14. Implementing a Simple Biospheric Feedback Model: 'Daisy World'

14.1. Preamble

The Daisy World model is intended to illustrate a mechanism through which — according to the Gaian hypothesis — biota might optimize their abiotic environment by means of negative feedback. The model does not attempt to describe all of the possible mechanisms and feedbacks which might influence the ways in which the plants and climate develop. Instead, it is an *heuristic* model — one that seeks to describe the ways in which this mechanism *might* work. The original model was developed by Watson and Lovelock (1983). A full description of the model can be found in Hardisty *et al.* (1993).

You should be aware that there has been considerable, quite heated debate, about the general validity of the Daisy World model, some of which is alluded to in Hardisty *et al.* (1993). It is not necessary to be conversant with this debate in order to implement and run the Daisy World model, but it will prove helpful to have read some of the supporting literature when you come write up your report on this project (which constitutes up to 40% of the marks for this course). A set of guidelines to help you structure your report are given in Section 14.7 on page 115.

14.2. Aim and Objectives

- To implement and test a mathematical model describing the possible influence of biota on an abiotic (climatic) system using GAWK and GNUPLOT;
- To test the hypothesis the 'there exist mechanisms through which biota can influence the planetary environment'.

14.3. Description of Daisy World

The following description of Daisy World is taken from Hardisty *et al.* (1993):

> Daisy World is an imaginary planet, with a transparent atmosphere, free from clouds and greenhouse gases. The planet is flat, resulting in similar changes in temperature with changing solar luminosity (energy from the sun) and albedo being experienced simultaneously over its surface, and does not experience any seasonality in climate. The composition of the planet's biota is similarly lacking in complexity: two species of daisies occur as discrete populations; one dark (black), the other light (white) in colour. In addition a species of herbivores grazes the daisies in a non-selective manner (*i.e.,* they show no preference for black or white daisies) and is responsible for recycling of any organic material. The herbivores do not, however, exert any other measurable effect on the system and are thus are not further considered here. Conditions on Daisy World are suitable for the growth of daisies over the entire surface of the planet.

14.4. Assumptions of the Model

The model makes a number of fundamental assumptions about the functioning of the system, namely:

1. The rate of population change for both species of daisy depends on the death rate and the potential birth rate for that species, and the amount of fertile land available for growth;
2. The birth rate for both species of daisy depends on the local temperature;
3. The local temperature depends on the difference between the global and local albedo, and on the global temperature;
4. The global temperature depends on the luminosity of the Sun and the planetary albedo;
5. The planetary albedo is the sum of the local albedo components (*i.e.*, the albedo of the black and white daisies and of the bare ground);
6. The amount of fertile land available for further growth of the black and white daisies depends on the total amount of fertile land (fixed) and the current coverage the two species of daisy.

14.5. Graphical Representation of the Daisy World Model

The basic functioning of Daisy World is shown graphically in Figure 14.1.

14.6. Mathematical Formulation of the Daisy World Model

The Daisy World model can be represented in mathematical terms by means of the following formulae:

1. The amount of fertile land available for daisy growth is given by:

$$x = [P - (a_b + a_w)] \tag{14.1}$$

   where

x	is the amount of available land,
P	is the proportion of land available for growth (default $P = 1.0$),
a_b	is the area of black daisies ($a_b = 0.2$ initially), and
a_w	is the area of white daisies ($a_w = 0.2$ initially).

2. The total (overall) albedo for the planet (albedo is the amount of radiation out divided by the amount of radiation in) is given by:

$$A = x(A_g) + a_b(A_b) + a_w(A_w) \tag{14.2}$$

   where

A	is the albedo of the planet,
A_g	albedo of bare ground (default $A_g = 0.5$),
A_b	albedo of black daisies (default $A_b = 0.25$), and
A_w	albedo of white daisies (default $A_w = 0.75$).

