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An Introduction to CLIMEX

The following information is covered in more detail in the CLIMEX User Guide. We recommend that you read the User Guide to get an overview of how the program works. This introduction is designed to give you a quick idea on what CLIMEX does.

CLIMEX has been evolving within CSIRO Entomology since 1985. The program was originally designed to predict where foreign species of plants and animals (mostly agricultural pests) would be able to survive if they were introduced into Australia. The ability to predict this risk is vital in the effort to prevent establishment of introduced species. Scientists needed to know which introduced species of pests are adapted to the climate in the recipient country in order to establish priorities for their control or eradication. CLIMEX is now used widely around the world to look at a range of species from insects to weeds, and plant diseases to earthworms. CLIMEX is being used in over 30 countries by agricultural, quarantine and conservation agencies, and in schools to teach the scientific method and other subjects.

CLIMEX Version 2 has been rebuilt using the DYMEX model building software. The procedures are therefore quite different to the original version. For DYMEX users, this new version will look quite familiar but for earlier users of CLIMEX there will be a need to relearn the new DYMEX paradigm.

The CLIMEX software contains two distinct functions: firstly a species-specific simulation model (CLIMEX), which describes the response of a species to climate. The model can be run in two different modes: *Compare Locations* in which the response is compared of a species to long-term average climate at different locations or *Compare Years* in which the response of a species to climates of different years at the same place is compared. The software also contains a facility, *Match Climates*, for matching or comparing meteorological data at different locations, without reference to any particular species preferences.

In order to provide support for CLIMEX users, the software also contains modules for managing meteorological data ('MetManager') and for customising maps ('MapManager'). Charts can also be customised.

So how does the CLIMEX model work? Just like us, plants and other animals prefer certain climates. In general climate determines where an animal or plant is found. There are often other factors such as soil type, topographical features, interactions between species (including humans), and natural boundaries (ie deserts, oceans and mountain ranges) that determine where a species can survive, but the predominant factor is climate. CLIMEX estimates the "climatic preferences" of the species by looking at its known geographical distribution. The process involves iterations with adjustments of relevant parameters in the program until the program's predictions match the species' known distribution. Once these parameters have been fitted, we can make predictions on the **potential** distribution of the species in other regions. This process is discussed in detail in the User Guide and it is covered in Tutorial 9 in these notes.

The species' parameters describe its response to climate. There are three groups of variables that limit geographical distributions. The weekly and annual "growth indices", GI_W and GI_A respectively, describe the most suitable temperature (Temperature Index, TI) and moisture (Moisture Index, MI) range for the growth and development of the species. The second set of

parameters, the “stress indices” (Cold (CS), Hot (HS), Dry (DS) and Wet (WS) Stress), show what extremes of temperature and moisture limit the distribution of the species and the “limiting conditions”, relate to advanced features such as the need of some species for dormancy or the need to accumulate a minimum amount of heat to complete a generation in a year. These indices are combined to give the EI for a species.

$EI = GI_A \times SI \times SX$, where

$$GI_A = (100(\sum_{i=1}^{52} GI_W)/52),$$

$SI = (1-CS/100)(1-DS/100)(1-HS/100)(1-WS/100)$ and CS, DS, HS and WS represent cold, dry, hot and wet stress respectively; and SX is the product of interaction terms involving a temperature and a moisture stress, i.e. CDX, CWX, HDX and HWX are the annual cold–dry, cold–wet, hot–dry and hot–wet stress interaction indices.

The EI is also affected by the constraints of having sufficient degree-days to complete the life cycle (PDD) and meeting the conditions required to complete diapause.

An easy way to understand these features is to use a “human” example. As a species, without the benefits of technology, you would probably be able to survive where the average daily temperature range is about 16 - 34°C. You would be most comfortable at 20 - 28°C. These temperatures correspond to the temperature growth parameters DV0 - DV3 used in CLIMEX. The parameters indicate the preferred temperature range for a species. At temperatures below 16°C (DV0) you would find all your energies taken up with surviving the cold conditions and you would be unable to survive in the long term. Temperatures between 20 and 28°C (DV1 - DV2) would be the optimum temperature range for growth and development. Average daily temperatures above 34°C (DV3) would, like low temperatures, reduce your ability to survive. These temperatures are your four “temperature growth parameters”. You would also have four “moisture growth parameters” (SM0 - SM3) that would indicate the amount of soil moisture required to sustain your needs for food and water. These two groups of growth parameters describe your ideal climatic range.

The “stress indices” are the factors limiting your distribution. They indicate the temperature and moisture levels at which you start getting stressed because the climate is too hot, cold, wet or dry. You can survive, but you would be uncomfortable. The more these levels are exceeded, the more stress you accumulate until you are unable to survive. A pot plant is a good example. If left unwatered for a few days in summer, the plant will begin to wilt. It is being stressed by the dry conditions but will survive if given water in time. The length of time before the plant dies will depend on the species, the soil, the size of the pot and a host of other factors. It can accumulate only so much “dry stress” before it will die.

Let’s use cold stress in the human example. We know from the growth indices that 20°C is the bottom of your ideal temperature range (DV1) and that at temperatures below 16°C (DV0) you will not be able to grow. Somewhere below 16°C there is a temperature below which you start getting stressed because it is too cold. You can survive below this cut-off up to a point, but at some stage the accumulated stress wears you down until you die. The stress indices indicate what the cut-off point is (the stress threshold) and how quickly you accumulate the stress.

The growth and stress indices together describe the species’ climatic requirements. We will not address the other special requirements of some species in these tutorials. The values of

the growth and stress parameters are provided for all the species used in the following examples. In preparing these CLIMEX tutorials, we have included the climatic preferences for a number of well known plants and animals. The species list ranges from familiar subjects such as dairy cattle and cane toads to species used in research such as the dung beetles, weeds and insect pests. We have prepared 9 tutorial lessons (with answers), ranging from simple introductory topics to advanced analysis.

Tutorials

The following activities are designed for inexperienced users. They start with a basic introduction to using CLIMEX in Tutorial 1, gradually decreasing in guidance to Tutorial 4. By the time Tutorial 4 is completed, most functions of CLIMEX will have been covered except for "Changing Species Responses". This is the most difficult use of CLIMEX and would usually be reserved for advanced students. It has been left until Tutorial 9. The activities should be attempted in sequence as Tutorials 1-4 provide a step-by-step set of instructions for each new program procedure. Minimal direction is provided after Tutorial 5 unless additional procedures are required. No extra information is required for any of the tutorials except where the student is directed to optional research. Suggested answers to the worksheets are provided.

TUTORIAL 1. Getting Started

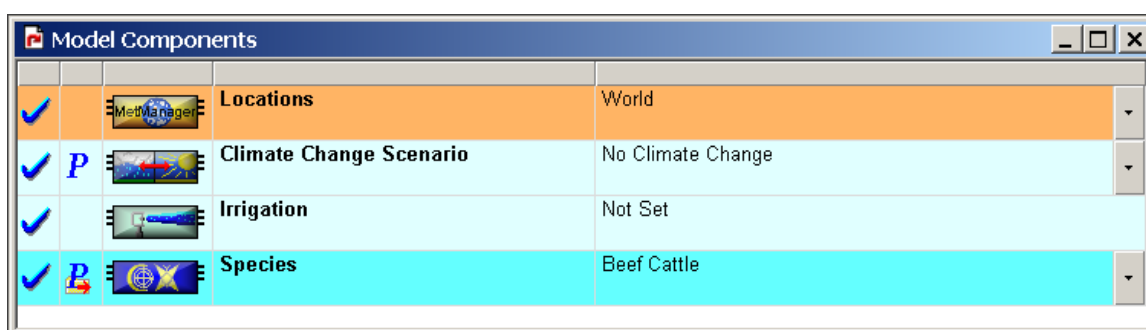
CLIMEX for Windows Version 2.0 is a computer program developed by scientists at CSIRO Entomology in Brisbane. Using CLIMEX, scientists can predict where plants or animals can live anywhere around the world, based on what climate they require. To do this, information about the plant or animal and meteorological data from locations all around the world must be collected. This information is then included in the CLIMEX program.

This tutorial will introduce you to CLIMEX, and show you some of the things it can do. You will need to answer the questions as you work through the activity.

The CLIMEX software contains accessory modules for importing/exporting or editing meteorological data ('MetManager') and for customising maps ('MapManager'). Charts can also be customised after they have been accessed through the Results/Table/ or Map/Chart Menu.

Instruction Steps

1. Using the mouse, move its cursor and double click on the DYMEX Simulator 2.0 icon. When DYMEX has started, select the **File** item from the main menu bar, followed by **Open**. From the list of models shown in the Models pane at the left click on "**Compare Locations (1 species)**" to select it. Then select the "**Climex\CL – Station Data.dxs**" Simulation File from the panel at the top right and then click on the **OK** button to open the selected model and Simulation File. An introductory screen explains the Compare Locations model. Clicking OK closes that window and reveals the Model Components window (see figure below). The program may take a few seconds to load up depending on the computer speed.



