Modeling the Gaia Hypothesis: Daisyworld

Phillipa Sessini

Outline

- Gaia Hypothesis
- Daisyworld Model
- Results
- Future Directions
- Conclusions

Gaia Hypothesis

- Proposed by James Lovelock
  - Developed in 1960s
  - First published in 1975
- Definition of Gaia:
  - *a complex entity involving the Earth's biosphere, atmosphere, oceans, and soil; the totality constituting a feedback or cybernetic system which seeks an optimal physical and chemical environment for life on this planet.* (Lovelock)

Daisyworld Model

- Daisyworld is a hypothetical planet orbiting a sun that increases in intensity
- The planet is inhabited by 2 species
  - Black daisies
  - White daisies
- Original Daisyworld model consisted of a system of differential equations
  - This project uses these equations to build a 2D cellular automata representation of Daisyworld

Daisyworld Model (2)

- Temperature of Daisyworld is based on the assumption that the planet is in radiative equilibrium (i.e. energy emitted = energy absorbed)

$$T_p = \sqrt[4]{\frac{S \times L(1-\alpha_p)}{\sigma_{SB}}}$$

- Albedo of the planet is computed based on the albedos of each type of daisy and the area covered by them

$$\alpha_p = a_{un}\alpha_{un} + a_b\alpha_b + a_b\alpha_b$$

Daisyworld Model (3)

- Area of daisies is modified according to the following equations

$$\frac{da_s}{dt} = a_s(a_{un}g_s - deathrate) + 0.001$$

$$g_s = 1 - \frac{4}{(40-5)^2}(22.5 - T_s)^2$$

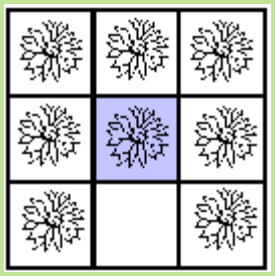
$$T_s = F_{HA}(\alpha_p - \alpha_s) + T_p$$

Daisyworld Model (4)

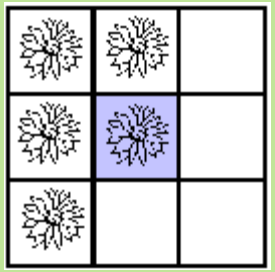
- 2D CA rules:
  - If da/dt > 0
    - If neighbors with no daisies < spreading threshold
      - » Bare neighbors grow daisy with probability: p = c*da/dt
    - Else if neighbors with no daisies >= spreading threshold
      - » Start new patch of daisies
  - If da/dt <= 0
    - Daisies die with probability p = -da/dt

