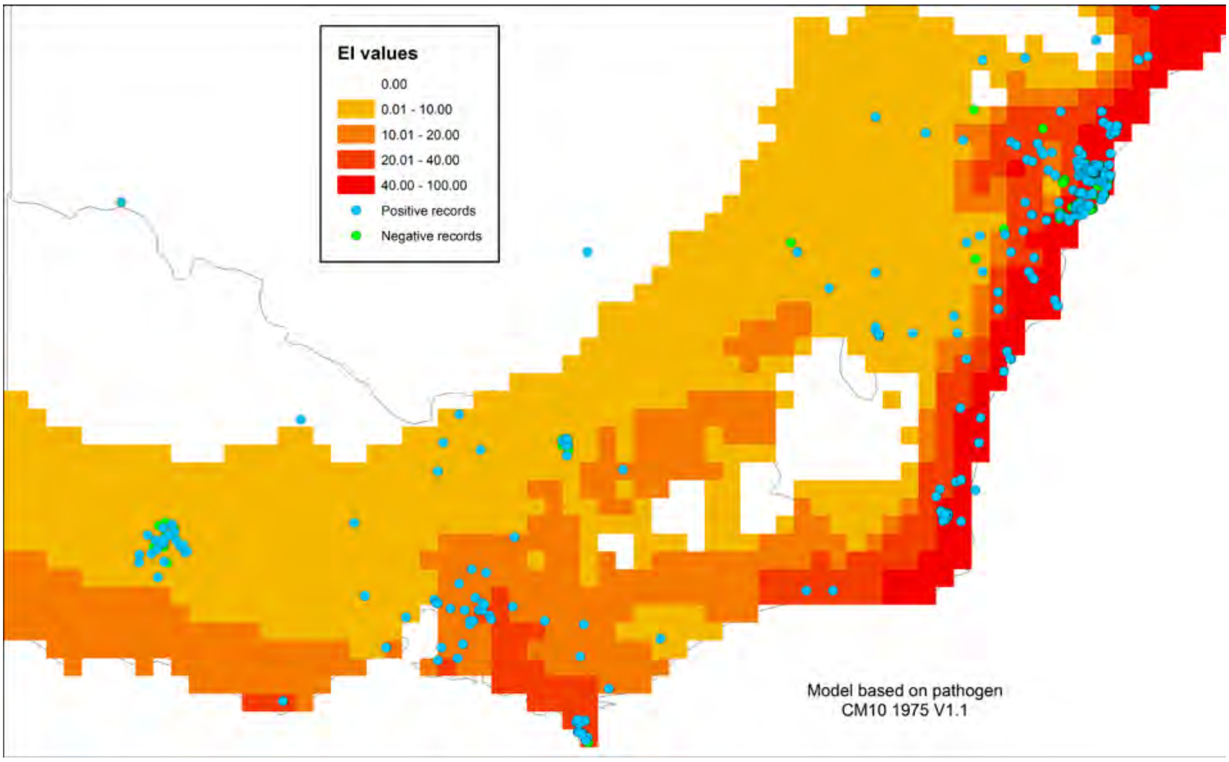


Figure 8. Historical climate suitability for *Phytophthora cinnamomi* ("pathogen" model) in Australia and qPCR results.

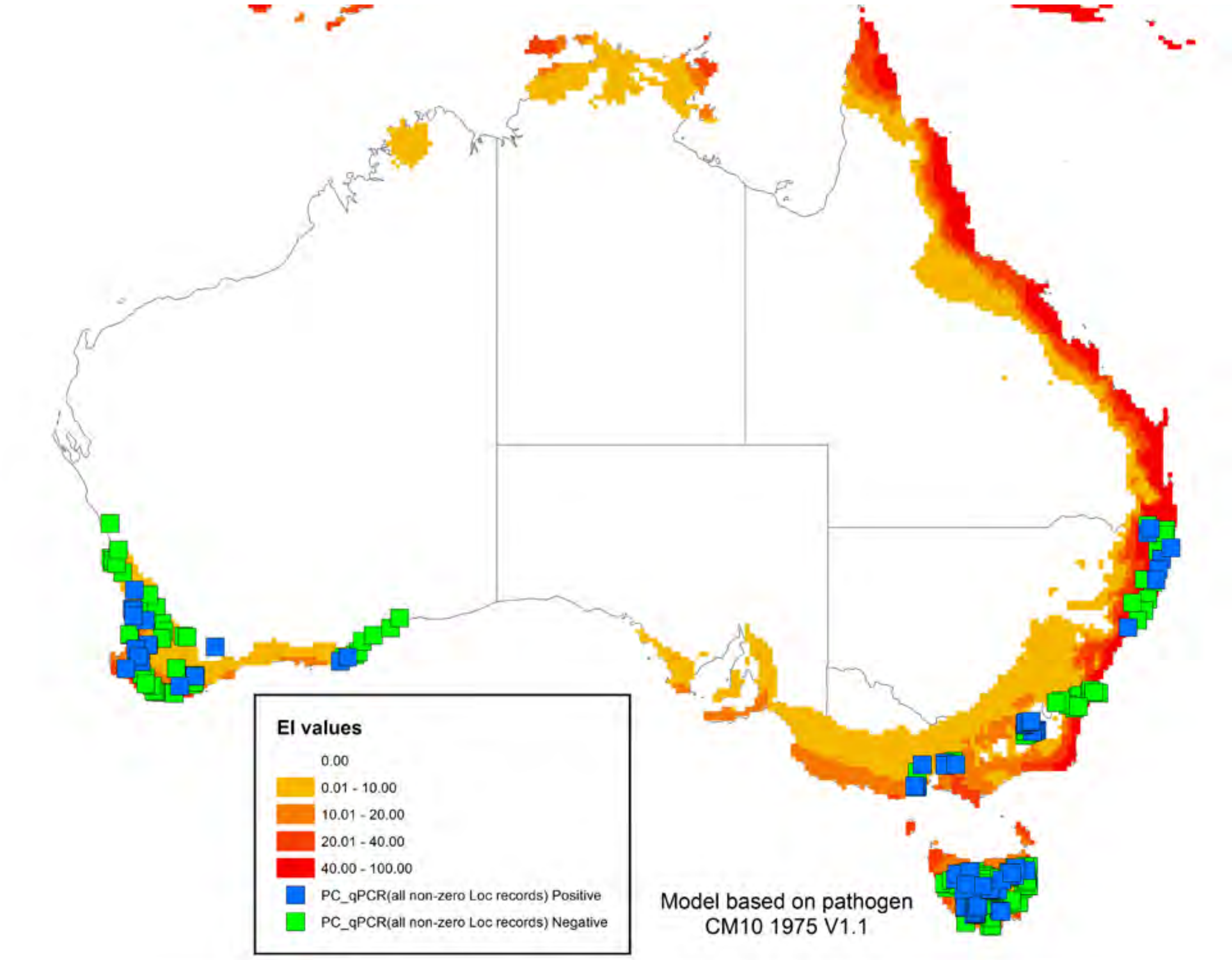


Figure 9. Historical climate suitability for *Phytophthora cinnamomi* (“pathogen” model) in south-west Australia and qPCR.

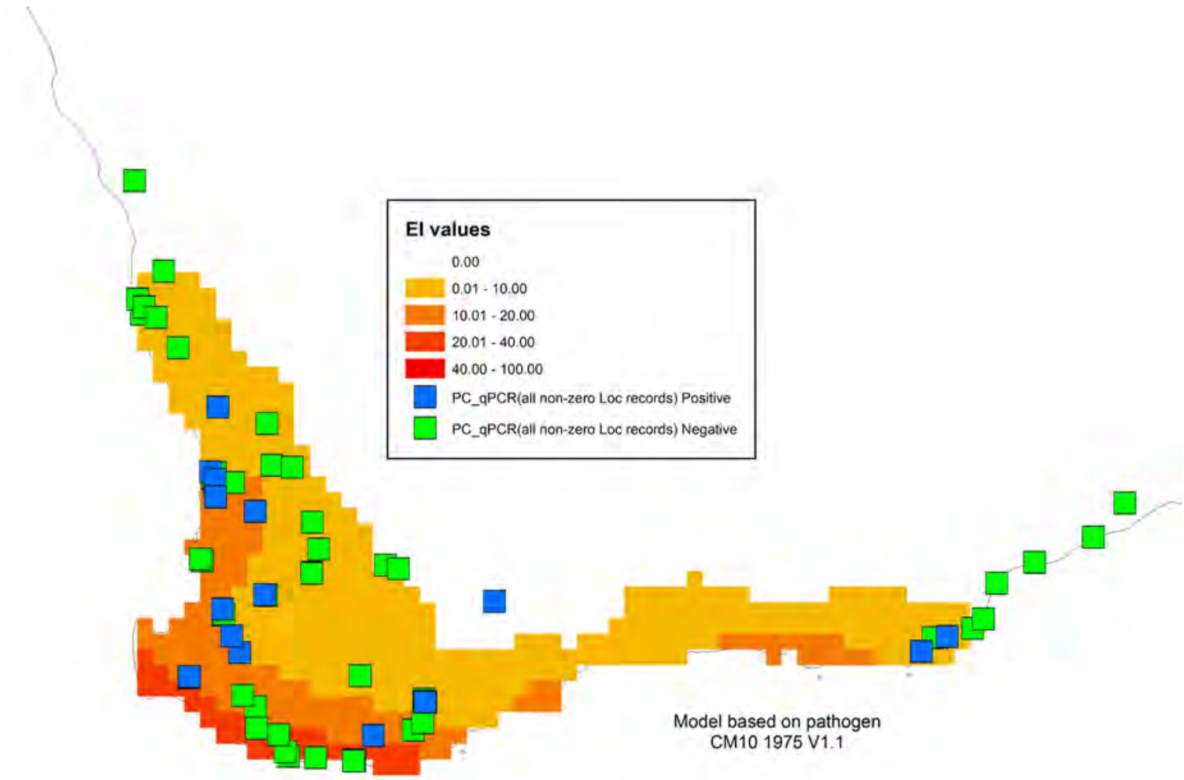


Figure 10. Historical climate suitability for *Phytophthora cinnamomi* (“pathogen” model) in Tasmania and qPCR results.

