MACROFUNGI AND CLIMEX: A COMPUTER PROGRAM WITH APPLICATIONS FOR MODELLING SPECIES' DISTRIBUTIONS

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The use of the CLIMEX program for fungal distribution hypotheses is discussed.

Keywords: CLIMEX, computing, ecology, biogeography, modelling.

During recent investigations into the Australian Hygrophoraceae, use was made of the CLIMEX computer program, a software package developed by the Commonwealth Scientific and Industrial Research Organisation (Sutherst & Maywald 1985) which has now been released in Windows format by the Cooperative Research Centre for Tropical Pest Management at the University of Queensland. The enormous advantages of the program are that it provides a means of inferring biogeographical distributions of a species from minimal data sets and it operates on a desktop computer. CLIMEX had already been applied to more than 150 species of insects, invertebrates, vertebrates and plants and it was decided to use the program to predict the likely distributions of two species of *Hygrocybe*.

CLIMEX is used to model a species' distribution on the assumption that it is defined by climatic parameters. In nature, species' distributions may be affected by numerous factors such as host/predator relationships, disease, human impact, soil type, *etc.*, nevertheless it is true to say that if climatic conditions do not permit a species' reproductive survival, then it cannot occur at otherwise favourable locations. In this sense, the CLIMEX program predicts the possible geographical range of a species based on a suitable climate, but it cannot say if the species will definitely be present at a given location. On the other hand, locations which are **not** included in a CLIMEX hypothetical range will very likely be unsuitable for the species. When formulating a distribution hypothesis, the CLIMEX software does not use a simple climatic comparison; the program's algorithm can account for such variables as diapause, light intensity and greenhouse effects. It also assumes that there exists a season in the year when the organism under investigation will come under climatic stress (winter, drought, heat, *etc.*).

To develop a distribution hypothesis, the CLIMEX user requires two sets of data: climatic parameters for the species to be modelled and a meteorological database for the regions to be tested. The software package includes a world database of over 2,000 meteorological stations but additional meteorological data can be readily added. Species parameters can be derived by the user from an organism's known distribution, but the software does contain species templates for four climatic types: wet tropical, temperate, mediterranean and semi-arid. At least two methods can be employed for parameter derivation by the user, but that selected for the investigation of the Hygrophoraceae was found to be both simple and effective.

The model assumes that each species has optimum ranges of temperature and soil moisture for reproduction and survival. Lower and upper values for the optimum range are selected based on the known distribution of the organism and, where possible, seasonal development. Selection is then made of a further two absolute lower and upper values beyond which the organism would be very unlikely to reproduce and survive. [For example, the Southern Beech (*Nothofagus cunninghamii*) is found in cool, very wet conditions of west coast Tasmania. Its optimum temperature range for development might be 8–15 Celsius, while the lower and upper absolute values might be 0 and 25 degrees Celsius respectively. Soil moisture settings might be 0.8, 1.5, 2.5 and 4, where a soil moisture value of 1 represents saturation and values above this represent run-off.]

An iterative procedure is then used to develop a set of species parameters. The first set of parameter values are essentially "reasonable guesses" and the program is then run to produce the inferred geographical distribution for comparison with the known distribution. If the CLIMEX prediction is incorrect (too small or covers areas where the species will definitely **not** be found, *etc.*) then the parameter values are modified until the inferred geographical distribution produced is a better fit. CLIMEX has stress parameters that are used to "fine tune" a distribution model until it reflects the known distribution. Once the parameters successfully model the known distribution, CLIMEX can then be used to predict where the species might occur outside its native distribution and becomes a powerful tool for pest management.

The two taxa selected for CLIMEX investigation were *Hygrocybe astatogala* (Heim) Heinemann and *Hygrocybe miniata* (Fr.: Fr.) Kummer. Both species occur naturally in a region that covers much of the eastern coast of Australia (including mountain regions of the Great Dividing Range), coastal Victoria and South Australia and parts of Tasmania but each species had different collection sites within this region (or occurrences at different times of the year) and climatic parameters were developed which reflected the individual distributions and/or occurrences. Table 1 shows the climatic values which were used to develop CLIMEX parameters for *H. astatogala* while Table 2 shows the initial and final values for the species parameters.

Table 1. Climatic values for *Hygrocybe astatogala* collection sites for the months during which collections were made.