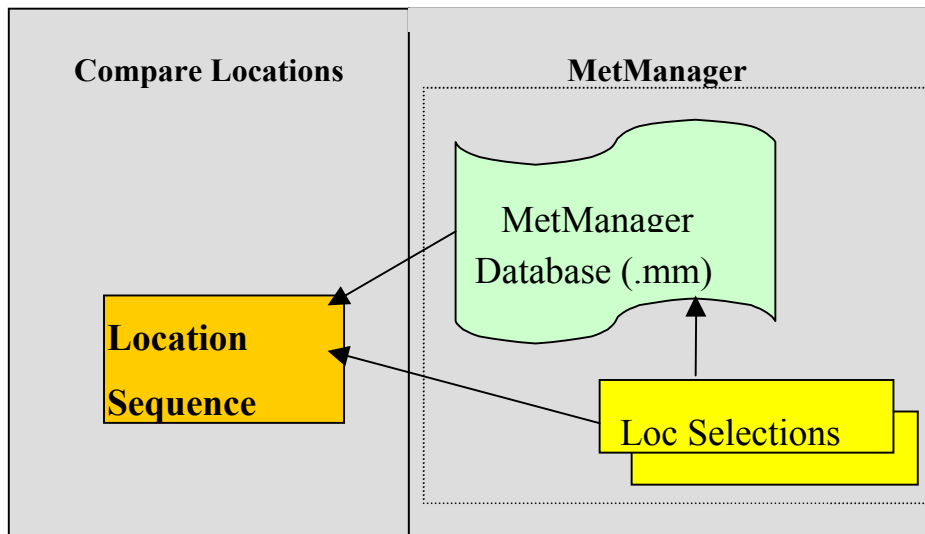
Four modules are shown in the window, each on one line.

The tick mark at the left of each module display indicates that the module is set up (values have been initialised) and ready to go. The column at the right shows the current setting for each module. In the example shown, CLIMEX would run a sequence of simulations called "**World**", with the "Location Sequence" of "**World**", no climate change scenario, no irrigation for the species "**Beef Cattle**".

To change any of the settings, use the "drop-down" button at the far right if one is present. For the "Irrigation" module, click on the "Irrigation" module bitmap, and select "Set Irrigation Scenario" from the resulting menu. Let us look at each module in turn to see how they are set up to run.

Locations:

The “Locations” module controls which locations (each represented by its climatic data) are included in the sequence of locations for the simulation run. A selection or subset of locations from a database in the MetManager is used to create a **Sequence** of runs of the model (the model requires one run for each location). For example, the “*metdata.mm*” database may contain a **Location Selection** (named “*Australia*”) that specifies all its Australian locations. A new sequence is created using the ‘(Add/edit/remove **Location Sequence**)’ option and then choosing the required database and the location selection that has been created in it previously. The **Location Sequence** will automatically be given the same name as the **Location Selection** that it encapsulates but you are free to choose your own name if you prefer.






Some commonly used sequences have already been specified to save time. To select an existing **Location Sequence** for a run, click on the grey button at the far right of the Locations module panel, and select it from the drop-down list.

- (a) To create a new **Location Sequence** from an existing **Location Selection** in a MetManager database, click on the grey button at the far right of the Locations module panel, and select “(Add/edit/remove *Location Sequence*)” from the drop-down list. The click on the “New” button in the Sequences dialog and fill in the details for the **Location Sequence**.
- (b) To create a new **Location Selection** in a **MetManager** database, select the **MetManager** item from the **File** menu. Use the “*Create/edit/delete location selections*” option to create the new selection or edit an existing one.

Species

The next aim is to select the species that is to be examined with CLIMEX. Click on the grey button at the far right of the Species module panel. A list of possible species and templates for various climatic locations will appear. Select the cane toad (*Bufo marinus*).

An example

1. Since we want to find the places in Australia that are favourable for the cane toad, we need to run the model with a sequence of locations in Australia. Go to the **Locations** module and select the Australia sequence from the drop-down list. Australia should now be displayed in the dialogue box and a blue 'tick' at the start of each row should be present, indicating that the program is ready to run.
2. The cursor is now moved to the **Run** icon  and clicked once. The Running Model window appears which tells you the progress of the program in its calculations. When CLIMEX has finished the Running Model window disappears and the results are ready for examination.
3. Now you are ready to look at the results by clicking on the **Results** in the top line of the screen. There are three ways of looking at them: a map, table or chart. Select **Map** and choose the CLIMEX variable that you want to examine, say the EI. The map will appear immediately. You can increase the size of the map by maximising the window. In the Map drop-down menu you can then choose one of three modes to explore the map further: **Query** mode, **Pan** mode or **Zoom** mode. Firstly, use the Zoom mode to zoom in on Australia and then use the Pan mode to centre the map and reorganise the positions of the title, legend and scale indicators by clicking and dragging them to vacant positions in the surrounding oceans. The map displays the possible distribution of the cane toad in Australia and gives an indication of the suitability of the particular location. The larger the circles, the more favourable the location is for the toad. A cross indicates that the location is unsuitable for the species.
4. CLIMEX works out a series of **indices** for the cane toad at each location, which can be viewed in Tables or Maps. The main one is the **Ecoclimatic Index** or EI. The higher the value of the EI, the more suitable a location is. An EI above 10 means the species could survive, while above 30 is very favourable. The circles displayed on the map in step 3 are based on the EI.
5. While you have any map displayed, you can also explore the data at each point on the map in the Query mode. Select **Query mode**. The cursor will change to indicate this mode (). Place the cursor on one of the locations on the map and click the left button once. A  window (Location Data) will appear and show the details of the location and the annual values of all the indexes and stress values for the location. To try other locations, just move the cursor there and click the left-hand button again.
6. There is a second method of looking at local conditions. Place the cursor on a location and click the right hand button once. A small menu box will appear with three options. Select "*Show Detail Table / Weekly Indices*" to view a Table of the weekly indices. Select "*Show Detail Table / Climate*" to view a week-by-week summary of all the climatic values as calculated by the program. To close this window, click once on the cross in the top right-hand corner.
7. Select '*Show Detail Chart*' and then '*Growth*' to chart weekly Growth, Temperature and Moisture indices and weekly temperature and rainfall.
8. Select '*Monthly Met.Data*' to view a table of yearly climatic data (based on a monthly average) for the selected location. Maximum and minimum temperatures are shown

in degrees centigrade. The rainfall is measured in millimetres and the relative humidity in percentage. There are two humidity readings, one at 9am and the other at 3pm. **Questions**

1. What type of climate do you think the cane toad prefers?
2.
 - a. What areas of Australia are not suitable for the toad?
 - b. What types of climates do these places have?
3.
 - a. Which location in Australia is most favourable for the cane toad?
 - b. What are the EI and GI values for Brisbane?
 - c. If the GI was zero, what would this do to the EI?
4. What time of the year is most suitable for the cane toad in Rockhampton?

(*Hint* - first map the distribution of the EI; then open the *Growth* chart for the location. The Growth Index will tell you when the species has most favourable growth conditions.)
5. Follow **Instruction Steps** 1-3 again, but this time map the area that is climatically suitable for the tiger snake in Australia.
 - a. What type of climate does it seem to prefer?
 - b. What is the most favourable location in Australia for the tiger snake?
6. Follow **Instruction Steps** 1-3 again, this time mapping the area suitable for the tiger snake around the world. (You will need to reselect the World as the **Location Sequence**.)
 - a. What areas are most suitable?

TUTORIAL 2. Enhanced Greenhouse Effect

CLIMEX predicts where animals or plants can live based upon climate. This does not necessarily mean an organism actually lives in all of the locations predicted by CLIMEX. It means that if the organism were introduced to that location, it could become established provided that its other needs (like food, shelter, soil type etc.) were met and that competitors or predators did not prevent it. CLIMEX can also make predictions about where species could live in the future under an enhanced Greenhouse Effect. The theory on the **Enhanced Greenhouse Effect** predicts that the world's climate will gradually warm as we pour more and more Greenhouse gases, mostly carbon dioxide from burning fossil fuels, into the atmosphere. Atmospheric gases are like a blanket around the earth, which keeps us warm, unlike the moon that is very cold because it does not have a blanket of gases. We need **Greenhouse** gases for warmth, but too much is expected to cause temperatures to rise. CLIMEX can show how different species may be affected by the increasing Greenhouse effect. Remember that climate change induced by humans is a theory, and scientists don't agree about how our climate will change as the concentration of gases in the earth's atmosphere increases. The results are therefore uncertain. This activity shows you CLIMEX's Greenhouse Option, which allows you to create climate change scenarios to explore possible future changes in the geographical distribution of species. Answer the questions as you work through the activity (assumes you have completed Tutorial 1).

Instruction Steps

1. Start DYMEX, and open the **Compare Locations file**. Use the same **Instruction Steps 1-4** as in Tutorial 1 but choose the tiger snake as the Species. Now click on the **Run** icon, select **Map** from the results window and then choose the EI to obtain a map of the estimated geographical distribution of the snake in Australia.
2. Minimise the map by using the **Minimise button on the Window** (the button with a single flat line and on the left of the three buttons in the top right corner of the window) and return to the **Model Components** window for the tiger snake. Your map is now an icon at the bottom left.
3. You are now going to set up a Greenhouse Scenario. Click on the arrow in the grey box on the right hand side of the **Climate Change Scenario** module. A sample scenario of 'Gradient - 0.1 deg C per degree lat' should be in the list and you can select it by clicking on it once.

This scenario changes the climate of your location selection by increasing the maximum and minimum temperatures by 0.1°C for each degree of latitude from the equator, and **decreasing** overall winter rainfall by 20% and **increasing** overall summer rainfall by 20%.