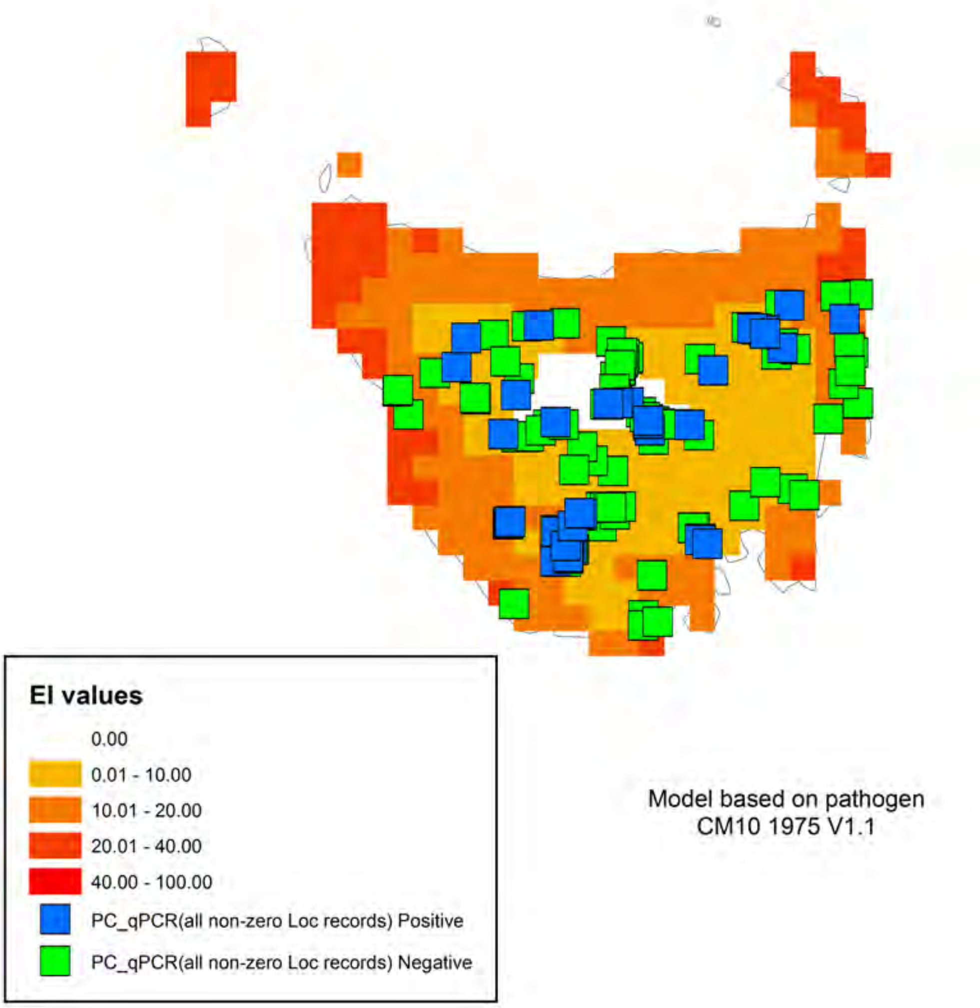
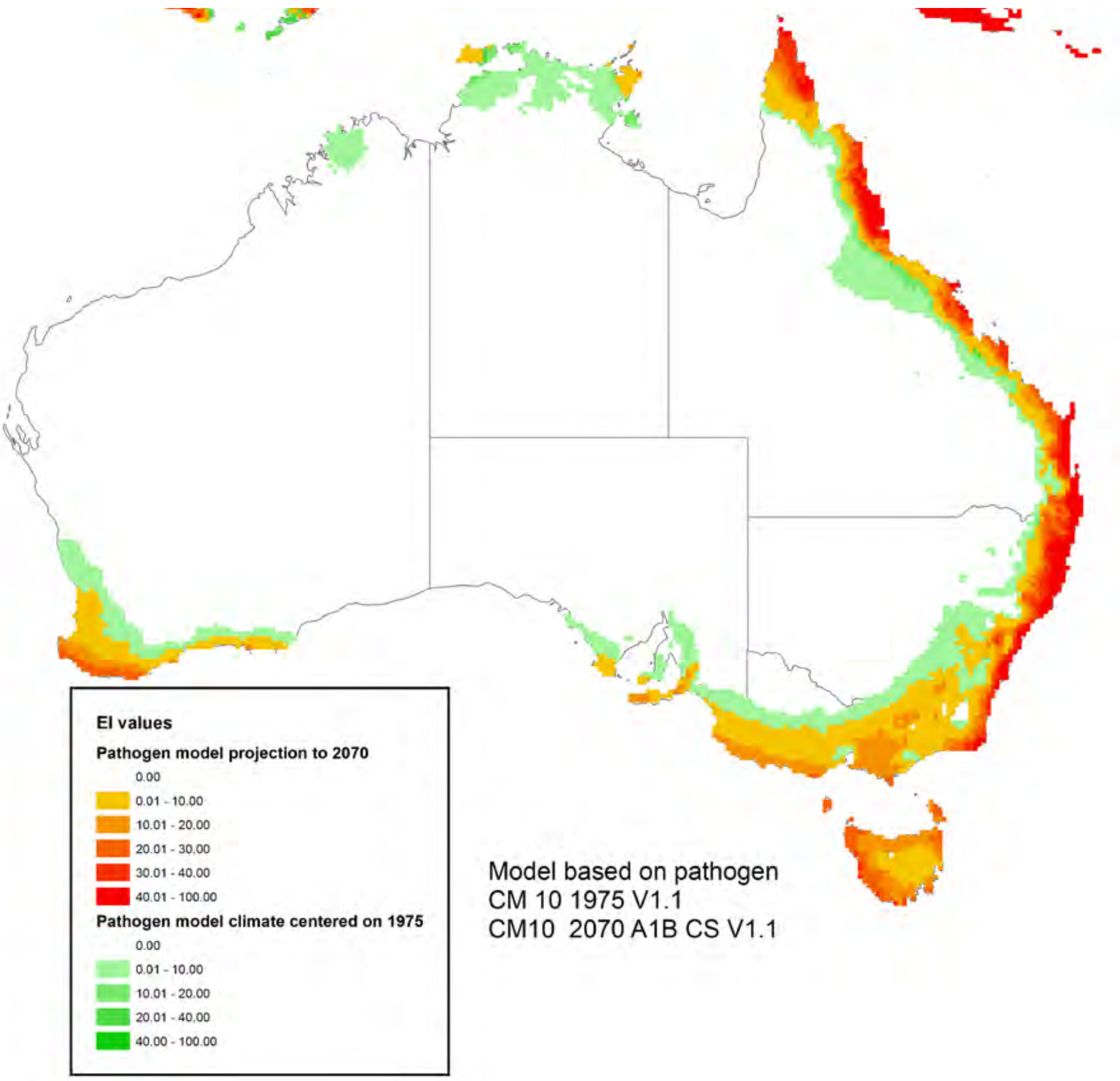


Figure 11. Climate suitability for *Phytophthora cinnamomi* Australia as indicated by the CLIMEX Ecoclimatic Index (EI) using CSIRO Mk3 projections for 2070 based on the A1B SRES scenario contrasted to the EI calculated on historical climate data centred on 1975.



Appendix 1

Localities of soil samples collected during the current study. Samples testing positive for *Phytophthora cinnamomi* (PC) are given in the final column.