3. The globally-averaged temperature of the planet is given by:

$$T_e = \left(\frac{SL(1 - A)}{s}\right)^{0.25} - 273 \tag{14.3}$$

   where

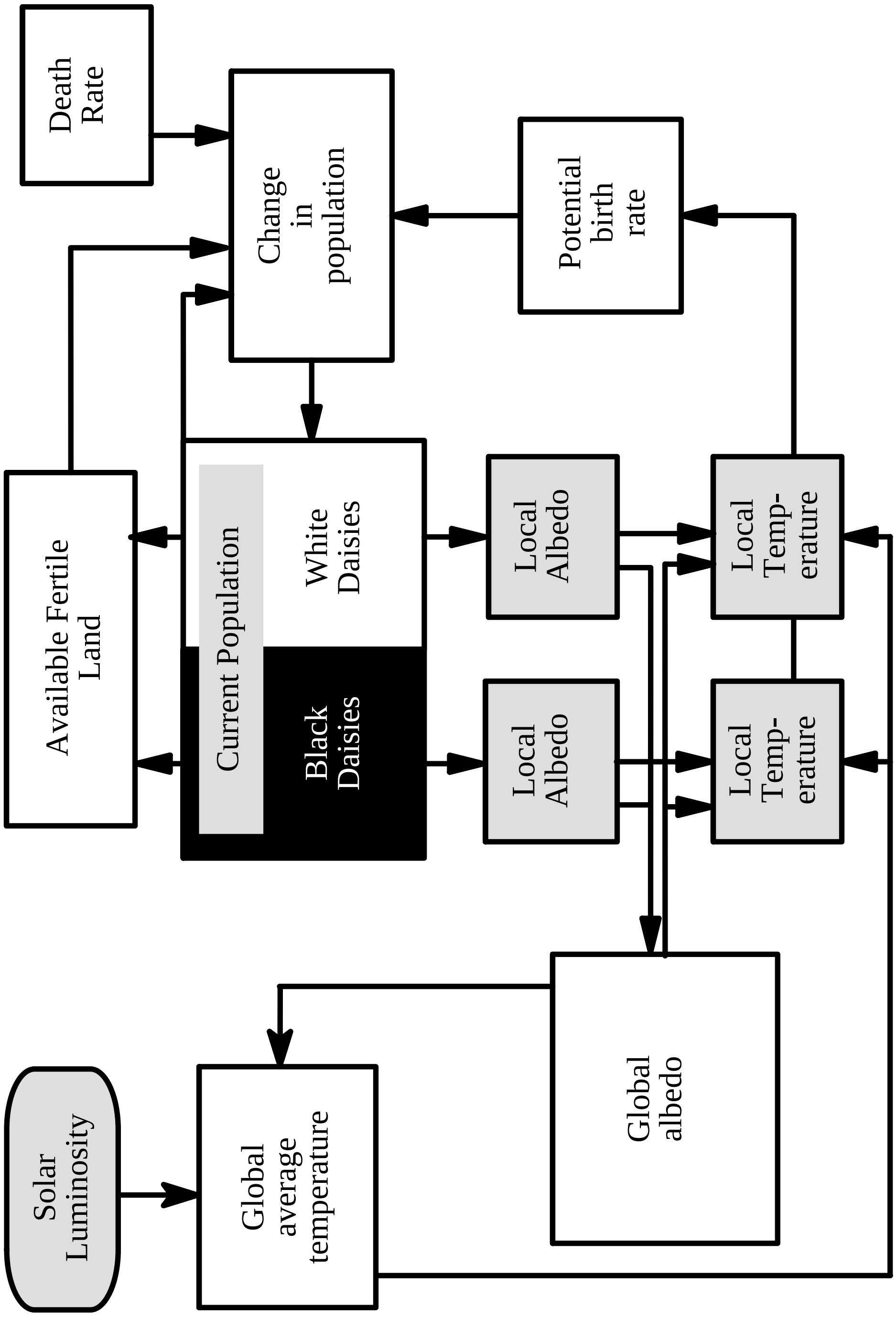

Figure 14.1.: Graphical representation of the functioning of the Daisy World model.