5. You are now ready to run the Climate Change Effect scenario. Your **Species** module still has the tiger snake and the Location Sequence is set to run the Australian locations. Click on the **Run** icon. Finally select **Results** then from the menu bar select **Map** to see the results of your run. Once you have looked at it, minimise this window as well so that you have two map icons at the bottom left.
6. a. Minimise the Model components window and the Run window in the usual way; this now gives you four minimised icons at the bottom left.

- b. Now click on the left button of each distribution map icon and you will have the two maps overlapping each other. If you now go to the Menu Bar and select **Window** and then **Tile**, you will have both maps one below the other for comparison. You will be able to access the data inside both map that you created by clicking on the map and setting the mode.
 - c. You will have noticed that the distribution of the tiger snake has been reduced markedly by the climate change.
7. Now exit back to the **Model Components** window by closing down the map and the Run minimised icons. The predicted Greenhouse effect is a theory, and some scientists disagree on the likely extent of climate change. CLIMEX allows you to set your own Greenhouse scenario. Once more click on arrow on the grey box to the right the **Climate Change Scenario** module.
8. This time select *Add/edit/remove Climate Change Scenario* at the bottom of the dialogue box to create a new scenario. Click **Create/Copy** with an existing scenario highlighted and supply a new name for the scenario using an informative title in the line provided. The new scenario has parameter values equal to those of the existing scenario that you select as a starting point. Click on the parameter icon and set the parameter values. Adjust the maximum and minimum temperatures for summer and winter, and for the equatorial area by 5°C by overwriting the existing values. This means that all temperatures are increased by five degrees Celsius. The range of permissible settings for this option is from -5°C to +5°C. Also, CLIMEX can increase or decrease temperatures by a set amount for every degree of latitude (range -0.1 to +0.1°C). This means that the change in temperature increases the further north or south the locations are from the equator. We will leave these settings at zero. You can create as many climate change scenarios as you wish. To run a particular scenario, ensure that it has been selected in the Climate Change Scenario dialogue box on the right of the Model Components window. Run the program again with the new scenario and see if there is any difference in what you had before.
9. A number of international research groups, including CSIRO, have created scenarios for climate change for this century. The settings that will give a scenario for the year 2030, based on a 1992 CSIRO scenario are an increase of 2°C over the whole globe instead of an increase per degree of latitude, and the amount of summer rainfall has been increased by 20%.

Questions

1.
 - a. According to CLIMEX's scenario, what changes will the increasing Greenhouse effect have on the tiger snake's distribution in Australia?
 - b. What does this tell you about the type of climate that tiger snakes prefer?
2.
 - a. Use CLIMEX to produce an increasing Greenhouse effect for the distribution of the cane toad in Australia. What is the difference between the normal and Greenhouse distributions?
 - b. What effects could this have on native animals?

3.
 - a. With a general increase in temperature or increase per degree of latitude, how does the distribution of the tiger snake under the new Greenhouse scenario you have set differ from the standard setting?
 - b. Why do you suppose the tiger snake is still able to exist in the isolated locations in New South Wales?
4. The CSIRO's scenario for the Greenhouse effect for the year 2030 can produce large changes in hypothetical species distributions. Run the 2030 scenario and comment on the resulting distributions for:
 - a. the tiger snake
 - b. the cane toad

TUTORIAL 3. Stress Indices

In every year, animals and plants usually have a good season, during which they reproduce successfully in numbers, and a bad season through which they need to survive. They experience stressful conditions mainly during winter or in the dry season, and these two stress-producing seasons may not occur at the same time depending upon the geographical location. For any species, CLIMEX calculates four types of stress: heat stress (HS), cold stress (CS), wet stress (WS) and dry stress (DS). If any stress index is greater than 100, the species cannot survive, and CLIMEX sets the Ecoclimatic Index to zero. Too much stress to an organism is therefore very destructive and can lead to its extinction at a particular place.

This Tutorial shows you how we can use stress indices in CLIMEX to find out why a species can't live in a particular area. Answer the questions as you work through the Tutorial (it is assumed you have completed tutorials 1 and 2).

Instruction Steps

1. Start DYMEX, and as in previous activities run CLIMEX for the cane toad in Australia, and map the results.
2. Choose a location in Tasmania where the toad can't survive (a cross), and point the cursor exactly on it.
3. Click on the cross using the left mouse button. This will give you the Location Data window. You can now answer Questions 1 and 2.
4. Select the **Cold Stress** to map the values around Australia. This maps the Cold Stress only, and shows areas where the toad cannot live because it is too cold. Filled circles mean stress isn't enough to kill them all, while striped circles mean the species won't survive. As you look at the map, you will see that the striped circles are at the southern part of Australia and extend about one third of the way up; the filled circles steadily diminish in size. This shows you that below the line of the largest filled circles, cold stress will kill the toad, while above this line, the effects of cold stress steadily diminish as you move towards the equator. The other indices can be mapped in the same way, and you should try to see what effects they have. If no circles at all appear on a map, then that particular stress has no effect on the species in the mapped region.

Questions

1. What is the main reason the cane toad can't survive in Tasmania?
2. Look at a location in central Australia. Why can't the cane toad survive there?
3.
 - a. Map the heat stress index for the cane toad. Is there anywhere in Australia that is hot enough to kill the toad and what is the general region?
 - b. Map the wet stress index. Is there anywhere in Australia that is too wet and what is the general region?

4.
 - a. Map heat stress for the tiger snake in Australia. Are there any areas where it is too hot and what is the general region?
 - b. Does wet stress influence where the tiger snake lives? If it does, describe what you believe is the effect.

TUTORIAL 4. Geography and Comparing Climates

CLIMEX has a large database (collection) of climatic information from over 3000 locations around the world. We can search the database to find places that have similar climates. CLIMEX can compare temperatures, rainfall and relative humidity (RH), and it produces a **Match Index** which describes the degree of similarity between one location and another. CLIMEX compares the weekly rainfall, temperature and RH and the seasonality of the rainfall. For example, a Match Index of 0.8 would be considered to be a close match, while a match of 0.6 or below indicates that some or all of the climatic variables are quite different. This tutorial assumes you have completed tutorials 1 - 3.

Instruction Steps

1. Start DYMEX and click **File/Open/Match Climates** to open the **Match Climates** file. The **Model Components** window will open and display five panels. The top two show the **Home** and **Away Locations**, the next two show the **Climate Change Scenario** panels for the Home and Away locations, and the final panel shows the **Match Climates** module.
2. In the first module panel select the **Home Location** (the one to be matched by others elsewhere) by clicking on the icon and then select **Initialize** on the top line. In the MetManager location Selection dialogue box that appears, browse for the database. Then select Brisbane from the drop down menu list. Now move to the **Away Locations** and, using the same process, select North America.
3. Now click on the **Match Climates** icon then set Match Properties to examine the **Match Index Weights** in the **Match Climates Settings** dialogue box. All values should be set to 1, except for the RH and soil moisture, which are set to zero to inactivate them. If any of the values are different, reset them.
4. In the **Masking** column on the right hand side of the dialogue box you can set weeks that you want to include in the comparison. Remember that the weeks refer to the **Home** location, with the **Away** locations being displaced by 6 months if they are in the opposite hemisphere. Close the window and leave this feature to explore later.
5. Run the model and open the 'total' map that should appear with circles marking the various town locations. The size of each circle indicates the degree of similarity of the climate at that location to Brisbane's climate. Enlarge the map to fill the screen. Putting the cursor on the location and left-clicking will bring up a **Location data** panel describing the location and the values of the various indices. You can now answer Question 1. Close the **Location data** window either by clicking on an empty space or on the top right hand corner.
6. To answer Question 2 you *could* inspect each location by clicking on it and finding the best matching location. This would be time consuming and boring and there is a better way. Close the map by clicking on the top right-hand button of the window. Now go to the **Results** menu and select **Table/Standard**. You will get a table of all the North American towns that had a total match index of 50 and over. Expand the table so that it fills the screen. The towns are ranked according to how well they match Brisbane, with the best match is at the top of the table, and the remainder with an index value greater than 0.5 are listed below in decreasing order. You can alter the minimum value by

selecting **Table/Edit Format/** highlighting the variable to be altered and selecting **Column Format** and altering the value. Alternatively, double clicking on any number in the table. The **Column Format** menu item can be selected to open the same **Column Format** window. Answer Question 2.

7. Close the window and then reselect the **Map/total** option in the **Results** menubox. Expand the map to full screen. Move the cursor to any location on the map and right click on the location. A drop-down box will appear in which you should select **Show Detail Chart/Standard**. Brisbane's monthly temperature and rainfall will be displayed (red) together with the corresponding match location information (blue). You can also tile the charts for comparison using a procedure similar to that given in Tutorial 2). Don't forget that northern hemisphere locations are shifted by six months to match seasons. You can now answer Questions 3 and 4.
8. Return to the **Match Climates** window and then change the **Home Location** to Sydney. Change the **Away Locations** to Australia, and then **Run** the program again. Display the map. Now close it and return to the Match Climates window. Select a scenario from the **Climate Change Scenario** (Home Locations). This will find locations that will be similar to Sydney when that town is under the influence of the increasing Greenhouse effect (check which Greenhouse scenario you are using). Results can be displayed in the same way as in steps 4 to 7. Finish the tutorial question set.

Questions

1. What part of North America has a climate similar to that of Brisbane?
2. What location in North America has the best match with Brisbane?
3. In what month does Brisbane have its highest rainfall?
4. What month has the lowest temperatures?
5. What place in Australia presently has a climate similar to what Sydney could have under the influence of the 'Greenhouse effect?
6. If you were travelling to Africa, where would you go to have a climate as close as possible to Brisbane?
7. What part of the world experiences a climate similar to that of Perth?
8. Choose an Australian town or city and find similar climates in different places around the world.