State	code	Latitude	Longitude	Altitude	Vegetation	collected_by	PC
TAS	TAS1	-43.3967	146.8607	25	wet eucalypt	TI Burgess	
TAS	TAS2	-43.4627	146.8595	110	wet eucalypt	TI Burgess	
TAS	TAS3	-43.4385	146.9557	47	heath	TI Burgess	
TAS	TAS4	-43.1315	146.9186	186	eucalypt	TI Burgess	
TAS	TAS5	-42.8159	147.2036	380	dry eucalypt	TI Burgess	
TAS	TAS6	-42.8181	147.1906	307	dry eucalypt	TI Burgess	
TAS	TAS7	-42.7251	146.4528	652	moreland	TI Burgess	
TAS	TAS8	-42.8322	146.3848	580	rainforest	TI Burgess	
TAS	TAS9	-43.0373	146.2776	462	moorland	TI Burgess	yes
TAS	TAS10	-42.9583	146.3621	339	moorland	TI Burgess	
TAS	TAS11	-42.7629	146.5360	310	wet eucalypt	TI Burgess	
TAS	TAS12	-42.8055	146.5846	529	*E. nitens* plantation	TI Burgess	
TAS	TAS13	-42.7275	146.6731	227	wet eucalypt	TI Burgess	
TAS	TAS14	-42.4407	146.6601	248	dry eucalypt	TI Burgess	
TAS	TAS15	-42.3732	146.5266	277	wet eucalypt	TI Burgess	
TAS	TAS16	-42.2804	146.4572	683	wet eucalypt	TI Burgess	
TAS	TAS17	-42.1363	146.2303	693	wet eucalypt	TI Burgess	
TAS	TAS18	-42.1363	146.2303	696	rainforest	TI Burgess	
TAS	TAS19	-42.1962	145.9339	546	moorland	TI Burgess	yes
TAS	TAS20	-42.0674	145.3086	264	moorland	TI Burgess	
TAS	TAS21	-41.9129	145.2345	204	coastal heath	TI Burgess	
TAS	TAS22	-41.9061	145.2390	212	wet eucalypt	TI Burgess	
TAS	TAS23	-41.7915	145.4800	175	wet eucalypt	TI Burgess	
TAS	TAS24	-41.7532	145.6242	193	wet eucalypt	TI Burgess	yes
TAS	TAS25	-41.5612	145.6891	690	wet eucalypt	TI Burgess	
TAS	TAS26	-41.5396	145.8682	935	moorland	TI Burgess	

State	code	Latitude	Longitude	Altitude	Vegetation	collected_by	PC
TAS	TAS27	-41.4829	146.0906	605	dry eucalypt	TI Burgess	
TAS	TAS28	-41.4778	146.1693	423	dry eucalypt	TI Burgess	yes
TAS	TAS29	-41.4650	146.3415	260	dry eucalypt	TI Burgess	
TAS	TAS30	-41.5848	146.6481	278	Podocarp	TI Burgess	
TAS	TAS31	-41.6594	146.7225	748	wet Eucalypt	TI Burgess	
TAS	TAS32	-41.7014	146.7231	946	wet Eucalypt	TI Burgess	
TAS	TAS33	-41.7207	146.7250	1098	gymnosperm - dieback	TI Burgess	
TAS	TAS34	-41.7407	146.7061	1207	pencil pines/ moorland	TI Burgess	
TAS	TAS35	-41.7776	146.7121	1069	eucalypt/typical snow gum	TI Burgess	
TAS	TAS36	-41.9197	146.6872	1062	grassland	TI Burgess	
TAS	TAS37	-42.1003	146.8920	860	eucalypt	TI Burgess	
TAS	TAS38	-42.6699	147.5290	275	dry eucalypt	TI Burgess	
TAS	TAS39	-42.5589	147.8495	18	dry eucalypt	TI Burgess	
TAS	TAS40	-42.6008	147.9262	95	dry eucalypt	TI Burgess	
TAS	TAS41	-42.0964	148.0857	3	dry eucalypt	TI Burgess	
TAS	TAS42	-41.9950	148.2799	63	coastal heath	TI Burgess	
TAS	TAS43	-41.9917	148.2820	37	coastal heath - dieback	TI Burgess	
TAS	TAS44	-41.8644	148.1877	92	dry eucalypt	TI Burgess	
TAS	TAS45	-41.6586	148.2502	98	eucalypt	TI Burgess	
TAS	TAS46	-41.6245	148.2234	337	eucalypt	TI Burgess	
TAS	TAS47	-41.2730	148.2831	50	dry eucalypt	TI Burgess	
TAS	TAS48	-41.2841	148.1347	90	eucalypt	TI Burgess	
TAS	TAS49	-41.4348	148.1937	65	eucalypt	TI Burgess	Yes
TAS	TAS50	-41.6351	147.8515	558	eucalypt	TI Burgess	
TAS	TAS51	-41.6258	147.7817	654	eucalypt	TI Burgess	yes
TAS	TAS52	-41.5967	147.7902	667	rainforest	TI Burgess	
TAS	TAS53	-41.6700	147.7411	584	eucalypt	TI Burgess	
TAS	TAS54	-41.5242	147.6633	1395	alpine heath	T Rudman	yes
TAS	TAS55	-41.5115	147.6617	1252	subalpine shrubland	T Rudman	yes
TAS	TAS56	-41.5037	147.6119	985	wet sclerophyll	T Rudman	
TAS	TAS57	-41.4983	147.5829	768	inland forest	T Rudman	yes
TAS	TAS58	-42.8898	147.2364	990	inland woodland	T Rudman	
TAS	TAS59	-41.7741	147.3231	213	inland forest	T Rudman	yes

State	code	Latitude	Longitude	Altitude	Vegetation	collected_by	PC
TAS	TAS60	-41.6994	147.2359	201	inland forest	T Rudman	
TAS	TAS61	-41.5024	147.6148	1013	wet sclerophyll	T Rudman	
TAS	TAS62	-41.5326	147.6686	1433	alpine heathland	T Rudman	yes
TAS	TAS63	-41.5003	147.6045	850	wet sclerophyll	T Rudman	
TAS	TAS64	-41.4909	147.5461	596	inland forest	T Rudman	
TAS	TAS65	-42.8948	147.2436	894	inland forest	T Rudman	yes
TAS	TAS66	-42.8965	147.2353	1268	alpine heathland	T Rudman	yes
TAS	TAS67	-42.9213	147.2859	350	inland forest	T Rudman	yes
TAS	TAS68	-42.5142	147.6699	230	inland forest	T Rudman	
TAS	TAS69	-41.7779	148.2312	95	inland forest	T Rudman	
TAS	TAS70	-41.9384	146.0180	1424	alpine heath	T Rudman	yes
TAS	TAS71	-42.2160	146.0197	383	scrub	W Dunstan	
TAS	TAS72	-42.2167	146.0762	557	scrub	W Dunstan	
TAS	TAS73	-42.2113	146.1041	831	sub-alpine scrub	W Dunstan	
TAS	TAS74	-42.1713	146.1821	738	buttongrass plain	W Dunstan	
TAS	TAS75	-42.1162	146.2805	790	wet sclerophyll	W Dunstan	yes
TAS	TAS76	-42.1333	146.3338	745	riparian	W Dunstan	
TAS	TAS77	-42.7332	146.4498	1006	wet sclerophyll	W Dunstan	yes
TAS	TAS78	-42.7311	146.4529	902	sub-alpine scrub	W Dunstan	
TAS	TAS79	-42.7283	146.4547	775	sub-alpine scrub	W Dunstan	
TAS	TAS80	-42.7250	146.4556	668	sphagnum bog	W Dunstan	
TAS	TAS81	-42.7242	146.4560	658	alpine moorland	W Dunstan	yes
TAS	TAS82	-42.7244	146.4551	651	alpine moorland	W Dunstan	
TAS	TAS83	-42.7248	146.4527	646	sub-alpine woodland	W Dunstan	
TAS	TAS84	-42.8452	146.2969	1147	wet sclerophyll	W Dunstan	
TAS	TAS85	-42.8432	146.2928	1051	wet sclerophyll	W Dunstan	
TAS	TAS86	-42.8425	146.2899	937	wet sclerophyll	W Dunstan	yes
TAS	TAS87	-42.8423	146.2881	878	wet sclerophyll	W Dunstan	yes
TAS	TAS88	-42.8420	146.2843	776	tussock grass plain	W Dunstan	
TAS	TAS89	-42.8383	146.2808	642	tussock grass plain	W Dunstan	
TAS	TAS90	-42.8324	146.2776	424	tussock grass plain	W Dunstan	
TAS	TAS91	-42.1730	146.9040	650	open woodland	W Dunstan	yes
TAS	TAS92	-42.1067	146.8925	848	sphagnum bog	W Dunstan	yes

