Current practice in applying CLIMATE for weed risk assessment in Australia

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Summary Climate matching models are used to help define the risk introduced species pose to natural and agricultural ecosystems. The models compare the climate of a species' current geographic range with the climate of a target site to show the potential range of the species. Other abiotic factors such as soil nutrients, aspect and disturbance regimes, and biotic factors, such as herbivory, disease and competition also affect a species' current and potential range. Hence, climate matching models must be considered in an ecological context. Reliable information should be sought to refine the input data and climatic parameters used in the model. Attributes that affect agricultural or environmental values are also considered when evaluating invasion risk or for supporting weed management decisions.

In Australia, a number of approaches have been developed that apply computer-based climate matching models to predict a species' range. The Bureau of Rural Sciences (BRS) has assessed one of these approaches by surveying climate matching practitioners and experts. The survey results are presented, along with results from climate matching analyses. Common methodology and limitations in the use of CLIMATE are discussed to show how climate matching models are applied.

Keywords Weed risk assessment, climate models, climate matching, pests, *Hieracium aurantiacum*.

INTRODUCTION

Climate matching models such as CLIMATE, BIOCLIM and CLIMEX are important components of risk evaluations undertaken by Australian State and Federal governments. Biosecurity Australia conducts risk assessments to screen new plants for potential weediness before import is permitted (pre-border Weed Risk Assessment, WRA). As part of this WRA, 49 biological, historical and biogeographical attributes, including four pertaining to climate and distribution, are evaluated with CLIMATE, BIOCLIM or CLIMEX. Western Australia's Department of Agriculture and Food undertakes risk assessments using CLIMATE for management of plant and vertebrate species already present in the state, and for assessment of species present in Australia but not present in the state (post-border risk assessment). Similar assessments are undertaken in other Australian States and Territories including South Australia and Queensland. Potential distribution is evaluated with either CLIMATE or CLIMEX as part of the National Weed Risk Management (WRM) protocol developed by the Cooperative Research Centre for Australian Weed Management and Standards Australia.

Accurate species location data is important for these evaluations. The climate profile of an area where a species evolved or has successfully naturalised indicates the climatic range where that species can survive. Computerised climate matching models provide a simple method of estimating climatic suitability for a species from presence only data by comparing locations with similar climatic parameters. Climate matching models generally assess abiotic rather than biotic influences on species distribution (Kriticos and Randall 2001). Results from these analyses should be considered as broad estimates, in light of the intended model application and ecology of the species of interest.

The components of many climate matching models include species locations, meteorological data consisting of either station climatic averages or an interpolated surface of climatic variables. Species location data are analysed with respect to climatic characteristics and locations with similar climatic characteristics are then plotted across a map of the target site. Species location data are obtained from a range of sources including plantation, natural or naturalised occurrence sites, specimen collection records from herbaria or museums or published information. Long-term global meteorological data from past climate records can be obtained from various datasets (New *et al*. 2000, GED 2006). CLIMATE imports these data configured as a set of 16 temperature and rainfall indices from BIOCLIM (Busby 1991, Table 1). An interpolated surface of climatic variables is created and can be analysed with overlays (e.g. land use, soils) in a geographic information system. The procedure used to generate a climatic surface from Australian meteorological station data was first tested and applied by Hutchinson *et al*. (1984), and is applied and discussed further in other publications, including Nix (1986).

Some climate matching models (such as CLIMATE) are statistically based, using classification matrices or algorithms calculating the difference in climatic variables between sites or species. The output is a similarity index or percentile match. For outputs from the Macintosh version of CLIMATE for example, a 10% match to the input data is close; 20% is less close and so on. Kriticos and Randall (2001) outline and compare some of the more common systems relevant to WRA. Selecting suitable climatic parameters and a reliable species location data set improves the accuracy of predictions. Outputs are verified by consulting experts and using knowledge of the species' biology.

We survey users to elicit practices undertaken during climate matching for weed risk assessments. While CLIMATE is the focus of this paper, the methods and applications identified from our survey are relevant to climate matching processes more broadly. Some options for further testing the decision processes used in climate matching are outlined.

MATERIALS AND METHODS

Eight leading CLIMATE users in Australia were consulted using questionnaires and example analyses. These users were selected based on their experience with climate matching analyses and/or in using the outputs in decision making processes. Most are working on weed risk assessment. Some conduct risk assessments for exotic vertebrates. The consultation questionnaire was designed to explore how CLIMATE was used. A second questionnaire (10 respondents) aimed to assess the CLIMATE outputs for a number of sleeper weeds in Australia (Cunningham and Brown 2006).