TUTORIAL 5. Biological Control

The use of natural enemies to control the growth of a weed or pest population is known as biological control. When choosing a biological control agent, you must find a species that can flourish where you plan to introduce it. It must also feed on or parasitise the pest you wish to control and be able to survive where the pest is able to live. Ideally it will only feed on the pest that you want to control.

The cane toad is an example of an unsuccessful attempt at biological control. Introduced by the sugar industry to control the cane beetle, it certainly flourished. However the toad did not go into cane fields and so did not feed on cane beetles. Even worse was to come because the toad eats almost anything else and has spread into southern NSW and in 2001 it invaded Kakadu, as predicted using the CLIMEX model some years ago. Also, it is poisonous to many native species of snakes, mammals and birds.

The weevil *Cyrtobagous salviniae* is an example of a very good biological control species. The weevil **only** feeds on *Salvinia* (a floating fern) and is an extremely voracious feeder once it becomes established. *Salvinia* choked Mt. Isa's water supply dam until the weevil was introduced and destroyed it; similarly, the weevil was able to destroy huge *Salvinia* infestations on rivers in New Guinea.

CLIMEX is used in biological control programs to find locations around the world with a climate similar to that of the area into which the species is to be introduced. This helps to select well-adapted species. Having made the choice, CLIMEX can be used to estimate how widespread the introduced species is likely to become.

Special Instructions

This tutorial assumes that you have completed tutorials 1-4. During the tutorial you can also use another feature of CLIMEX that allows you to run two species simultaneously. In **File/Open** select **Compare Locations 2 species**. Suppose you wanted to see if tiger snakes were threatened by eating poisonous cane toads. Select tiger snakes as the first species and cane toads as the second, then select Australia as the location and run the program and map the EI for both species. If the two distributions do not overlap, then the tiger snake is in no danger from the cane toad; if the distributions do overlap, then tiger snake populations might be in danger in the overlap area. CLIMEX shows overlap regions as half circles with two colours and gives a colour key to each species. In this way you can test the usefulness of host/parasite relations for biological control or other situations where two species are interacting.

Case Study - The Dung Beetle

Sheep, horses and cattle were introduced into Australia with the First Fleet in 1788. After two centuries we have about 30 million cows, producing some 300 million dung pads per day. In the dry season most pads dry out to a hard cake and take a long time to disintegrate, putting out of service millions of hectares of pasture each year. A second problem is that fresh pads are the breeding ground for certain pests, particularly the bush-fly and the introduced buffalo fly, a blood-sucking cattle pest. In Africa, home of many large animals such as elephants that produce large amounts of dung, the pads are dispersed by some 2000 species of dung beetle. Just a few hours after a dung pad is produced, almost nothing remains of the pad. Most beetles excavate tunnels under or near the pad, and carry the dung down and make it into balls

in which females lay their eggs. This process: i) removes the dung from the surface; ii) kills most of the fly larvae in the dung; and iii) both aerates and fertilises the soil.

All countries of the world (including Australia) have some dung beetles. However Australian dung beetles are not well suited to living in cattle pads, as they are adapted to deal with the dry pellet droppings produced by most marsupials. In 1963, CSIRO scientists began a project to introduce dung beetles from Africa. Many species are now firmly established in Australia, and observations indicate that they have buried large amounts of dung over wide areas of the country. It is less clear what effect dung beetles are having on fly populations but reports claim good suppression of bush fly breeding in inland Australia but little effect on numbers of buffalo flies.

Questions

1. Use CLIMEX to find the distribution of climatic areas suitable for the buffalo fly (*Haematobia irritans exigua*) in Australia. Briefly describe its distribution.
2.
 - a. Using CLIMEX, predict which countries you would visit in order to find suitable areas from which dung beetles could be imported which would bury dung and control buffalo fly in tropical northern Australia. (Hint: the dung beetle would be required to be active wherever the buffalo fly was active - so, try looking for countries where the buffalo fly could exist.)
 - b. An isolated group of locations in northern Africa is within the potential range of the buffalo fly. Suggest whether this would be a good place to look for suitable species of dung beetles and explain your answer.
3. The grey dung roller beetle (*Sisyphus spinipes*) has been introduced to Australia. What is its potential distribution?
4. How suitable do you think the grey dung roller is for controlling the buffalo fly, based on climate?
5. What effect will the increasing Greenhouse effect have on the distribution of the buffalo fly and the grey dung roller? (Use the default Greenhouse settings as shown in Tutorial 2 and make sure that your settings are correct.)
6. Does the increasing Greenhouse effect change the prospects of the grey dung roller for controlling buffalo fly?
7. Would the grey dung roller beetle be suitable for controlling bush fly breeding in dairy cattle cowpats? (explain your answer). (Hint: try running two species together - the grey dung roller beetle and dairy cattle and see what you get.)
7. (For further research) What precautions should be taken before introducing a new species into another country?
8. (For further research) Investigate the biological control of the prickly pear in Australia.

TUTORIAL 6. Quarantine Part 1

This tutorial assumes tutorials 1 to 5 have been completed. It does not contain any ***Instruction Steps***.

There are many plants and animals overseas that could cause serious damage to the Australian environment, agriculture or our own health. Australia's strict quarantine laws are to ensure that these pests do not enter our continent. If a known pest is accidentally introduced into a country, quarantine measures must be put in place rapidly so that the pest doesn't become established. Some pests have already caused great costs to rural industries in Australia. An example is the buffalo fly, which is a blood-sucking insect that feeds on cattle. It was introduced from south-east Asia last century and has become established in northern parts of Australia.

Quarantine measures are expensive and inconvenient. In some cases, they are unnecessary, because the introduced pest cannot survive in the area in which it was introduced. CLIMEX can be used to estimate how favourable an area is for a pest, and a decision can then be made on what quarantine measures are needed. It can also be used to get an idea of the area at risk from an exotic species. Estimates of its economic effect on crop yields or stock can then be made.

The time of the year that the pest is introduced can be important. If the CLIMEX Growth Index for the pest at a certain location is zero, or soon will be, the pest may not be able to establish a large enough population to survive a time of stressful conditions, even if it reaches that location.

Case Study 1 - The Russian Wheat Aphid

The wheat industry in Africa and the United States has been severely affected by recent invasions of the Russian wheat aphid (*Diuraphis noxia*). Crop losses of 80-100% have been reported in these countries. The aphid has not been reported in Australia yet, but CLIMEX has been used to estimate its potential as a pest of wheat in Australia. The study reports that the aphid is potentially a severe threat. Wheat is Australia's most important crop, generating 2.5 billion in export revenue.

Questions

1. Use CLIMEX to estimate what parts of Africa are susceptible to the wheat aphid.
2. Australia's wheat belt is a narrow crescent stretching in a curve from central Queensland through New South Wales, Victoria and South Australia. It continues around the south-west of Western Australia. (See Figure 1.) How favourable is this area for the wheat aphid?

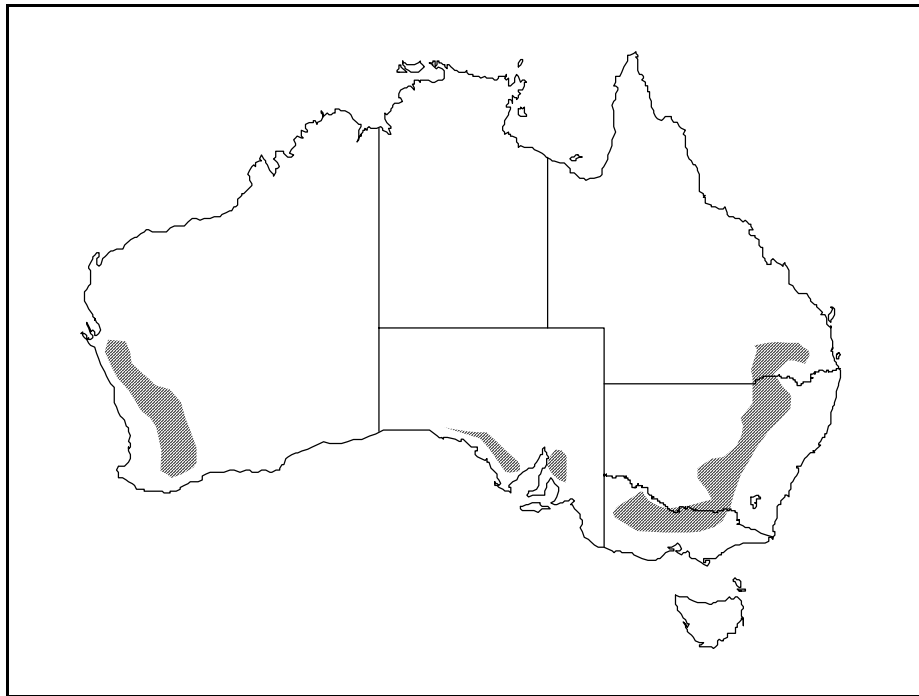


Figure 1. Australia's wheat belt

3. You are a quarantine officer in the Australian Quarantine and Inspection Service. Wheat aphids have been reported in Darwin. You have access to CLIMEX. What action would you take? Explain.
4. Why are areas right on the coastline of eastern Australia unfavourable for the aphid?
5. A similar situation to that in Question 3 has occurred in Brisbane, during September. Although Brisbane is generally unfavourable, what problems can you see? How far is Brisbane from very favourable areas?