State	code	Latitude	Longitude	Altitude	Vegetation	collected_by	PC
TAS	TAS93	-42.1274	146.8939	882	wet sclerophyll	W Dunstan	yes
TAS	TAS94	-42.0519	146.8454	898	rainforest	W Dunstan	
TAS	TAS95	-41.9873	146.7629	1047	sclerophyll	W Dunstan	yes
TAS	TAS96	-41.9905	146.6887	1041	wet sclerophyll	W Dunstan	yes
TAS	TAS97	-41.8884	146.6839	1059	wet sclerophyll	W Dunstan	
TAS	TAS98	-41.7738	146.7094	1137	wet sclerophyll	W Dunstan	
TAS	TAS99	-41.6601	146.7203	768	bog	W Dunstan	
TAS	TAS100	-41.6986	146.7570	533	rainforest	W Dunstan	
TAS	TAS101	-41.6880	146.7611	703	rainforest	W Dunstan	
TAS	TAS102	-41.6720	146.7365	764	buttongrass plain	W Dunstan	
TAS	TAS103	-41.7105	146.7283	656	wet woodland	W Dunstan	
TAS	TAS104	-41.7305	146.7159	817	wet woodland	W Dunstan	
TAS	TAS105	-41.7427	146.7058	829	wet woodland	W Dunstan	
TAS	TAS106	-41.7434	146.7060	828	alpine heathland	W Dunstan	
TAS	TAS107	-42.7872	145.9633	960	alpine heathland	W Dunstan	
TAS	TAS108	-42.7918	145.9636	1063	alpine heathland	W Dunstan	
TAS	TAS109	-42.7828	145.9662	851	wet woodland	W Dunstan	yes
TAS	TAS110	-42.7796	145.9741	656	wet woodland	W Dunstan	yes
TAS	TAS111	-42.7778	145.9801	457	buttongrass plain	W Dunstan	yes
TAS	TAS112	-42.7742	145.9804	301	heathland	W Dunstan	
TAS	TAS113	-42.9626	146.4018	1053	buttongrass plain	W Dunstan	
TAS	TAS114	-42.9622	146.4011	1042	alpine heathland	W Dunstan	
TAS	TAS115	-42.9625	146.3917	894	alpine heathland	W Dunstan	
TAS	TAS116	-42.9599	146.3849	663	imbricate rainforest	W Dunstan	yes
TAS	TAS117	-42.9584	146.3704	475	imbricate rainforest	W Dunstan	
TAS	TAS118	-42.9582	146.3622	338	rainforest	W Dunstan	
TAS	TAS119	-42.6767	146.7115	250	rainforest	W Dunstan	
TAS	TAS120	-42.6850	146.5912	1037	riparian rainforest	W Dunstan	
TAS	TAS121	-42.6821	146.5905	1054	alpine heathland	W Dunstan	
TAS	TAS122	-42.6788	146.5904	1059	alpine heathland	W Dunstan	
TAS	TAS123	-42.6806	146.5805	1256	buttongrass plain	W Dunstan	
TAS	TAS124	-42.6826	146.6089	1070	buttongrass plain	W Dunstan	
TAS	TAS125	-42.6791	146.6304	962	buttongrass plain	W Dunstan	

State	code	Latitude	Longitude	Altitude	Vegetation	collected_by	PC
TAS	TAS126	-42.6817	146.6470	1029	riparian rainforest	W Dunstan	
TAS	TAS127	-42.1354	147.1674	820	inland woodland	T Rudman	yes
TAS	TAS128	-43.0186	146.3659	353	wet sclerophyll	T Rudman	yes
TAS	TAS129	-43.0091	146.3623	358	short rainforest	T Rudman	yes
TAS	TAS130	-42.9358	146.3460	337	Buttongrass moorland	T Rudman	yes
TAS	TAS131	-42.8048	146.3945	560	buttongrass	T Rudman	yes
TAS	TAS132	-42.7212	146.4396	580	disturbed roadside	T Rudman	yes
TAS	TAS133	-42.7214	146.4386	570	wet sclerophyll	T Rudman	
TAS	TAS134	-42.7244	146.4493	640	buttongrass moorland	T Rudman	
TAS	TAS135	-42.7244	146.4489	640	Disturbed roadside	T Rudman	
TAS	TAS136	-42.2321	146.9283	590	Agricultural land roadside	T Rudman	
TAS	TAS137	-42.1564	146.9029	700	Disturbed roadsid	T Rudman	
TAS	TAS138	-42.1395	146.8920	765	Disturbed roadside	T Rudman	
TAS	TAS139	-42.1275	146.8929	855	Disturbed roadside	T Rudman	yes
TAS	TAS140	-42.0840	146.8708	885	Disturbed roadside	T Rudman	
TAS	TAS141	-42.1066	146.8925	853	inland woodland	T Rudman	
TAS	TAS142	-42.1132	146.9345	770	wet sclerophyll	T Rudman	
TAS	TAS143	-42.1287	146.9716	797	Disturbed roadside	T Rudman	
TAS	TAS144	-42.1324	147.0072	957	Disturbed roadside	T Rudman	
TAS	TAS145	-42.1331	147.0826	900	Disturbed roadside	T Rudman	
TAS	TAS147	-43.0401	146.2895	322	wet sclerophyll	T Rudman	
TAS	TAS148	-43.0404	146.3497	335	wet sclerophyll	T Rudman	
TAS	TAS149	-42.1278	146.8936	860	inland forest	T Rudman	
TAS	TAS150	-42.1091	146.8929	848	inland woodland	T Rudman	yes
TAS	TAS151	-42.2052	147.2309	805	wet sclerophyll	T Rudman	
TAS	TAS152	-41.8186	146.6755	1058	inland woodland	T Rudman	
TAS	TAS153	-41.8187	146.6755	1053	inland woodland	T Rudman	
TAS	TAS154	-41.7426	146.7060	1198	bog	T Rudman	
TAS	TAS155	-41.7409	146.7060	1198	bog	T Rudman	
TAS	TAS156	-41.9998	146.6100	1031	bog	T Rudman	
TAS	TAS157	-41.9999	146.6097	1029	bog	T Rudman	
TAS	TAS158	-41.8993	146.6713		inland woodland	T Rudman	
TAS	TAS159	-41.8992	146.6712		inland woodland	T Rudman	

State	code	Latitude	Longitude	Altitude	Vegetation	collected_by	PC
TAS	TAS160	-41.9951	146.6283	1032	inland woodland	T Rudman	yes
TAS	TAS161	-42.0011	146.6328	1019	inland woodland	T Rudman	
TAS	TAS162	-42.8322	146.3849	580	short rainforest	T Rudman	
TAS	TAS162	-42.8322	146.3849	580		T Rudman	
TAS	TAS165	-43.3198	146.0051	10		T Rudman	
TAS	TAS166	-42.4333	146.4018	1197		T Rudman	
TAS	TAS167	-41.9660	145.7534	840		T Rudman	
TAS	TAS168	-41.9578	145.7448	850		T Rudman	
TAS	TAS169	-41.8293	146.0379	860		T Rudman	
TAS	TAS170	-41.3423	147.7687	810		T Rudman	
TAS	TAS171	-41.3436	147.8270	800		T Rudman	yes
TAS	TAS172	-41.7150	145.9471	1020		T Rudman	
TAS	TAS173	-41.6356	147.8674	510		T Rudman	
NSW	NSW1	-36.3578	148.5872	980	open forest	K. McDougall	yes
NSW	NSW2	-36.3497	148.5822	1050	open forest	K. McDougall	
NSW	NSW3	-36.3444	148.5789	1110	open forest	K. McDougall	
NSW	NSW4	-36.3467	148.5696	1170	riparian woodland	K. McDougall	
NSW	NSW5	-36.3549	148.5617	1220	open forest	K. McDougall	
NSW	NSW6	-36.3518	148.5466	1290	open forest	K. McDougall	
NSW	NSW7	-36.3458	148.5388	1375	open forest	K. McDougall	
NSW	NSW8	-36.3483	148.5317	1405	riparian shrubland	K. McDougall	
NSW	NSW9	-36.3525	148.5188	1460	wetland	K. McDougall	
NSW	NSW10	-36.3580	148.5123	1530	woodland	K. McDougall	yes
NSW	NSW11	-36.3632	148.5020	1580	grassland	K. McDougall	
NSW	NSW12	-36.3889	148.4463	1620	wetland	K. McDougall	yes
NSW	NSW13	-36.3986	148.4233	1700	woodland	K. McDougall	yes
NSW	NSW14	-36.4250	148.3771	1750	open heathland	K. McDougall	
NSW	NSW15	-36.4323	148.3310	1820	shrubland	K. McDougall	
NSW	NSW16	-36.4428	148.3142	1875	shrubland	K. McDougall	
NSW	NSW17	-36.4577	148.3004	1940	wetland / grassland	K. McDougall	
NSW	NSW18	-36.4525	148.2837	2000	grassland	K. McDougall	
NSW	NSW19	-36.4539	148.2735	2065	wetland / grassland	K. McDougall	
NSW	NSW20	-36.4584	148.2687	2125	open heathland	K. McDougall	