Example of Daisy Crowding

- Spreading-threshold = 6



=> Start new patch of daisies



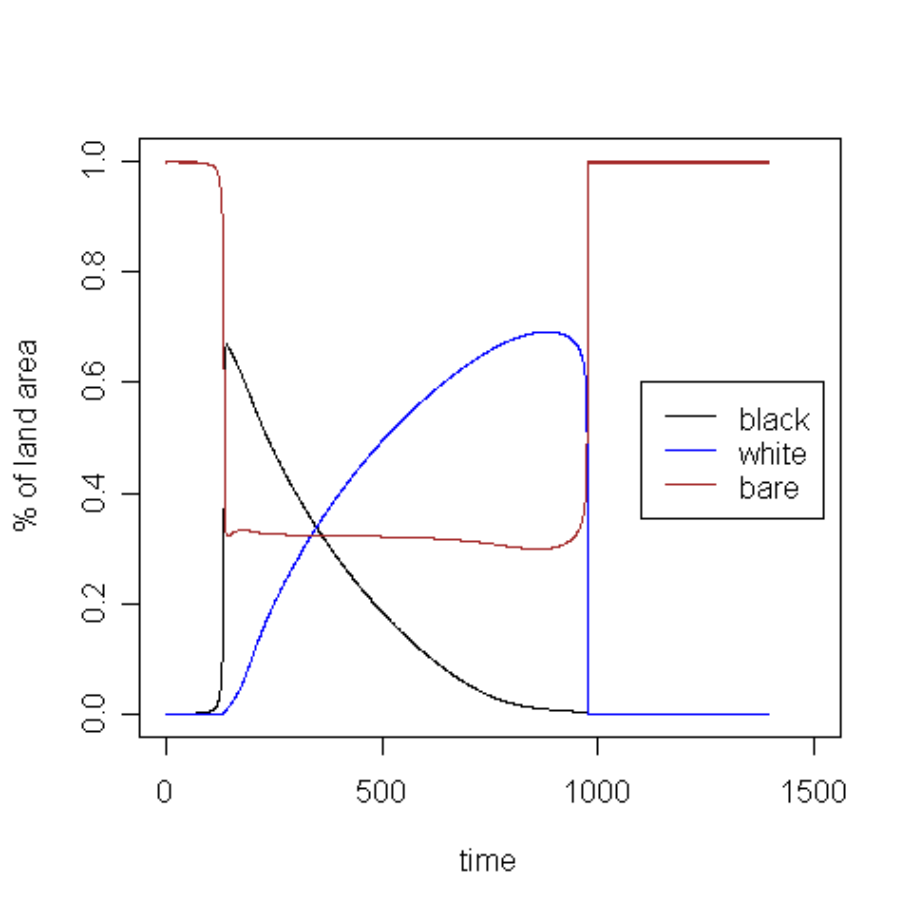
=> Don’t start new patch

Parameter Settings

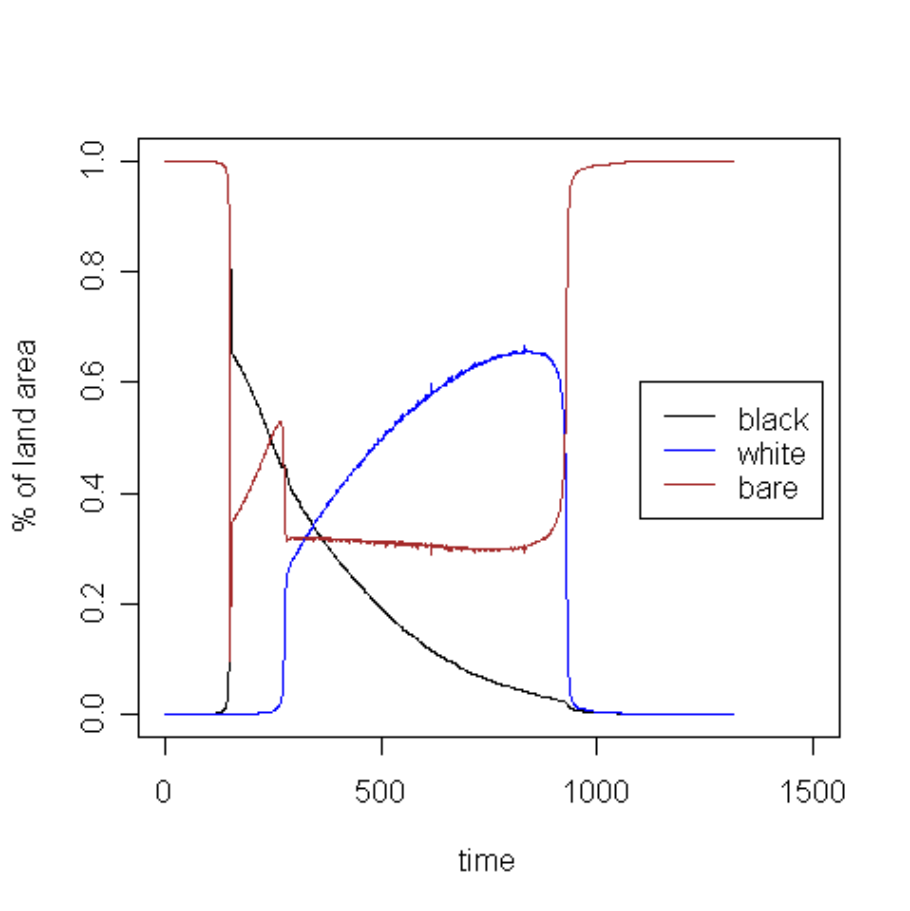
- Two different temperature models
  - Automatic linear increase of solar luminosity
  - Manual adjustment of solar luminosity
- Death-rate: 0.3
- Albedo of white daisies: 0.75
- Albedo of black daisies: 0.25
- Albedo of bare land: 0.50
- Spreading threshold: 8
- Optimal daisy growth temperature: 22.5 C