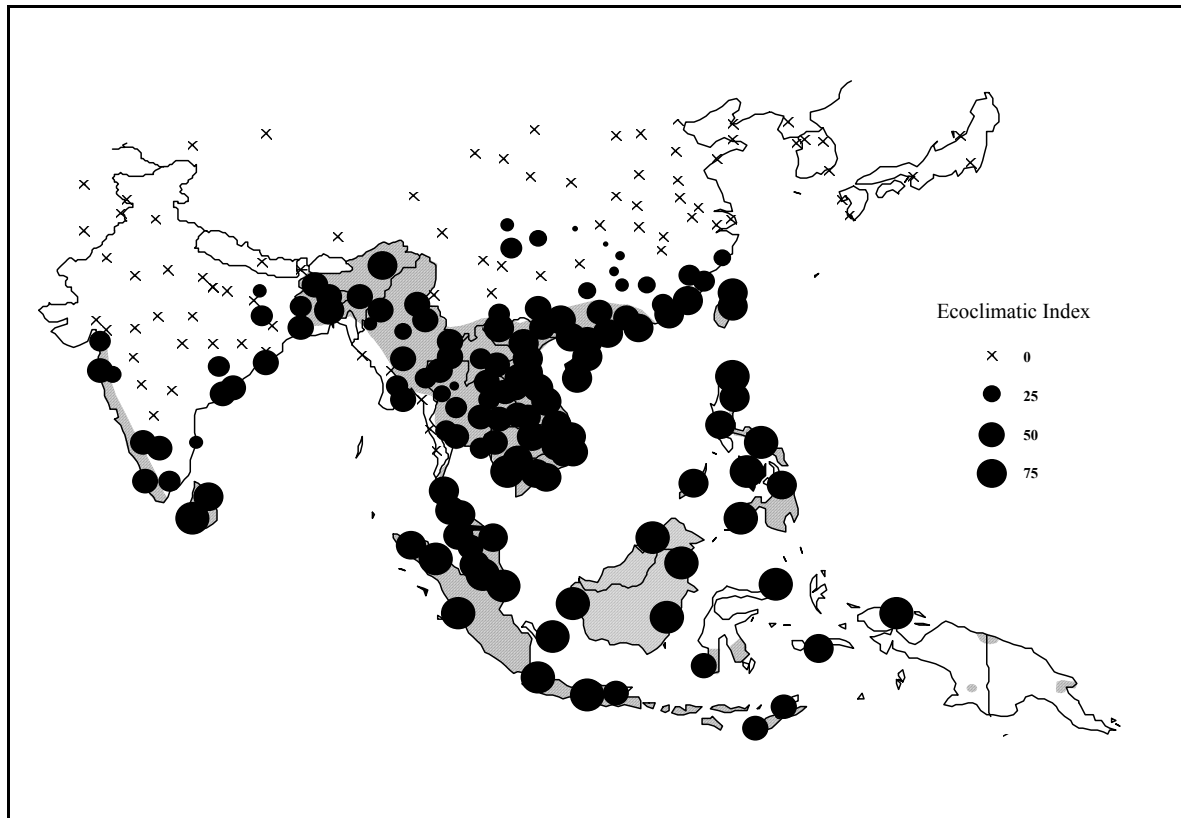
Case Study 2 - Siam Weed, *Chromolaena odorata*.

Weeds are one of the greatest threats to agricultural and environmentally sensitive land in Australia. Introduced plants are able to cover vast areas, often out-competing native species because their natural predators or diseases are usually not brought with them. They are often of no benefit to native animals and can harbour introduced pests like foxes and rabbits. Lantana and blackberry plants make wonderful cover for these two species. National park agencies around the country battle to control thousands of different species of weeds that are invading land and water habitats. Farmers spend hundreds of millions of dollars on controlling weeds every year, including the use of chemicals that pose hazards to humans and wildlife. It is estimated that weeds cost Australia \$3 billion annually.

Siam weed is considered to be one of the world's worst weeds. Native to South America, this plant has spread rapidly throughout south-east Asia after it was introduced into India in 1845 as a garden plant. Many of the weed species introduced into Australia were brought in as ornamentals (lantana, mimosa, water hyacinth), as fodder for sheep and cattle (prickly acacia) or accidentally in shipments of seeds (parthenium). In July 1994 Siam weed was discovered on the Tully River near Mission Beach in north Queensland, probably introduced with seed from Brazil. If it becomes established, the weed has the potential to seriously degrade land

used for agriculture, forestry and conservation. It is the biggest threat to disturbed forest land, because it needs exposure to sunlight to survive. It will not flourish in the shady environment of a dense forest. Five million dollars was allocated for control of Siam weed over 5 years.

A CLIMEX prediction for Siam weed showed a very large potential distribution and prompted weed control agencies to develop a control strategy to implement rapidly. A map of the distribution of Siam weed in south-east Asia is shown below along with the CLIMEX prediction. The shaded area is the current distribution of the weed.



Questions

6. Looking only at the map above and without running CLIMEX, what do you think are the climatic preferences of Siam weed and where do you think it will survive in Australia? You will need to think about the geography of south-east Asia. An atlas may be useful.
7. Run a CLIMEX prediction for Siam weed in Australia. What agricultural industries and conservation areas are threatened by the potential distribution of the weed?
8. Siam weed has spread south and east from Asia through the islands of Indonesia to Irian Jaya and Papua New Guinea. Machinery, humans and animals spread the seeds. What is the likely threat of Siam weed being introduced into Australia from PNG or nearby islands? What can the government do about it?

TUTORIAL 7. Quarantine Part 2

This Tutorial assumes that Tutorials 1 to 6 have been completed.

Case Study - The Screw-worm Fly

The screw-worm fly, *Chrysomya bessiana*, is a parasite of warm-blooded animals, particularly livestock, although it has been recorded in dogs, cats, bears, elephants, kangaroos, lions and humans. Flies lay eggs on the edges of wounds or body orifices such as the mouth or ears and the larvae then eat their way into the animal's flesh. The screw-worm fly occurs throughout tropical Africa, India, south-east Asia, and New Guinea. If the fly ever became established in Australia it is estimated that it would cost the livestock industry hundreds of millions of dollars.

Large numbers of feral cattle exist in the northern tip of Cape York Peninsula, and Torres Strait is only 152 km wide at its narrowest point. Islands reduce the longest stretch of water to 32 km. The screw-worm fly is a common pest in New Guinea, so the risk of introduction in the north is real. Introduction by sea is considered to be the most likely scenario.

Questions

1. Use CLIMEX to describe the climatic conditions preferred by the screw-worm fly.
2. In November and December of 1987, screw-worm flies were intercepted in Sydney. How likely is it that the fly could become established in Sydney and why do you make this assessment?
3. In April 1988 screw-worm flies were intercepted in Darwin harbour. Compare this situation with the interception in Sydney.
4. Does an increased Greenhouse effect alter the answers you have given for questions 2 and 3? (Use the standard scenario)
5. Screw-worm fly was introduced to countries in the Persian Gulf via a ship load of live sheep from Western Australia in 1980. **There has never been a screw-worm fly outbreak in Western Australia.** Use CLIMEX to help you explain this anomaly. (Hint: consider the most direct route used by a ship that would take it from Australia to the Persian Gulf.)
6. Although the screw-worm fly reached Darwin (see Question 3), it did not become established. This is despite the fact that the location has a very good Growth Index. Can you suggest a reason as to why this happened? (Hint: Look at the graphical display of meteorological data and temperature/moisture/heat stress indices for Darwin.)

TUTORIAL 8. Limitations of Scientific Models

CLIMEX is a moderately complex computer modelling package. Scientists make models as accurate as possible, but the system being modelled is usually very complex. This means that the computer model is at best an approximation of what it is trying to represent. Always remember that the values, which CLIMEX calculates for its indices, are close approximations. For example, if one location has an EI of 23 for a species, and another has an EI of 25, we can't really say that the second location is more suitable; all we can say is their suitability for the survival of that species is similar. A computer model depends on the accuracy of its data and how closely the model simulates the real conditions. If the data on which CLIMEX does all its calculations is incorrect and/or the CLIMEX mathematical model is not accurate, all its predictions will be incorrect. This Tutorial asks you to think about scientific models, CLIMEX in particular, and realise that these models do have limitations, and must therefore be used with the limitations in mind.

Questions

1. On what two sets of data does CLIMEX base its predictions?
2. How do you think the scientists who designed CLIMEX collected all the information?
3. What errors do you think there could be in the data that CLIMEX uses, or in the way CLIMEX processes that data?
4. What is the main assumption CLIMEX uses to make its predictions?
5. What other factors could affect a species' geographical distribution besides the climate of the region?

TUTORIAL 9. Changing Species Responses

CLIMEX uses a series of parameters (or variables) for each species to model how it will respond to temperature and moisture. The parameters for a species describe the range of conditions that are needed for it to develop and survive. For example, CLIMEX uses four species parameters related to temperature, DV0, DV1, DV2 and DV3. DV1-DV2 define the range in which the species is best able to grow and reproduce; DV0 and DV3 are the lowest and highest temperatures at which a species can develop. As CLIMEX is a complex computer model, a large number of parameters are used. An example of a first pass estimate of parameters for a species is illustrated in the *Nothofagus* sp file.