State	code	Latitude	Longitude	Altitude	Vegetation	collected_by	PC
NSW	NSW21	-36.1758	148.1525	455	open forest	K. McDougall	
NSW	NSW22	-36.1677	148.1560	500	shrubland	K. McDougall	yes
NSW	NSW23	-36.1571	148.1566	565	open forest	K. McDougall	
NSW	NSW24	-36.1459	148.1561	640	tall forest	K. McDougall	yes
NSW	NSW25	-36.1415	148.1563	700	tall forest	K. McDougall	
NSW	NSW26	-36.0947	148.1694	740	tall forest	K. McDougall	
NSW	NSW27	-36.0925	148.1758	800	tall forest	K. McDougall	
NSW	NSW28	-36.0897	148.1812	860	open forest	K. McDougall	yes
NSW	NSW29	-36.0883	148.1832	920	tall forest	K. McDougall	
NSW	NSW30	-36.0826	148.1854	980	tall forest	K. McDougall	yes
NSW	NSW31	-36.0770	148.1917	1060	tall forest	K. McDougall	
NSW	NSW32	-36.0787	148.2059	1100	tall forest	K. McDougall	
NSW	NSW33	-36.0711	148.2222	1140	tall riparian forest	K. McDougall	
NSW	NSW34	-36.0690	148.2334	1200	tall forest	K. McDougall	
NSW	NSW35	-36.0518	148.3000	1280	tall forest	K. McDougall	
NSW	NSW36	-36.0387	148.3228	1320	grassland / shrubland	K. McDougall	yes
NSW	NSW37	-36.0364	148.3264	1340	tall forest	K. McDougall	
NSW	NSW38	-36.0379	148.3369	1440	tall forest	K. McDougall	
NSW	NSW39	-36.0410	148.3474	1520	woodland	K. McDougall	
NSW	NSW40	-36.0208	148.3745	1580	grassland	K. McDougall	yes
NSW	NSW41	-35.2041	150.0514	580	open forest	K. McDougall	
NSW	NSW42	-35.1489	150.0692	600	shrubland	K. McDougall	
NSW	NSW43	-35.0800	150.1478	775	heathland on sandstone	K. McDougall	
NSW	NSW44	-34.9686	150.5028	170	woodland	K. McDougall	
NSW	NSW45	-34.8936	150.5436	60	open forest	K. McDougall	
NSW	NSW46	-35.0067	150.8336	20	woodland	K. McDougall	
NSW	NSW47	-34.9646	150.6513	70	open forest	K. McDougall	
NSW	NSW48	-35.5344	149.9568	760	rainforest	K. McDougall	
NSW	NSW49	-35.5519	149.9519	785	shrubland / wetland	K. McDougall	
NSW	NSW50	-36.5261	148.1936	1010	tall forest	K. McDougall	
NSW	NSW51	-36.5383	148.1344	525	cleared woodland	K. McDougall	
NSW	NSW52	-36.3853	148.1811	425	cleared forest	K. McDougall	
NSW	NSW53	-35.4269	149.7144	625	shrubland	K. McDougall	

State	code	Latitude	Longitude	Altitude	Vegetation	collected_by	PC
NSW	NSW54	-35.2830	149.4400	710	grassland	K. McDougall	
NSW	NSW55	-35.3450	149.2790	720	woodland	K. McDougall	
NSW	NSW56	-35.4861	150.0838	275	woodland	K. McDougall	
NSW	NSW59	-36.0378	146.9894	195	Disturbed riparian	K. McDougall	yes
NSW	NSW60	-35.9875	146.6228	145	*Eucalyptus camaldulensis*	K. McDougall	
NSW	NSW63	-30.9938	152.7937			M. Nagel+M. Horwood	
NSW	NSW64	-30.1369	153.1062			A. Carnegie	yes
NSW	NSW65	-30.1507	153.1091			A. Carnegie	yes
NSW	NSW66	-31.5925	152.6070			M. Nagel+M. Horwood	
NSW	NSW67	-32.0153	152.4661			A. Carnegie	
NSW	NSW68	-32.3667	152.2401		wet sclerophyll	A. Carnegie	
NSW	NSW69	-30.5234	152.9935		wet sclerophyll	A. Carnegie	yes
NSW	NSW70	-29.1971	152.6036			A. Carnegie	yes
NSW	NSW71	-29.7434	153.4442			A. Carnegie	yes
NSW	NSW72	-32.6214	151.8884		dry sclerophyll	A. Carnegie	yes
NSW	NSW73	-29.0925	153.2672		plantation	A. Carnegie	
NSW	NSW74	-29.2626	153.2186		wet sclerophyll	A. Carnegie	
NSW	NSW75	-28.9233	152.5983		dry sclerophyll	A. Carnegie	
NSW	NSW76	-29.0330	152.7063			A. Carnegie	yes
NSW	NSW77	-30.8983	152.9097			A. Carnegie	yes
NSW	NSW78	-31.7312	152.0485			M. Nagel+M. Horwood	
NSW	NSW79				wet sclerophyll	A. Carnegie	
NSW	NSW80	-29.8325	152.9750			A. Carnegie	
NSW	NSW81	-30.8792	152.4707			M. Nagel+M. Horwood	
NSW	NSW82	-37.179	149.75	430	*Eucalyptus sieberi* forest	K. McDougall	
NSW	NSW83	-36.514	149.282	1080	Disturbed creek	K. McDougall	yes
NSW	NSW84	-36.594	149.444	840	tall wet forest	K. McDougall	
NSW	NSW85	-37.013	149.908	190	Dry forest	K. McDougall	
VIC	VIC1	-37.5917	145.6425	580		D. Cahill	

State	code	Latitude	Longitude	Altitude	Vegetation	collected_by	PC
VIC	VIC2	-37.5917	145.6425	580		D. Cahill	
VIC	VIC3	-37.5917	145.6425	580		D. Cahill	
VIC	VIC4	-37.5917	145.6425	580		D. Cahill	yes
VIC	VIC5	-37.5917	145.6425	580		D. Cahill	
VIC	VIC6	-37.5917	145.6425	580		D. Cahill	yes
VIC	VIC7	-37.4803	145.5456	420		D. Cahill	
VIC	VIC8	-37.4803	145.5456	420		D. Cahill	
VIC	VIC9	-37.4803	145.5456	420		D. Cahill	
VIC	VIC10	-37.4803	145.5456	420		D. Cahill	
VIC	VIC11	-37.5306	145.2436	581		D. Cahill	yes
VIC	VIC12	-37.5306	145.2436	581		D. Cahill	
VIC	VIC13	-37.5306	145.2436	581		D. Cahill	
VIC	VIC14	-37.5306	145.2436	581		D. Cahill	
VIC	VIC15	-37.6156	145.2511			D. Cahill	
VIC	VIC16	-37.6156	145.2511			D. Cahill	yes
VIC	VIC17	-37.6156	145.2511			D. Cahill	
VIC	VIC18	-37.6156	145.2511			D. Cahill	
VIC	VIC19	-37.6017	144.4256	157		D. Cahill	
VIC	VIC20	-37.6017	144.4256	157		D. Cahill	
VIC	VIC21	-37.6017	144.4256	157		D. Cahill	yes
VIC	VIC22	-37.6017	144.4256	157		D. Cahill	
VIC	VIC23	-37.8664	144.2486	362		D. Cahill	
VIC	VIC24	-37.8664	144.2486	362		D. Cahill	
VIC	VIC25	-37.8664	144.2486	362		D. Cahill	
VIC	VIC26	-37.8664	144.2486	362		D. Cahill	
VIC	VIC27	-37.8664	144.2486	362		D. Cahill	
VIC	VIC28	-37.8664	144.2486	362		D. Cahill	
VIC	VIC29	-38.3956	144.2536		Ironbark	D. Cahill	yes
VIC	VIC30	-38.3956	144.2536		Isopogon	D. Cahill	
VIC	VIC31	-38.3956	144.2536		Isopogon	D. Cahill	
VIC	VIC32	-38.3956	144.2536		Xanthorrhoea	D. Cahill	
VIC	VIC33	-38.3956	144.2536		Xanthorrhoea	D. Cahill	yes