Location	Months	Av. Temp.(^{0}C) Max.	Min.	Rainfall (mm)	Rel. Hum. (%)
Sydney (NSW)	iv/v/vi	22.8	8.1	98–126	57–73
Katoomba (NSW)	v/vi	13	3.7	103–125	65–77
Adelaide (SA)	v	18.4	9.3	58	57–72
Binna Burra (QLD)	ii/iv	23.2	11.6	163–449	70–80
Mt Wellington (TAS)	v	11.3	4.1	64	69–73

Table 2. Species parameters for *Hygrocybe astatogala*, showing initial and final values.

Temperature (^{0}C)			**Moisture (0 ⇒ dry; 1 ⇒ saturated; >1 ⇒ runoff)**		
	Init.	Final		Init.	Final
DV0	8	4	SM0	0.4	0.6
DV1	16	10	SM1	0.7	0.8
DV2	27	25	SM2	1.5	1.6
DV3	32	30	SM3	2.5	2.5
Cold Stress			**Heat Stress**		
TTCS	5	6	TTHS	28	28
THCS	0.00001	0.001	THHS	0.001	0.003
Dry Stress			**Wet Stress**		
SMDS	0.5	0.4	SMWS	1.6	1.8
HDS	0.01	0.007	HWS	0.0001	0.005

Once initial species parameter values are set, the next step is to run the CLIMEX program and examine the distribution hypothesis. The parameters are then adjusted until the best fit for the actual distribution is obtained. Stress parameters have two values: the first is the threshold temperature or soil moisture level at which stress begins to accumulate; the second (a value between 0 and 1) is a rate parameter which determines the rate of accumulation of the stress to the organism: the larger the rate parameter, the greater the resulting stress. (A glossary of the parameters is given at the end of the paper.) Figure 1 shows the distribution hypothesis for the initial values set for *Hygrocybe astatogala* and Figure 2 shows the final result. The distributions are plotted for values of a CLIMEX variable called the "Ecoclimatic Index". This has a value from 0–100 and shows the likelihood of species survival at a particular location. An EI < 10 would indicate a low possibility of survival; 10–20 would indicate only moderate possibilities, but EI values greater than 20 indicate progressively greater chances of species survival at any location.

Figure 1. Hypothetical distribution for *Hygrocybe astatogala* based on initial values for CLIMEX parameters.

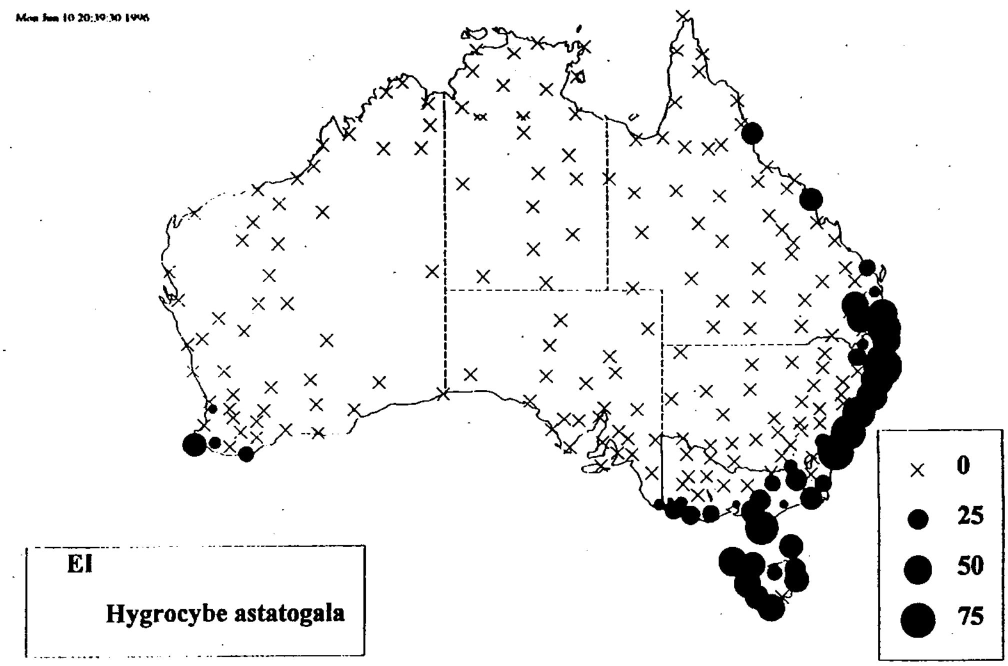
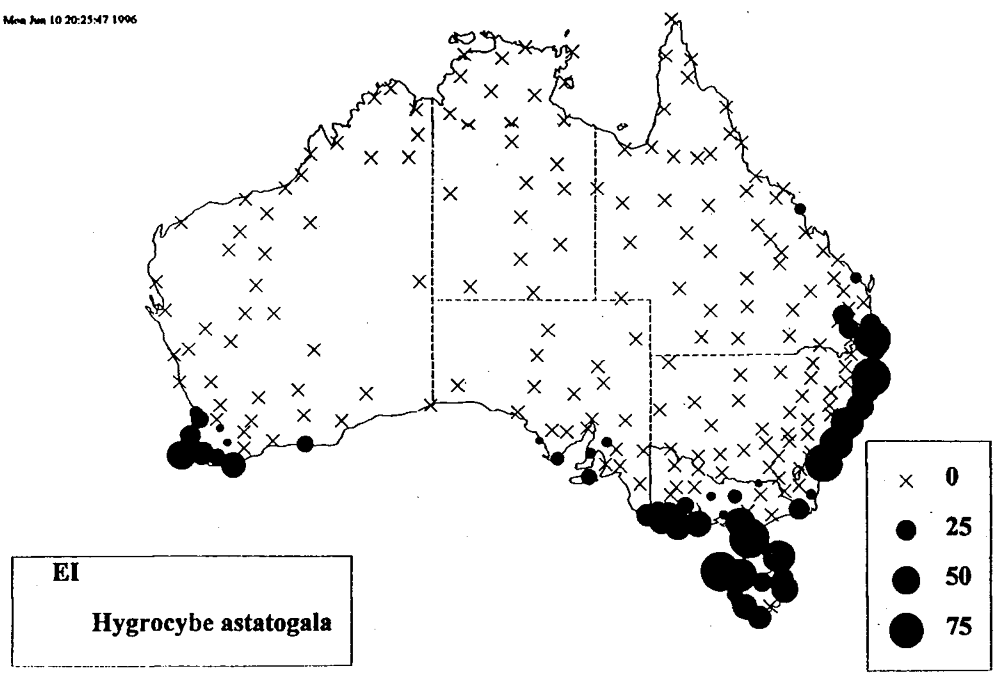