This particular genus is the Antarctic Beech, species of which can be found in Australia from the Queensland-New South Wales border to Tasmania, but only in certain locations that satisfy this species' climatic requirements. Only the Temperature and Moisture parameters have been given values and these are first estimates for the values. Unlike many programs, CLIMEX does not expect exact values for a species to begin with. You start by knowing where a species is definitely found and then you insert your initial guesses of the parameter values that might match the species' response to the local climatic conditions. For example, we know that species of *Nothofagus* have the distribution as noted above. Call up a map of Australia with all locations and look at such places as Mt. Tamborine, Queensland (very close to where the beech grows but at a lower altitude) and Strathgordon in Tasmania. Beech prefers areas that have a lot of rain at all times of the year and rarely experience temperatures above 28 - 30°C. Also, they are areas that might be expected to have frosts, if not some sleet, during winter.

Task 1. Using the values given in the *Nothofagus* sp. file run the species for Australia.

Instruction Steps

1. In the Compare Locations model, select **Species** and from the drop-down menu select **Add/Edit/Remove CLIMEX species**. In the **Name** box, type in *Nothofagus moorei*. and then select the *Nothofagus* sp file from which to copy. Now close the dialogue box and click on the **Species** icon and *Show parameters* to edit parameter values.
2. There are two small traps. First, you must always have at least a “zero” (0) for any parameter; if you don't, the program will prompt you to fix it up by telling you there is an invalid value for the parameter. Second, sometimes the parameters you want to enter may overlap existing parameter values in another function. For example your chosen value for ‘dry stress threshold’ (SMDS) may be 0.2, which is a higher level of soil moisture than the minimum moisture level that supports growth (SM0), say 0.1. CLIMEX will not allow you to do that because it is not logical. You will be prompted and will need to re-set the existing parameters first, or even delete some incorrect values and set them to the default of zero. When you are finished close the dialogue box and the parameters will be saved automatically.
3. First run the CLIMEX model with the original parameters to generate a hypothetical distribution.

CLIMEX compares a location's meteorological data with the values of the species parameters to see how well they match up. A series of indices are produced describing the response of the species to the climate of that location. The Temperature Index and Moisture Index are combined into a Growth Index, which summarises how suitable the location is in terms of the temperature, moisture and thus potential for growth of populations of the species. The higher these indices, on a scale from 0 to 100, the more suitable is the location. Stress indices are also calculated. These describe how stressful the location is for the species in terms of extreme heat, cold, wetness and dryness. The higher the stress indices, the more stressful and hence more unsuitable is the location. A stress index of 100 means that the species cannot survive at the location. All these indices are combined to give the overall Ecoclimatic Index (EI), which is a single value summarising the suitability of the location for the species. The higher the EI, the more suitable the location.

4. Now look at your hypothetical distribution for *Nothofagus moorei*. You can see that the species is shown to have a very wide potential distribution up and down the east coast and into subtropical regions. This is obviously incorrect, because *Nothofagus moorei* does not occur any further north than the NSW-Queensland border region in Lamington National Park. We need to get a better picture of the Antarctic beech's distribution and you now move into CLIMEX's most powerful research use: the capability to move through an iterative procedure. This means that you re-run the program again and again while you test changes in your species parameter file.
5. Close the distribution map. Now open the 'Show parameter' window in the **Species** module after selecting *Nothofagus moorei*.
6. If you look at the temperature settings, you can see that they are rather high for a very cool climate species, so reduce the values. Try using 0, 8, 15 and 25 for the four DV parameters. Re-run the program using this new parameter values.
7. Assuming that you have done everything correctly, you will find there is a very large change in the distribution of the beeches: there is far less suitable area up the Queensland coast. There is still a problem however as the distribution suggests that the beech trees are able to survive in parts of inland Australia, which is quite wrong. We need to adjust the parameters again.
8. This time we can alter the requirements for soil moisture. *Nothofagus moorei* lives in areas of high rainfall, so we will alter the parameters to reflect that climatic situation. Recall that a value of SM = 1 means that the soil is saturated. Now the beech locations are such that both rain and mist produce large water run-off, so a better set of values for Moisture might be 0.7, 0.9, 1.8, and 3.0. Open the **show parameters** box and change the **Moisture** values to the new set and re-run the program.
9. Again there is a large difference: there are almost no locations in the inland areas and the indicated distribution north of the Queensland border has almost been removed. We are approaching a much better model of the species distribution, but to fine tune it we need to begin using stress indices such as Cold, Heat, Dry and Wet stresses.
10. Once more, close the distribution map and return to the parameter setting box for *Nothofagus moorei*. Antarctic beeches are a species that developed during a period when Gondwanaland was cold, so it is reasonable to assume they really do become stressed under high temperatures. In the Show Parameter box select **Heat Stress** and then reduce TTHS to

25 and change THHS to 0.001. This means that you are telling the program that Heat Stress really begins to damage the beeches once the temperature reaches 25°C and that the “multiplier effect” for the computer mathematical equations is 0.001. **Please remember** that these values are only guesses - we now have to run the program to see what happens. Never change two sets of parameters at the same time - you will not be able to tell which parameter caused the change in the distribution.

11. As you can see, the change is large and has reduced the distribution on the mainland. This is much too large a change as the Antarctic beech does occur in mountain regions of central New South Wales and Victoria. So, reduce the “multiplier effect” of THHS to 0.0001 and see what happens.

12. Much better. You could try a series of values between 0.0001 and 0.001 to see which is the best fit.

13. There are still inland areas included. To reduce these, we need to consider **Dry Stress**. Once more return to the editing mode for *Nothofagus moorei*. This time select Dry Stress and try inserting values of 0.6 and 0.001 for SMDS and HDS. Re-run the program.

14. There is little change, so increase the value of HDS to 0.01 and re-run the program.

15. The hypothetical distribution is now very similar to the actual distribution. South Australia and Western Australia locations have all been eliminated, and only an east coast Australia-Tasmania distribution is left.

16. You have now created a hypothesis on the factors that limit the geographical distribution of the Antarctic beech. The next step is to see how CLIMEX can predict where the *Nothofagus moorei* should be able to grow if it is taken elsewhere in the world. Keep your species parameter settings and this time select the **World Level One** as your Location Selection; run the program and produce a species distribution map.

17. Examination of the world map shows that the beech would be able to survive in New Zealand and South America (where it is found). However, it is also shown in a number of other locations where today it is extinct or where it never reached during the earth’s history: Africa, North America and Europe. In this way, CLIMEX can be used to estimate a species’ global distribution based on its known Australian distribution. This is a very useful tool for scientists who are looking at either Australian species escaping overseas or the opposite situation when an overseas species becomes a pest in Australia.

Task 2

You are now going to examine the distribution of the tiger snake. Since you do not want to alter the master copy of the tiger snake in the CLIMEX species file, you must first produce your own copy file (which you can call “Tsnake”) and then give your copy the same parameter values as those of the tiger snake. To do this, follow these steps:

- a. In the Species module select *Notechis scutatus* Tiger Snake from the list of species and then return to the list and select ****Add/edit/remove CLIMEX species** from the bottom of the list of species. A **Parameter File Selection** window will open. Select **Create/Copy** and another smaller window will open with the title **Create CLIMEX Species**. In the top line you will see the name of the species

that was chosen to be copied as a template for your new species, ie *Notechis scutatus*. Type 'Tsnake' into the second line and click on the "OK" button. CLIMEX responds with a message: 'New CLIMEX species created successfully. Go to Parameter initialization to set up the parameter values'. You now have a copy of the tiger snake's parameters, which you can modify as you wish by clicking on the 'P' icon in the Species module.

- b. You are now going to modify the parameters for Tsnake. Each time you change parameters, CLIMEX must be run to recalculate the indices and you can then map the results. Although you have seen how parameters are changed during **Task 1**, there are some useful hints on changing parameters:
 - i) If the species is experiencing too much dry stress in a region, reduce the value of the dry stress threshold, SMDS.
 - ii) If the species is experiencing too much wet stress in a region, increase the wet stress threshold, SMWS.
 - iii) If the species is experiencing too much heat stress in a region, increase the heat stress temperature threshold (you may need to increase the growth limiting high temperature, DV3, as well) or the heat stress degree-days threshold, depending on which is used for the species.
 - iv) If the species is experiencing too much cold stress in a region, decrease the cold stress temperature threshold, TTCS (you may need to decrease the limiting low temperature, DV0, as well) or the cold stress day-degree threshold DTCS, depending on which is used for the species.
 - v) Now repeat the above steps with the Hot-Wet Stress to see how the snake is affected by increases or decreases in the value of the PHW parameter.

Remember: Only change one parameter at a time. This is the basis of scientific experimentation. Keep a running record of what you have changed. Map stress indices to see how they have been affected by your changes.

Alter the parameter values so that coastal Queensland up to the Rockhampton area, and all of coastal New South Wales, are now favourable. You should initially map stress indices to decide what parameters to alter. Note your final values.

Task 3

1. Make your own copy of the cattle tick (*Boophilus microplus*) in Australia, run CLIMEX and map the EI.
2. Notice that central and southern parts of Australia are unfavourable for the tick. Map the individual stress indices (if you have forgotten, see Tutorial 3) and then answer Question 1.

Questions

1. a. What stress makes central Australia unfavourable for the cattle tick?

- b. as above for southern Australia?
2. Change the species parameters so that southern Australia, including Tasmania, is also favourable for cattle tick. Note your final values.
 3. Change the species parameters so that central Australia is also favourable for cattle tick. Note your final values.