T_e	is the globally-averaged temperature,
S	is a solar constant (energy from the sun; default $S = 1000$),
L	is the solar luminosity (proportion of present day value; 0.7 initially, but increasing in steps of 0.025), and
s	is Stefan's constant (5.67×10^{-8}).

4. The local temperatures for populations of black and white daisies are:

$$T_b = (q(A - A_b) + T_e) \tag{14.4}$$
$$T_w = (q(A - A_w) + T_e) \tag{14.5}$$

where

T_b	is the local temperature of black daisies,
T_w	is the local temperature of white daisies, and
q	is a constant used to calculate local temperature as a function of albedo (default $q = 20$).

5. The growth rate of the populations of black and white daisies is given by:

$$B_b = \left\{1 - \left[0.003265\,(22.5 - T_b)^2\right]\right\} \tag{14.6}$$
$$B_w = \left\{1 - \left[0.003265\,(22.5 - T_w)^2\right]\right\} \tag{14.7}$$

where

B_b	is the growth rate for black daisies,
B_w	is the growth rate for white daisies and
1, 0.003265 and 22.5	are all constants so that growth occurs between $5°C$ and $40°C$ and peaks at $22°C$.

6. The change in area of black and white daisies over time is given by:

$$\frac{da_b}{dt} = (a_b(xB_b - y)) \tag{14.8}$$
$$\frac{da_w}{dt} = (a_w(xB_w - y)) \tag{14.9}$$

where

da_b	is the change in area of black daisies[1],
da_w	is the change in area of white daisies,
y	is the death rate (default $y = 0.2$), and
t	is time.

7. The new area of black and white daisies is given by:

$$a_b = \left(\frac{da_b}{dt} + a_b\right) \tag{14.10}$$
$$a_w = \left(\frac{da_w}{dt} + a_w\right) \tag{14.11}$$

where

a_b	is the new area of black daisies, and
a_w	is the new area of white daisies.

[1]Note that $\frac{da_b}{dt}$ means the change in area of black daisies over a given period of time (dt). It does **not** mean that you should divide the change in area of daisies by the change in time.

14.7. Assignment

You are required to produce a written report on your work to implement the Daisy World model in GAWK and to test the resulting implementation. The report should contain the following elements:

1. An executive summary (one page);
2. An introduction to the Daisy World model and its assumptions;
3. A discussion of the computational methods (*e.g.*, assignments, loops, functions[2]) used in your implementation of the Daisy World model;
4. An explanation of the results obtained from your implementation of the Daisy World model. The discussion should make use of example graphs where appropriate and should include a short sensitivity analysis[3] of the model (*e.g.*, by varying the albedo values of the black and white daisies, or by including an additional species of daisy having different albedo values);
5. A brief comparison of the results obtained using Daisy World with those obtained using the Energy Balance Climate Model (EBCM)[4];
6. A list of references, as appropriate; and,
7. An appendix containing the GAWK code used in your implementation of the model, with line numbers appended.

14.8. Tips

- When converting the formulae presented above for the Daisy World model into GAWK code, work a line at a time. Make sure each new line of code that you add is working before proceeding to the next line.
- Rename each new version of your code (*e.g.*, `daisy1.awk`, `daisy2.awk`, ... `daisy6.awk`), keeping copies of the the previous versions as back-ups. That way, if you do make a mistake, you will be able to back-track to a previous, working programme.
- Be careful about the names you assign to variables. Use variable names that mean something to you (*e.g.*, `area_black_daisies` in preference to `ab`): the small amount of extra typing will be more than rewarded by the ease with which you will be able to spot mistakes in the code. Remember that, as far as GAWK is concerned, `Area` and `area` are different variables.
- Don't panic if your program doesn't appear to work. Calmly go back over the code to look for mistakes. Remember that GAWK, like all computer programming languages, requires you to type the code in exactly as expected.

14.9. Deadline

Your report should be handed in to the Departmental Office no later than 3.30pm on the final day of the spring semester.

[2]Note that the use of functions will be covered in next week's lecture and practical.
[3]Note that sensitivity analysis will be covered in the lecture and practical delivered two weeks time.
[4]Note that this model will be covered in two weeks time.

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