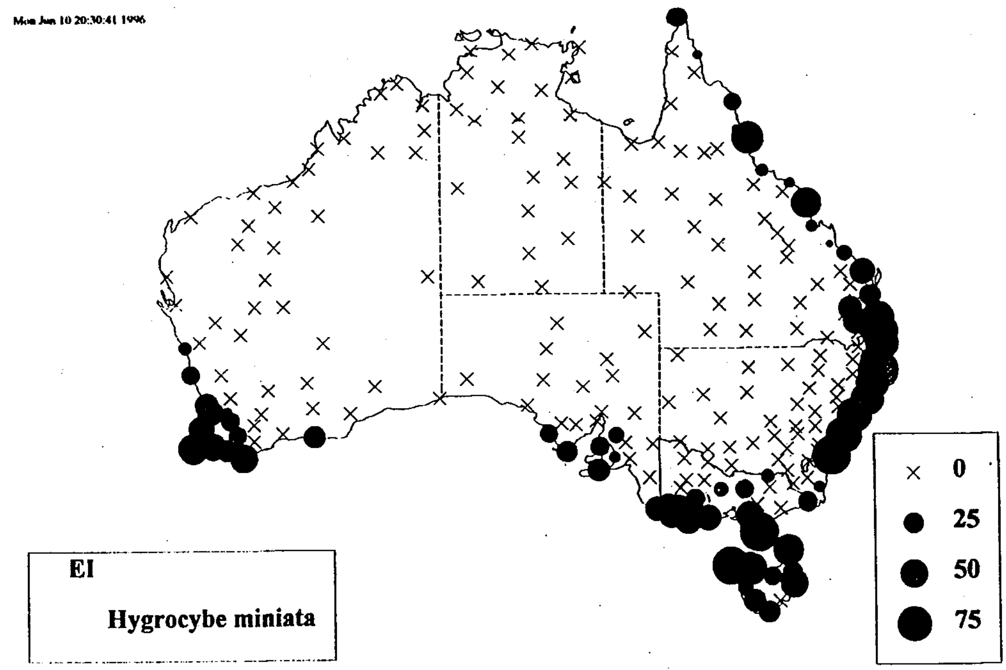
Figure 2. Hypothetical distribution for *Hygrocybe astatogala* based on final values of CLIMEX parameters.



To test the validity of the final species parameter values, the program was used to simulate a potential world distribution for the species. This successfully predicted that *Hygrocybe astatogala* should occur at the previously recorded site of Auckland (New Zealand) and also indicated locations within Madagascar (holotype locality). Figure 2 has therefore implications that *H. astatogala* will occur in Western Australia, but so far this has not been confirmed.