This procedure is the one used by scientists to work out parameters for a species. They start from a known distribution of their species of interest somewhere in the world, which has been recorded through field observations by other scientists. They then alter parameters systematically until CLIMEX gives the same distribution. Laboratory data can give a starting point for parameters. Once parameters are decided, CLIMEX can be used to predict favourability in other regions or countries.

SUGGESTED ANSWERS

Tutorial 1. Getting Started

1. What type of climate do you think the cane toad prefers? *Warm and wet.*
2.
 - a. What areas of Australia are not suitable for the toad? *Southern and central parts of Australia.*
 - b. What types of climates do these places have? *Southern parts are cool, while central parts are hot but very dry.*
3.
 - a. Which location in Australia is most favourable for the cane toad? *Lockhardt River and Cooktown both have an EI of 53.*
 - b. What are the EI and GI of Brisbane? *EI = 23, GI = 35*
 - c. If the GI was zero, what would this do to the EI? *It means EI will also be zero. If GI is 0, the species can't reproduce, and therefore the location's overall suitability is 0.*
4. What time of the year is most suitable for the cane toad in Rockhampton? *Summer - December, January and February is when the GI is best.*
5.
 - a. Following *Instruction Steps* 4 and 5 again, map the area that is climatically suitable for the tiger snake in Australia. What type of climate does it seem to prefer? *The southern parts of Australia - a reasonably cool climate.*
 - b. What is the most favourable location in Australia for the tiger snake? *Bicheno, in Tasmania (EI = 64).*
6. Do steps 4 and 5 again, this time mapping the area suitable for the tiger snake around the world. What areas are most suitable? *Cooler areas are most suitable, such as Europe, Canada, southern Australia.*

Tutorial 2. Greenhouse Effect

1.
 - a. According to CLIMEX's prediction, what changes will the increasing Greenhouse Effect produce on the tiger snake's distribution in Australia? *It could almost eliminate the tiger snake in mainland Australia.*
 - b. What does this tell you about the type of climate that tiger snakes prefer? *The tiger snake prefers quite a cool climate - a few degrees increase overall is too much for it.*
2.

Use CLIMEX to produce an increasing Greenhouse Effect for the distribution of the cane toad in Australia. What is the difference between the normal and Greenhouse distributions? *The cane toad could survive further south, such as in Sydney, and possibly in Perth.*

 - b. What effects could this have on native animals? *Cane toads poison or eat many native species - the effect could be very severe depending on the species.*
3.
 - a. With a general increase in temperature as well as the increase per degree of latitude, how does the distribution of the tiger snake under the new Greenhouse scenario you have set differ from the standard setting? *With this Greenhouse scenario, the tiger snake is predicted to almost completely vanish from the Australian mainland. It only has residual populations in isolated east coast areas of New South Wales and southern coastal Victoria.*
 - b. Why do you suppose the tiger snake is still able to exist in the isolated locations in New South Wales? *They are alpine areas that provide the cooler climatic conditions required by this species.*
4.
 - a. The CSIRO's predictions for the Greenhouse effect for the year 2030 can produce large changes in hypothetical species distributions. Run the 2030 scenario and comment on the resulting distributions for:
 - a. The tiger snake. *There is not as large a change as in the normal Greenhouse Scenario, probably because the 2030 prediction does not have such a large change in rainfall. The tiger snake is reduced in its potential range does remain over considerable areas of mountain regions in eastern Australia, especially New South Wales.*
 - b. The cane toad. *The range differs very little except that Sydney and its region are no longer included as good potential locations within the species hypothetical distribution. The cane toad will potentially be able to reach Taree, but has little chance of surviving in the Sydney region.*

Tutorial 3. Stress Indices

1. What is the main reason the cane toad can't survive in Tasmania? *Cold stress - Tasmania's climate is too cold.*
2. Look at a location in Central Australia. Why can't the cane toad survive there? *Cold stress contributes, but dry stress is the major reason (dry stress index is greater than 100).*
3.
 - a. Map the heat stress index for the cane toad. Is there anywhere in Australia that is hot enough to kill the toad? *Marble Bar in Western Australia is the only location stored in CLIMEX that is too hot.*
 - b. Map the wet stress index. Is there anywhere in Australia that is too wet? *No location has a wet stress index for the cane toad close to 100.*
4.
 - a. Map heat stress for the tiger snake in Australia. Are there any areas where it is too hot and what is the general region? *Most of northern and central Australia is too hot - southern Victoria and Tasmania are the main areas free from heat stress for the tiger snake.*
 - b. Does wet stress influence where the tiger snake lives? If it does, describe what you believe is the effect. *Yes, but not to nearly the same extent as heat stress. Any area where wet stress is too great causes excessive heat stress as well in Australia. The Northern Territory and far north Queensland are the main areas where wet stress is too great.*

Tutorial 4. Comparing Climates

1. What part of North America has a climate similar to that of Brisbane? *Florida, the lower east coast of the U.S.A., and the coast line bordering the Gulf of Mexico.*
2. What location in North America has the best match with Brisbane? *Jacksonville, U.S.A. (0.76 match index).*
3. In what month does Brisbane have its highest rainfall? *February.*
4. What month has the lowest temperatures? *July or August.*
5. What place in Australia presently has a climate similar to what Sydney could have under the influence of the Greenhouse effect? *Brisbane.*
6. If you were travelling to Africa, where would you go to have a climate as close as possible to Brisbane? *There is a small group of locations in south-eastern Africa with such places as Hlabisa (index 74), Cape St Lucia (index 77), Mt Edgecombe (index 72), and Durban (index 72).*
7. What part of the world experiences a climate similar to that of Perth? *The Mediterranean region.*

Tutorial 5. Biological Control

1. Use CLIMEX to find the distribution of climatic areas suitable for the buffalo fly (*Haematobia irritans exigua*) in Australia. Briefly describe the distribution: *The buffalo fly's potential distribution is all coastal areas north from northern New South Wales, around the Cape and past Darwin.*
2.
 - a. Using CLIMEX, what countries would you visit in order to find suitable areas from which dung beetles could be imported which would bury dung and control buffalo fly in tropical northern Australia? (Hint: the dung beetle would be required to be active wherever the buffalo fly was active - so, try looking for countries where the buffalo fly could exist.) *The countries that would most likely hold good prospects for suitable species of dung beetle would be those in Central America, but stretching all the way into central Southern America, tropical and southern Africa and India and South East Asia.*
 - b. A potential range for the buffalo fly is an isolated set of locations in northern Africa. Suggest whether this would be a good place to look for suitable species of dung beetles and explain your answer. *This region would not be a good place to look for suitable species as the beetles concerned would be more likely adapted to a warm temperate climate rather than the tropical climate needed for the Australian conditions.*
3. The grey dung roller beetle (*Sisyphus spinipes*) has been introduced to Australia. What is its potential distribution? *The grey dung roller's potential distribution is very similar to that of the buffalo fly; it covers the tropical northern part of Australia together with most of the eastern coastline.*
4. How suitable do you think the grey dung roller is for controlling the buffalo fly, based on climate? *Since their distributions are so similar, very suitable - both should survive in similar areas, so where the fly has been established, the grey dung roller should also be able to become established.*
5. What effect will the increasing Greenhouse effect have on the distribution of the buffalo fly and the grey dung roller? *The grey dung roller's distribution increases on the east coast, around Perth and Tasmania, while decreasing in northern Australia. The buffalo fly's distribution changes in a similar way but not to the same extent.*
6. Does the increasing Greenhouse effect appear to change the prospects of the grey dung roller for controlling buffalo fly? *No, there are not significant areas suitable for the buffalo fly that are not suitable for the roller.*
7. (For further research) What precautions should be taken before introducing a new species into another country? *Some ideas: will it flourish in areas beyond where it is needed for control? Does it exclusively feed on the species it is being used to control? Is it poisonous to possible native predators? How is it being brought into the country - could it be carrying diseases?*

Tutorial 6. Quarantine 1.

1. Use CLIMEX to estimate what parts of Africa are susceptible to the wheat aphid: *Mainly South Africa and the Mediterranean coast.*
2. Australia's wheat belt is a narrow crescent stretching in a curve from central Queensland through New South Wales, Victoria and South Australia. It continues around the south-west of Western Australia. (See figure 1.) How favourable is this area for the wheat aphid? *Very favourable - the potential distribution of the wheat aphid is almost identical to the wheat belt. This is why the introduction of the wheat aphid could be disastrous to the wheat industry.*
3. You are a quarantine officer in the Department of Primary Industries. Wheat aphids have been reported in Darwin. You have CLIMEX for your use. What action would you take? Explain: *Wet stress for the aphid is extremely high in Darwin - the aphid would not survive the wet season, although it could briefly survive during the spring. Another factor is that wheat is not grown in Darwin or any where near Darwin for hundreds of kilometres. You should monitor the situation and ensure that any aphids found were destroyed, however the chances of aphids escaping out of the Darwin areas to the wheat areas of Australia is remote. You would also need to check that the aphid could **not** survive on an alternative host plant, which would then allow it to form a permanent infection focus for northern Australia.*
4. Why are areas right on the coastline of eastern Australia unfavourable for the aphid? *Wet stress on the coastline is too great to allow survival.*
5. A similar situation to Question 3 has occurred in Brisbane, during September. Although Brisbane is generally unfavourable, what problems can you see? How far is Brisbane from very favourable areas? *During September and October, the aphid could flourish in the Brisbane region. Brisbane is also very close to drier areas that are favourable for the aphid, such as Amberley, or Warwick. It would not be difficult for wheat aphids to be dispersed in these areas and then it could travel into the Darling Downs areas - a prime wheat growing region. You would need to take action immediately to destroy the aphids if that is possible and you would probably try to quarantine the region.*
6. Looking only at the map above and not running CLIMEX, what do you think are the climatic preferences of Siam weed and where do you think it will survive in Australia? *Prefers hot wet tropical conditions but will probably survive at milder coastal locations with high rainfall based on its distribution through southern China. In Australia, Siam weed will survive primarily in the tropical regions of the Northern Territory, Western Australia and Queensland but also on the coastal zones of Queensland and NSW as far south as Sydney.*
7. Run the CLIMEX prediction for Siam weed in Australia. What agricultural industries and conservation areas are threatened by the potential distribution of the weed? *Agricultural industries would include cattle, sugar cane, tropical fruits, forestry and horticulture. Conservation areas at risk include Cape York, Daintree World Heritage area, Kakadu, National Parks throughout SE Queensland and Northern NSW could all be threatened. Conservation areas are most at risk if the parks have been disturbed before the weed was introduced. Disturbances can occur from cyclones, pests such*