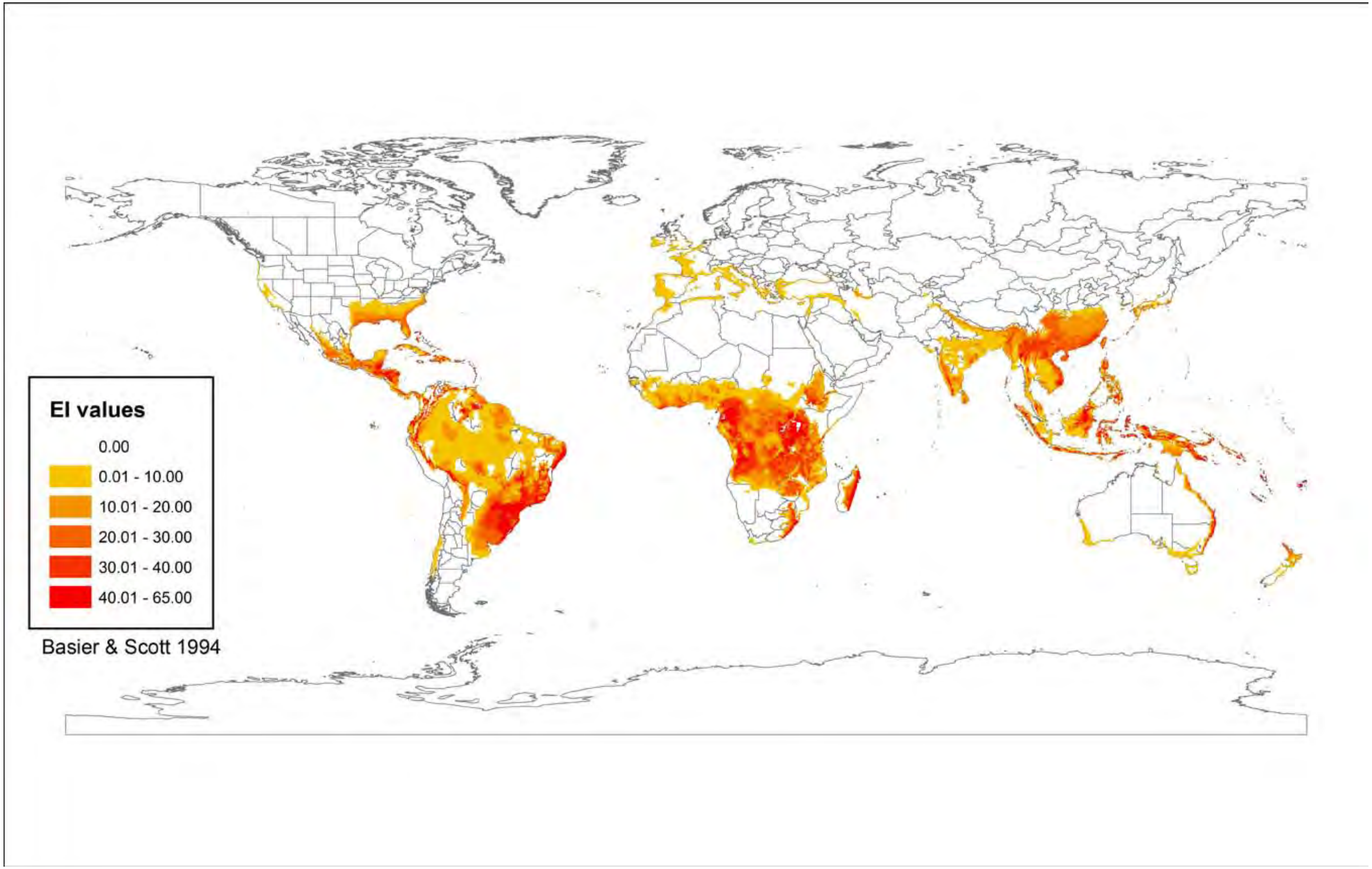
State	code	Latitude	Longitude	Altitude	Vegetation	collected_by	PC
VIC	VIC34	-38.3956	144.2536		Xanthorrhoea	D. Cahill	yes
VIC	VIC35	-38.4072	144.1858		Xanthorrhoea	D. Cahill	
VIC	VIC36	-38.4072	144.1858		Xanthorrhoea	D. Cahill	yes
VIC	VIC37	-38.4072	144.1858		Xanthorrhoea	D. Cahill	
VIC	VIC38	-38.4072	144.1858		Xanthorrhoea	D. Cahill	
VIC	VIC39	-38.4072	144.1858		Xanthorrhoea	D. Cahill	
VIC	VIC40	-38.4072	144.1858		Xanthorrhoea	D. Cahill	
VIC	VIC41	-38.3624	144.1514		Xanthorrhoea	D. Cahill	yes
VIC	VIC42	-38.3624	144.1514		Xanthorrhoea	D. Cahill	
VIC	VIC43	-38.3624	144.1514		Xanthorrhoea	D. Cahill	
VIC	VIC44	-38.3624	144.1514		Xanthorrhoea	D. Cahill	
WA	WA1	-33.4644	115.9110		jarrah forest	T. Burgess	
WA	WA2	-33.4644	115.9110		riparian	T. Burgess	
WA	WA3	-33.4558	115.9223		jarrah forest	T. Burgess	
WA	WA4	-32.8909	115.6918	9	tuart forest	T. Burgess	
WA	WA5	-32.8731	115.6728	4	tuart forest	T. Burgess	
WA	WA6	-35.0017	117.3066		karri forest	T. Burgess	
WA	WA7	-35.0084	117.3046		karri forest	T. Burgess	
WA	WA8	-35.0145	117.2952		coastal heath	T. Burgess	
WA	WA9	-32.2145	115.8320	0	Melaluca swamp	T. Burgess	yes
WA	WA10	-32.2148	115.8323	3	*E. rudis*	T. Burgess	
WA	WA11	-32.2150	115.8308	20	Banksia woodland	T. Burgess	yes
WA	WA12	-31.8781	116.4282	313	marri woodland	T. Paap	
WA	WA13	-31.8997	116.6480	314	wandoo woodland	T. Paap	
WA	WA14	-32.4823	116.8565	320	powderbark woodland	T. Paap	
WA	WA15	-32.9369	117.6335	337	sheoak woodland	T. Paap	
WA	WA16	-32.7684	116.9264		marri woodland	T. Paap	
WA	WA17	-32.0177	115.7988	0	Melaluca swamp	T. Burgess	
WA	WA18	-31.9468	115.7792		coastal woodland	T. Burgess	yes
WA	WA19	-31.9593	115.8290		Banksia woodland	T. Burgess	
WA	WA20	-30.2754	115.0467		kwongan vegetation	T. Burgess	
WA	WA21	-30.1150	115.0067		kwongan vegetation	T. Burgess	
WA	WA22	-30.1189	115.0050		kwongan vegetation	T. Burgess	

State	code	Latitude	Longitude	Altitude	Vegetation	collected_by	PC
WA	WA23	-30.1967	115.0735		kwongan vegetation	T. Burgess	
WA	WA24	-30.2014	115.0729		kwongan vegetation	T. Burgess	
WA	WA25	-32.0926	115.8212	18	disturbed, dying *E. rudis*	T. Burgess	
WA	WA26	-32.3676	116.2535	457	jarrah forest	T. Burgess	yes
WA	WA27	-32.3699	116.2522	409	jarrah forest	T. Burgess	
WA	WA28	-33.0163	116.8533		wandoo woodland	T. Burgess	
WA	WA29	-33.0239	116.8536		york gum woodland	T. Burgess	
WA	WA30	-34.1122	117.3674		wandoo woodland	T. Burgess	
WA	WA31	-34.3838	118.0490	1052	wandoo woodland	T. Burgess	yes
WA	WA32	-34.3845	118.0485	988	callistemon	T. Burgess	
WA	WA33	-34.3850	118.0488	851	callistemon	T. Burgess	yes
WA	WA34	-34.3862	118.0497	786	acacia	T. Burgess	
WA	WA35	-34.3883	118.0519	638	marri	T. Burgess	
WA	WA36	-34.3902	118.0537	633	scree slope	T. Burgess	Yes
WA	WA37	-34.3910	118.0566	516	marri/heath	T. Burgess	Yes
WA	WA38	-34.3919	118.0629	441	bottom	T. Burgess	
WA	WA39	-34.3584	118.0391	317	heathland	T. Burgess	
WA	WA40	-34.6870	117.9311		karri	T. Burgess	
WA	WA41	-34.7436	117.5059	108	banksia heathlands	T. Burgess	Yes
WA	WA42	-34.9784	116.8943	182	tingle, sheoak	T. Burgess	
WA	WA43	-34.9655	116.6053	50	karri	T. Burgess	
WA	WA44	-34.9175	116.5692	16	marri/heath	T. Burgess	
WA	WA45	-34.7364	116.4997	116	karri	T. Burgess	
WA	WA46	-34.4394	116.2558	156	karri/marri/healthy understory	T. Burgess	
WA	WA47	-34.3199	116.1206	317	karri	T. Burgess	
WA	WA48	-33.8646	116.0882		jarrah/marri	T. Burgess	Yes
WA	WA49	-31.4341	116.3780	264	wandoo woodland	T. Paap	
WA	WA50	-30.6321	115.4338		kwongan vegetation	T. Paap	
WA	WA51	-30.3102	115.2014	53	kwongan vegetation	T. Paap	
WA	WA52	-28.8599	114.9720	108	kwongan vegetation	T. Paap	
WA	WA53	-31.2606	115.8570	101	kwongan vegetation	T. Paap	Yes
WA	WA54	-32.9768	117.7710			T. Paap	
WA	WA55	-32.0635	116.0202		banksia woodland	M. Stukely	