An example CLIMATE analysis of orange hawkweed (*Hieracium aurantiacum* L.) using the methods described by respondents (all 16 climatic variables in Table 1 and a reliable input data set from a range of sources) is presented (Figure 1). Analyses of *H. aurantiacum* with some of the potentially less relevant climatic variables removed were also conducted. To indicate the effects on outputs of using fewer input data points, CLIMATE analyses were undertaken for five sleeper weed species, repeated with fewer input data points. The results were plotted as the sum of all matches within the 60% match classes against the total number of input data points.

RESULTS

Consultation identified that the match classes 10% to 60% (for Macintosh CLIMATE analyses in WRA) are currently being used to display potential distributions.

Table 1. Climatic parameters used in CLIMATE (from Busby 1991).

No.	Climatic parameter	Unit
1	annual mean temperature	°C
2	minimum temperature of coolest month	°C
3	maximum of warmest month	°C
4	annual temperature range (3-2)	°C
5	mean temperature of coolest quarter	°C
6	mean temperature of warmest quarter	°C
7	mean temperature of wettest quarter	°C
8	mean temperature of driest quarter	°C
9	annual mean precipitation	mm
10	precipitation of wettest month	mm
11	precipitation of driest month	mm
12	co-efficient of variation of monthly precipitation	–
13	precipitation of wettest quarter	mm
14	precipitation of driest quarter	mm
15	precipitation of coolest quarter	mm
16	precipitation of warmest quarter	mm

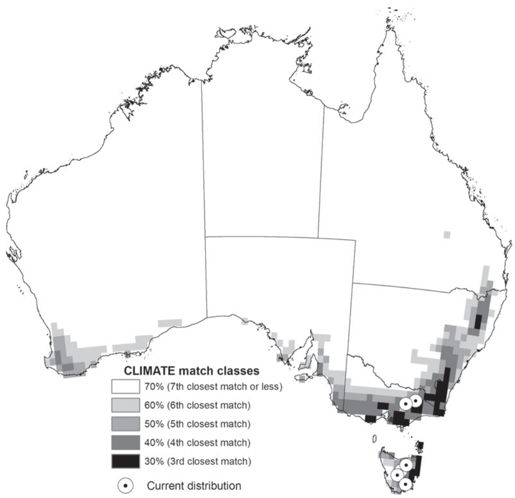

Figure 1. Potential range of *H. aurantiacum* according to 60% match using PC CLIMATE analysis.

Equivalent classes (that respondents also identified as relevant for sleeper weeds analysis) for the PC version of CLIMATE are match classes 10 to 5.

Selection of climatic variables Survey respondents either use all 16 climatic variables (Table 1) in analyses or those considered by expert opinion or published evidence to be ecologically significant. Interdependence between variables, absolute minimum temperature (for frost sensitive species) (Booth *et al*. 2002), seasonality of the source and target sites and number of sunlight hours were other factors associated with climatic variables that users reported considering.

Selection of input data Herbarium and specimen collection data and published information are the primary data sources used by survey respondents. Other sources include published references, abstract lists, internet databases and specialist advice. For pre-border risk assessments (WRA and vertebrate risk assessments) and initial iterations of post-border assessments (e.g. WRM), location data (if any) from the target site are withheld from analysis. These locations are then checked to see whether they occur within the match regions to verify predictions. For post-border assessment, some practitioners then add the target site location data to the input data and re-run analyses. Respondents also test output accuracy by adding or removing data points to see if this changes outputs greatly, using results in models and by consulting experts.

Example analysis On advice from experts consulted while analysing the potential distribution of a number of potential sleeper weeds, including *H. aurantiacum*, a PC version CLIMATE analysis using all 16 climatic parameters and more points from the native range of *H. aurantiacum* in Western Europe was conducted. The current distribution of the species in Australia was overlaid (Figure 1). Independent analyses using an earlier Macintosh version of CLIMATE yielded a similar result (R. Randall pers. comm.).

As this is a summer-growing species in the northern hemisphere, further analyses with the summer rainfall climate variable excluded, and then with both the summer and winter rainfall variables excluded were undertaken. Some experts advised that including climatic variables such as these might confound effects of seasonal differences in rainfall between the northern and southern hemispheres. Other experts indicated that the climatic variables are independent of hemispherical effects. These analyses only slightly increased the overall climatic range predicted to be suitable for *H. aurantiacum*.