as wild pigs, goats, rabbits, horses and buffalo, bushfires, high levels of tourism or clearing (for building, campsites etc.) Undamaged rainforests and dense eucalypt forests are at less risk because Siam weed requires direct sunlight to survive.

8. Siam weed has spread south and east from Asia through the islands of Indonesia to Irian Jaya and Papua New Guinea. Machinery, humans and animals spread the seeds. What is the likely threat of Siam weed being introduced from PNG or nearby islands? What can the government do about it? *The spread of Siam weed (along with a huge range of potential pests) is very likely to come from Australia's northern neighbours. The Australian mainland is only 30km from a chain of islands that run through to Papua New Guinea. Islander communities use canoes and boats to travel between these islands carrying goods and livestock. It is only be a matter of time before seed is carried over.*

The Australian Quarantine Inspection Service (AQIS) is very aware of this problem and has a strong presence in the area. They face a huge problem covering this vast area from a number of stations spread out over thousands of miles of coastline. The cost of running continuous surveillance using aircraft, boats and vehicles is too great to maintain. One of their most important tasks is to educate these communities on the importance of quarantine controls to protect themselves and Australia from further pest introductions.

Tutorial 7. Quarantine 2.

1. Use CLIMEX to describe the climatic conditions preferred by the screw-worm fly. *Warm and wet conditions.*
2. In November and December of 1987, screw-worm flies were intercepted in Sydney. How likely is it that the fly could become established in Sydney and why do you make this assessment? *There is only a low possibility of permanent establishment because Sydney is too cold (see cold stress index and examine the graph for the species at Sydney), although during warmer months it is possible, particularly if it was a warm year. The possibility would then exist for the fly to be transported to more favourable areas.*
3. In April 1988 screw-worm flies were intercepted in Darwin harbour. Comment on the risk of establishment of the fly: Darwin has an EI of 14 for the screw-worm fly, which is adequate - the risk of establishment is correspondingly high.
4. Does an increased Greenhouse effect alter the answers you have given for questions 2 and 3? *Yes, Sydney becomes quite favourable for the screw-worm fly, and Darwin even more favourable. The risk of establishment in the Sydney region has grown substantially.*
5. Screw-worm fly was introduced to countries in the Persian Gulf via a ship load of live sheep from Western Australia in 1980. **There has never been a screw-worm fly outbreak in Western Australia.** Use CLIMEX to help you explain this anomaly. (**Hint:** consider the most direct route used by a ship that would take it from Australia to the Persian Gulf.). *Screw-worm fly is found extensively in the Indian sub-continent and at least some flies are blown out to sea by coastal winds. Unfortunately, the ship load of sheep was like a homing beacon to the flies, which then attacked the sheep. One would presume that all future ships stayed well out to sea from the Indian coastline.*
6. Although the screw-worm fly reached Darwin (see Question 3), it did not become established. This is despite the fact that the location has adequate Ecoclimatic Index. Can you suggest a reason as to why this happened? (**Hint:** Look at the graphical display of the monthly meteorological data and the Growth, temperature/moisture/heat stress indices for Darwin). *Even though the EI is adequate in Darwin, the GI tapers off in May, meaning that reproduction cannot occur for some time. This could mean that introduced flies die before a population can be established, especially during low GI periods. In 1988 in fact the rains finished a month early making establishment more difficult.*

Tutorial 8 Limitations of Scientific Models

1. On what two sets of data does CLIMEX base its predictions? *Meteorological data from different locations, and data about the particular species being mapped. These are compared using a series of equations to find the overall favourability of a given location for a certain species.*
2. How do you think the scientists who designed CLIMEX collected all the information? *Meteorological data from the Bureau of Meteorology, species data from scientific journals and other published material, and data collected from field trips and experiments.*
3. What errors do you think there could be in the data that CLIMEX uses or in the way CLIMEX processes that data? *Meteorological data could easily be incorrect or incomplete, species data could be incorrect or slightly inaccurate. The equations used in the model itself are approximations only - CLIMEX aims to produce a useful, working hypothesis for a species potential distribution.*
4. What is the main assumption CLIMEX uses to make its predictions? *CLIMEX assumes that climate is the major factor affecting the distribution of a species.*
5. What other factors could affect a species geographical distribution besides climate? *Available food supply, predators, local conditions such as swamps or pollution, cross-breeding with other species in the area, dispersal by wind, available water supply (not necessarily determined by rainfall), human impact, physical aspects of the habitat (eg. some species prefer shade for most of the day), soil, disease..... there are probably others you could think of.*

Tutorial 9. Changing Species Responses

1.
 - a. What stress makes central Australia unfavourable for the cattle tick? *central Australia is mainly too dry for the cattle tick, although cold stress is still significant.*
 - b. southern Australia? *Southern Australia is unfavourable mostly due to cold stress, but dry stress does have an effect as well.*
2. Change the species parameters so that southern Australia, including Tasmania, is also favourable for cattle tick. Note your final values. *Temperature parameters need to be altered to make southern Australia more suitable. Try decreasing lower limiting temperature (eg 10°C), decreasing lower optimal temperature (eg. 15°C) and decreasing day-degree threshold (eg. 9). These changes should be done one by one, not all at once. These values are suggestions only - a wide variety of parameter changes will make southern Australia suitable.*
3. Change parameters so that central Australia is also favourable for cattle tick. Note your final values. *Decreasing the dry stress threshold (eg. 0.10) is effective in making central Australia more suitable for the cattle tick.*
4. Examination of the distribution of the tiger snake. Alter parameter values so that coastal Queensland up to the Rockhampton area, and all of coastal New South Wales, are now favourable. You should initially map stress indices to decide what parameters to alter. Note your final values. *Mapping stress values for the tiger snake indicates that heat stress is the main obstacle to being established on the northern New South Wales and southern Queensland coast. Increasing the limiting high temperature and the upper optimal temperature to values similar to the temperatures experienced in these regions is a good start. (eg 30°C, 35°C respectively). Increasing the heat stress day-degree threshold will also help (eg. 120). Remember that parameters should be altered one at a time.*

Default Values for CLIMEX Templates

Parameter Group	Parameter	Wet Tropical Template	Mediterranean Template	Temperate Template	Semi-arid Template	Desert Template
Temperature Index	DV0	15	10	8	14	15
	DV1	26	16	18	28	25
	DV2	33	24	24	36	40
	DV3	36	28	28	40	44
	PDD	0	600	600	0	0
Moisture Index	SM0	0.3	0.1	0.25	0.05	0
	SM1	0.5	0.4	0.8	0.1	0.001
	SM2	1.75	0.7	1.5	0.4	0.2
	SM3	2.0	1.5	2.0	0.6	0.3
Cold Stress	TTCS	0	0	0	6	2
	THCS	0	0.005	0	0.01	0.001
	DTCS	25	15	25	15	15
	DHCS	0.0015	0.001	0.0001	0.0002	0.0005
Heat Stress	TTHS	36	30	30	40	44
	THHS	0.001	0.002	0.005	0.002	0.001
	DTHS	0	0	0	0	0
	DHHS	0	0	0	0	0
Dry Stress	SMDS	0.3	0.02	0.2	0.05	0
	HDS	0.006	0.05	0.005	0.005	0
Wet Stress	SMWS	2.0	1.6	2.0	0.6	0.3
	HWS	0.002	0.0015	0.002	0.005	0.1
Hot-Wet Stress	TTHW		23			
	MTHW		0.5			
	PHW		0.075			

Table 1. Parameters templates, representative of different geographical distributions, that are provided with CLIMEX.

Template for CLIMEX Species Report

Name:

Biology:

Distribution:

CABI CPC Ref: etc

Comments and literature review related to fitting CLIMEX parameters

Distribution records used to estimate CLIMEX parameter values

Citations

Evidence for non-climatic limits to distribution

Physical barriers

Hosts

Vectors

Other species

Artificial environments (eg irrigation or glasshouses)

Stress indices

Hot

Cold

Dry

Wet

Climatic Constraints

Obligate diapause

Length of growing season

Growth

Temperature

Moisture

Results

Goodness of Fit

Independent Validation

Source Risks

Geographical

Seasonal

Destination Risks

Geographical

Seasonal

Discussion

References