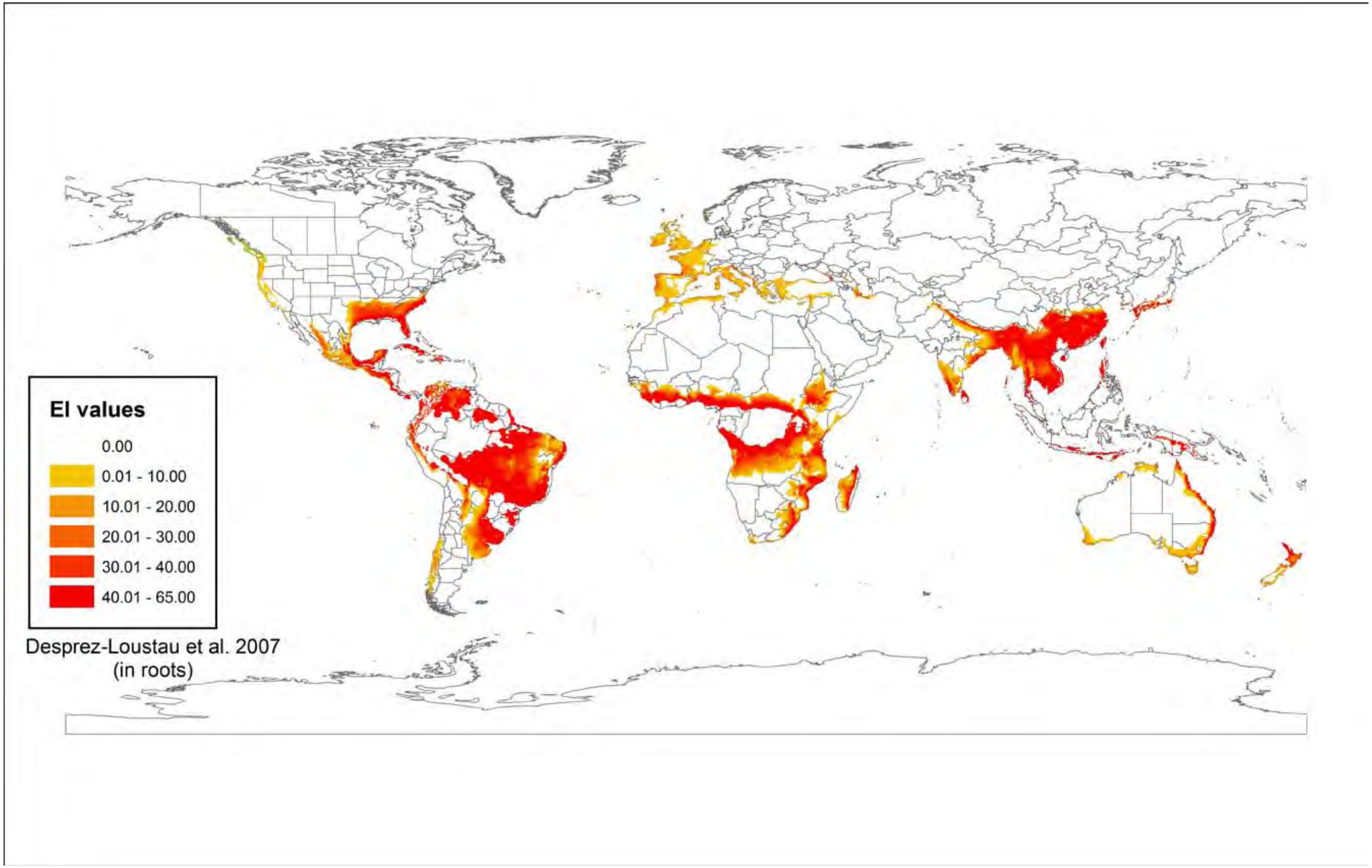
State	code	Latitude	Longitude	Altitude	Vegetation	collected_by	PC
WA	WA56	-34.6698	116.2668		coastal heath	M. Stukely	
WA	WA57	-29.8191	115.2806		kwongan vegetation	M. Stukely	
WA	WA58	-33.2601	116.3727			M. Stukely	
WA	WA59	-33.2556	116.3546			M. Stukely	
WA	WA60	-33.2528	116.3521			M. Stukely	Yes
WA	WA61	-33.4046	115.9054			M. Stukely	Yes
WA	WA62	-33.6899	116.0033			M. Stukely	Yes
WA	WA63	-33.3243	118.7910			M. Stukely	Yes
WA	WA64	-32.0276	115.8272		coastal woodland	M. Stukely	Yes
WA	WA65	-34.1206	115.5577			M. Stukely	Yes
WA	WA66	-34.1319	115.5460			M. Stukely	
WA	WA67	-34.6100	118.0312			M. Stukely	
WA	WA68	-33.8526	123.3202		coastal heath	C. Crane	
WA	WA69	-33.8529	123.3208		coastal heath	C. Crane	
WA	WA70	-33.8525	123.3209		coastal heath	C. Crane	Yes
WA	WA71	-33.7062	123.4451		coastal heath	C. Crane	
WA	WA72	-33.6962	123.5942		coastal heath	C. Crane	Yes
WA	WA73	-33.6102	123.8628		coastal heath	C. Crane	
WA	WA74	-33.5081	123.9780		coastal heath	C. Crane	
WA	WA75	-33.1289	124.1198		coastal heath	C. Crane	
WA	WA76	-32.9083	124.5220		coastal heath	C. Crane	
WA	WA77	-32.6403	125.1466		coastal heath	C. Crane	
WA	WA78	-32.2803	125.4786		coastal heath	C. Crane	

Appendix 2

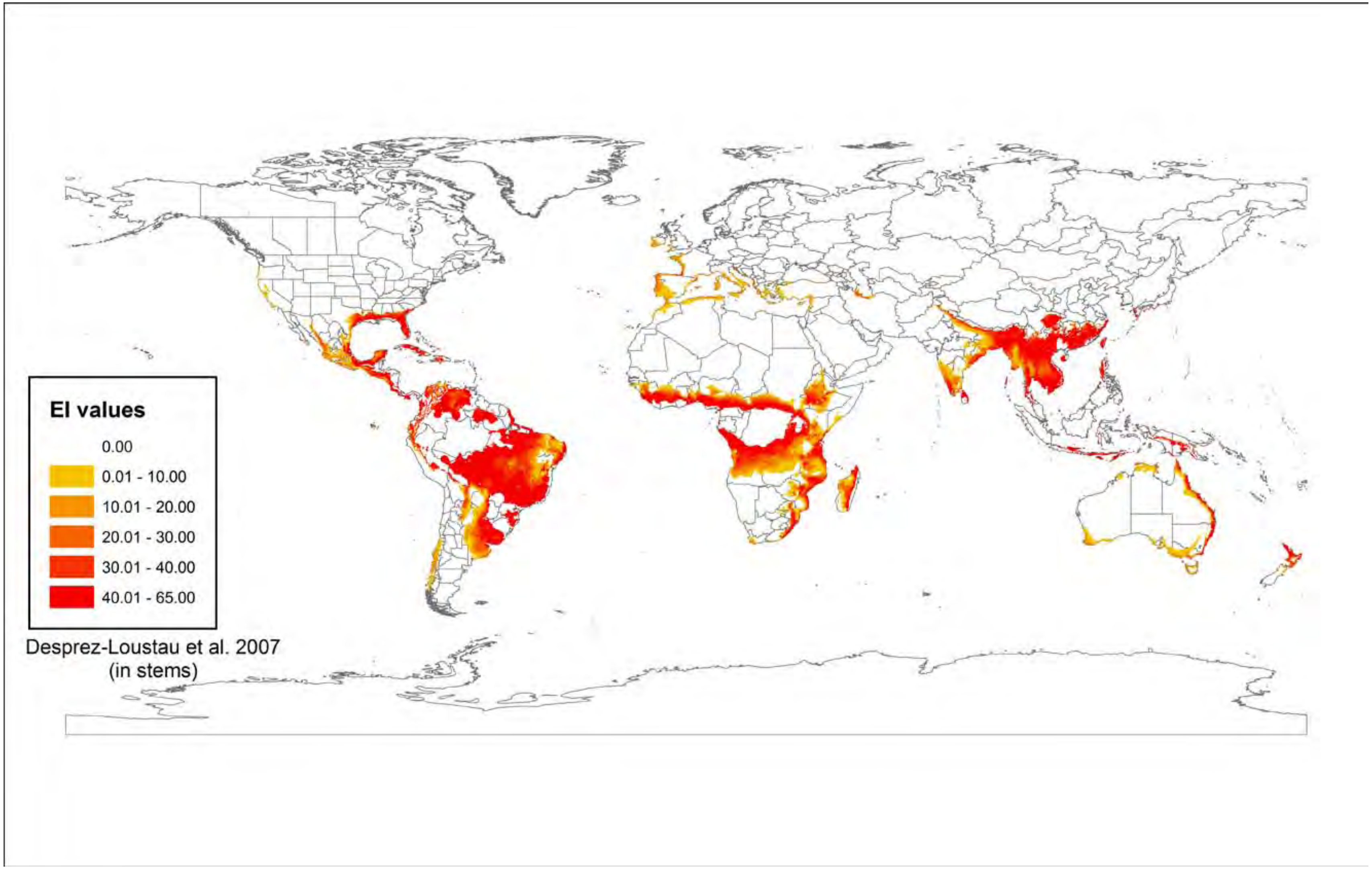
CLIMEX world distribution model for *Phytophthora cinnamomi* based on parameters (Table 3) given in Scott and Brasier (1994).