Number of input data points Survey respondents indicated that using few input data points may reduce output reliability. This was tested by graphing the sum of matches within the 60% match classes (relevant classes as identified from survey) against the number of input points for five sleeper weed species. Results are presented in Figure 2. This simple testing indicated that for the weed species investigated, the sum of matches within 60% match classes is stable when more than 60 input points are used. The sum of matches within 60% match classes generally drops more steeply when the number of input points is less than 30.

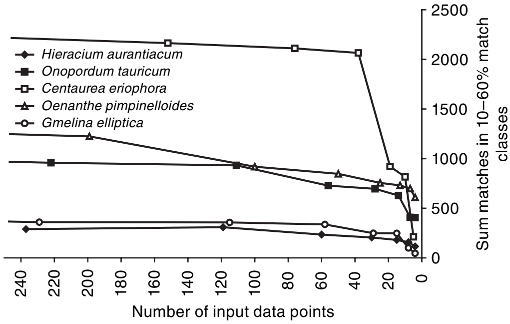

Figure 2. Number of input data points plotted against sum matches in 10–60% classes.

CONCLUSIONS

Models such as CLIMATE can be used to estimate a species' potential range using presence only data for regions where there is little or no known location data. Hence these models are used to assess risk of species introduction, or for prioritising species such as sleeper weeds. Where available, reliable input data from a range of sources should be used in climate matching analyses (Virtue *et al*. 2001, Kriticos and Randall 2001).

Expert consultation and information on the ecology of the species can be used to improve predictions. Initial expert consultation on the CLIMATE outputs of *H. aurantiacum* indicated that the potential distribution did not cover parts of Victoria and Tasmania, as was expected for this cooler climate species. The potential distribution output was improved to cover this cooler climate range by including more input data points from the species' native range.

Species location data points from the target analysis site can be withheld from analysis and used to cross-check predictions (Virtue *et al*. 2001, Kriticos and Randall 2001). For this example analysis the known current distribution falls within the closer match (≤30%) classes of the predicted climatic range (Figure 1). This may be partly due to introduction effort, rather than simple climatic suitability because this species has been grown as a garden plant in alpine regions.

This validation method can be tested for predictions within Australia of species that have spread across a broad range of the continent. Known distributions in the eastern half of Australia can be used to predict distributions in the western half of Australia, and vice versa.

Survey respondents found that predictions were improved by using fewer, but more accurate inputs. Respondents also noted however, that when the number of input points was low, CLIMATE often gave a poor match even if the input locations were climatically suited to Australia. For example, when fewer than 15 input locations were used, results became less reliable. Our analyses indicate that more than 30–60 input data points are needed to consistently represent potential range of the selected sleeper weeds (Figure 2). More analyses are needed to explore this for other species. In a heterogeneous dataset where fewer data points are used, each point has greater influence on the overall output. It is, however, reasonable to assume that fewer data points may be used provided they accurately represent the species' climatic range.

Where meteorological stations are sparse, an inconsistent match may be made between the specimen point data and the input meteorological station data, or suitable locations are not able to be included in the global meteorological station database (Booth *et al*. 2002). In addition, the 0.5 degree interpolated climatic grid used in most climate matching applications may not provide adequate resolution for predicting distribution of the species of interest (Nix 1986, Virtue *et al*. 2001). Predictive error in climatic values is small (5–10%), but higher where climatic gradients are steep and/or complex and if the meteorological station network is sparse (Nix 1986).

A species' overseas range may be restricted by non-climatic factors, such as competition, herbivory and disease (biotic), or soil type and land use (abiotic). Biotic factors often cannot be quantified. The species' potential range in the target site, as predicted by an analysis based on such a restricted input range, may be less than the true potential range. Conversely, a species' full potential range in the target site may be smaller than predicted by climate matching, if such biotic or abiotic factors also restrict the species' spread.

Despite these potential sources of error, potential distribution maps from climate matching analyses of presence only data are very useful for communicating risk on a broad or national scale. The outputs can be used as input to models to determine potential industries or ecosystems at risk from spread of a species. Climate matching applications are already an integral part of risk assessment processes, which include consideration of other traits such as the dispersal and reproductive capacity of a species.

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