The final distribution map for *Hygrocybe miniata* is given in Figure 3 below. The generally warmer climates able to be exploited by this species are shown by a more tropical distribution, but again the south-west corner of Western Australia is depicted as a favourable location. It is very satisfying to report that at the time the original distribution was prepared (June 1995) the presence of *Hygrocybe miniata* in Western Australia was not known. Recent collections examined by the author (January 1996) have now confirmed *H. miniata* is present in the area suggested by CLIMEX and there is therefore a strong possibility that confirmation of the presence of *Hygrocybe astatogala* may only be a matter of time.

Figure 3. Hypothetical distribution for *Hygrocybe miniata* based on final values for CLIMEX parameters.



Only two fungal taxa have been examined using the program but the results are very encouraging. The main limitation of the program (apart from its necessary climatic assumption) is the size of the data base used for comparison purposes: CLIMEX may not locate suitable areas purely because its data base does not contain meteorological data for those locations. This has already been addressed for local work in Australia and the ability of the program to add more locations has proven very successful so there seems no reason why more use could not be made of CLIMEX to produce distribution predictions for other fungal species.

References

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CLIMEX Parameters

DV0-3: Temperature Index; DV0 = Limiting low temperature; DV1–DV2 = Optimal range; DV3= Limiting high temperature.

SM0–3: Soil Moisture Index; SM0 = Limiting low moisture; *etc.*

TTCS: Temperature Threshold Cold Stress; the temperature below which cold stress accumulates. THCS: Cold Stress temperature rate; rate parameter for cold stress values.

SMDS: Soil Moisture Dry Stress threshold; dry stress is accumulated if soil moisture levels drop below this value. HDS: Dry stress rate; rate parameter for dry stress values.

TTHS: Temperature Threshold Heat Stress; heat stress accumulates if temperatures rise above this value. THHS: Temperature rate Heat Stress; rate parameter for heat stress values.

SMWS: Soil Moisture Wet Stress; wet stress is accumulated if moisture levels go above this value. HWS: rate of Wet Stress; rate parameter for wet stress values.

The CLIMEX software package is available from The Software Applications Officer, CRC for Tropical Pest Management, Gehrmann Laboratories, University of Queensland, Brisbane, Qld, 4072. Cost: $295, plus $10 postage and packing. ph: 07 3365 1851; fax: 07 3365 1855. EMAIL: CLIMEX@ctpm.uq.edu.au

SUBMISSION TO THE COMMITTEE OF INQUIRY TO REVIEW AUSTRALIA'S QUARANTINE POLICIES AND PROGRAMS

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On 13 June 1996 J. Simpson & C. Grgurinovic made a verbal presentation to the Quarantine Committee of

Review. The notes we provided to the Committeee follow below. It was our impression that the idea of fungi as weeds was novel to the Committee members. We also thought the Committee had not determined how to make economic assessments of the value of conservation of native flora and fauna or biodiversity in either the short or long term.

Submission to Public Hearing of the Australian Quarantine Review Committee in Sydney 13 June 1996.

We are in broad agreement with the recommendations of the Australian Academy of Science concerning exotic pathogens and invertebrate pests. However, we have concerns about introduction of fungi that are not known pathogens and their potential impacts on the Australian biota.

1. Timber imports.

Timber can be imported into Australia in a 'green' *i.e.* not dried condition. Sometimes the shipping documents state the timber has been treated with an 'anti-sapstain' but what that treatment was is rarely specified. On arrival in Australia the timber is inspected by AQIS and if insects are detected the timber is fumigated before clearance. However, regardless of the extent of fungus growth, or of sapstain or decay in the timber AQIS do not refuse entry. The occurrence of pitch canker fungus on species of *Pinus* and *Pseudotsuga* on the west coast of North America, a major source of imported timber, makes present quarantine practices a matter of great concern.

2. Bio-remediation agents.

There is much work being done on use of fungi to breakdown complex organic pollutants of soil. AQIS seems to be permitting entry of such fungi provided they are not known to be pathogens. Fortunately the State Environment Protection Agencies seem to have more responsible approaches and generally are insisting upon use of isolates of fungi from Australia.

3. Fungi for biological control of pathogens.

AQIS are allowing entry of diverse saprophytes for use as biological control agents *e.g.* species of *Trichoderma* for control of species of *Armillaria* and *Chondrostereum*. *Trichoderma* is a large and difficult genus with more than