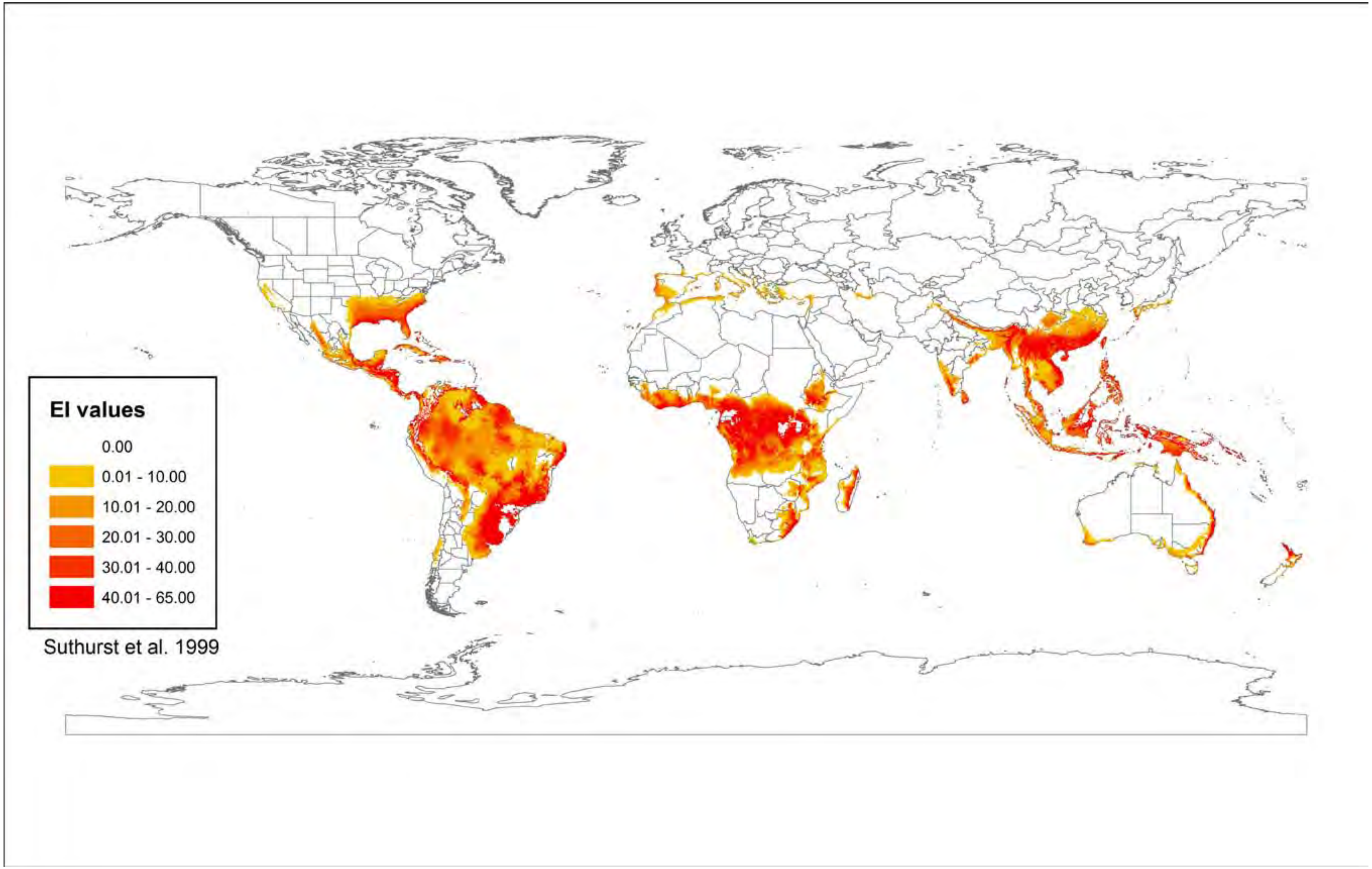
CLIMEX world distribution model for *Phytophthora cinnamomi* based on parameters (Table 3, roots) given in Desprez-Loustau et al. (2007)



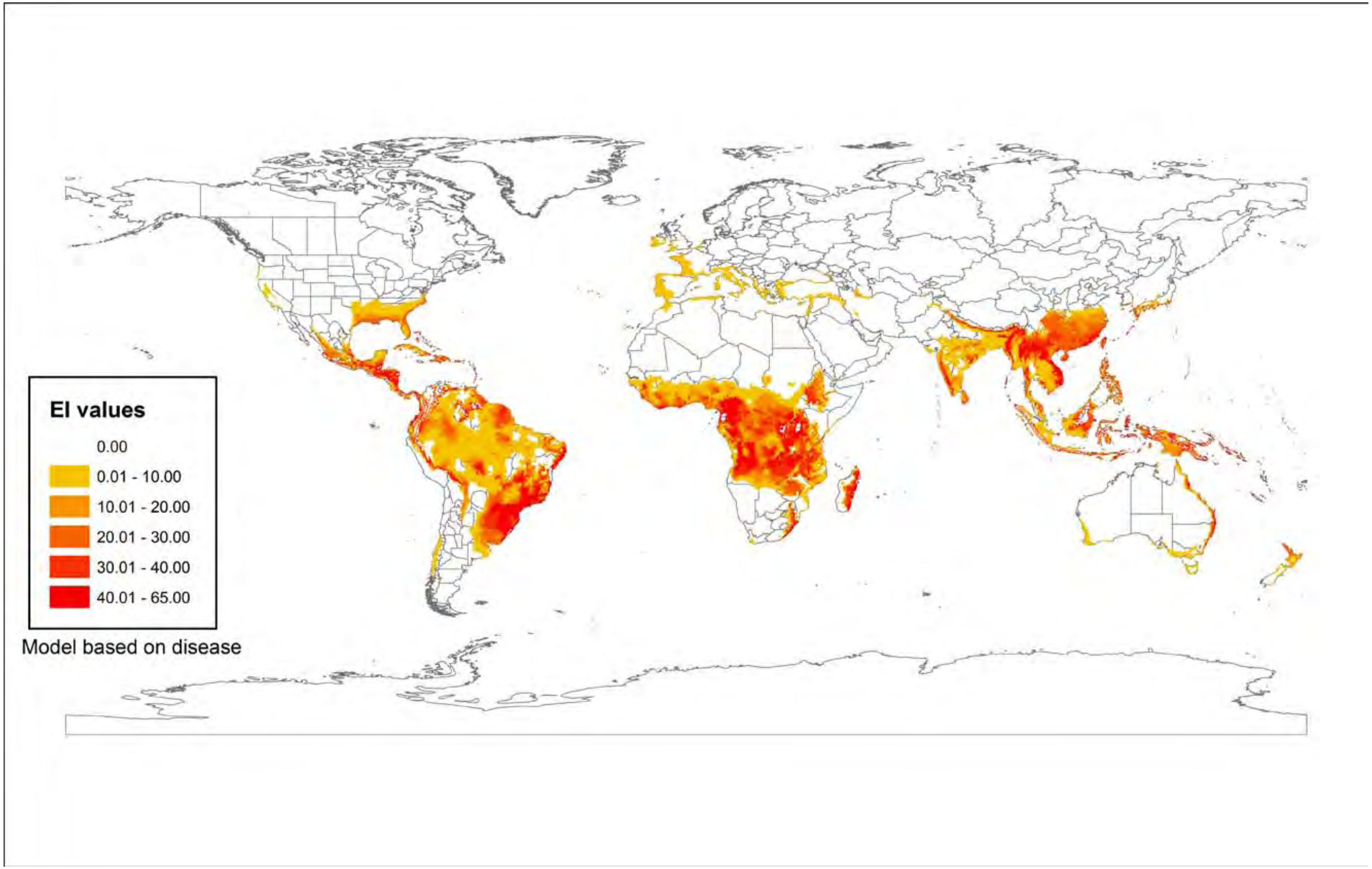
CLIMEX world distribution model for *Phytophthora cinnamomi* based on parameters (Table 3, stems) given in Desprez-Loustau et al. (2007).



CLIMEX world distribution model for *Phytophthora cinnamomi* based on parameters (Table 3) given Sutherst (1999)



CLIMEX world distribution model for *Phytophthora cinnamomi* based on parameters (Table 3, disease)



CLIMEX world distribution model for *Phytophthora cinnamomi* based on parameters (Table 3, pathogen).