Spatial Daisyworld vs. Mathematical Daisyworld

Area Occupied by Daisies



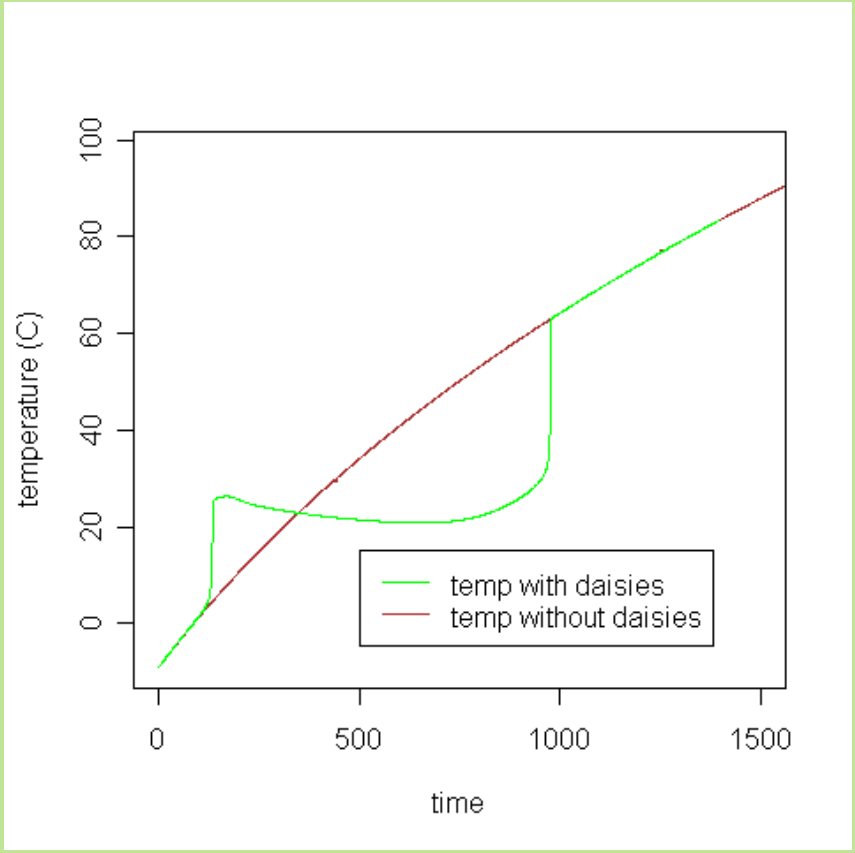
(Mathematical Model)



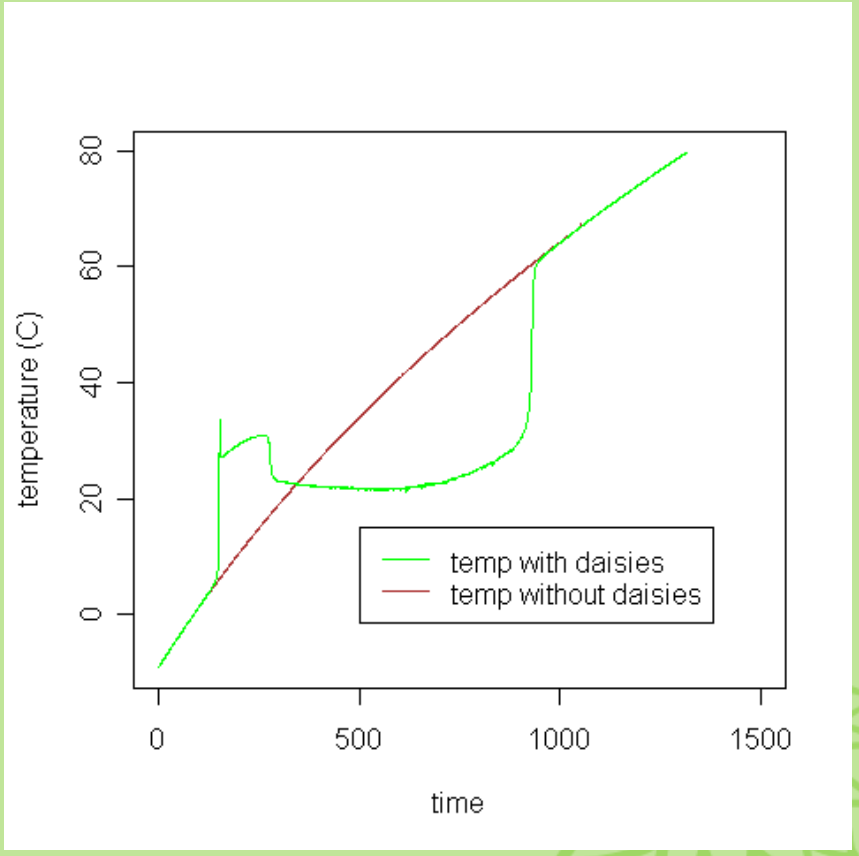
(Spatial Model)

Spatial Daisyworld vs. Mathematical Daisyworld (2)

Temperature of Daisyworld

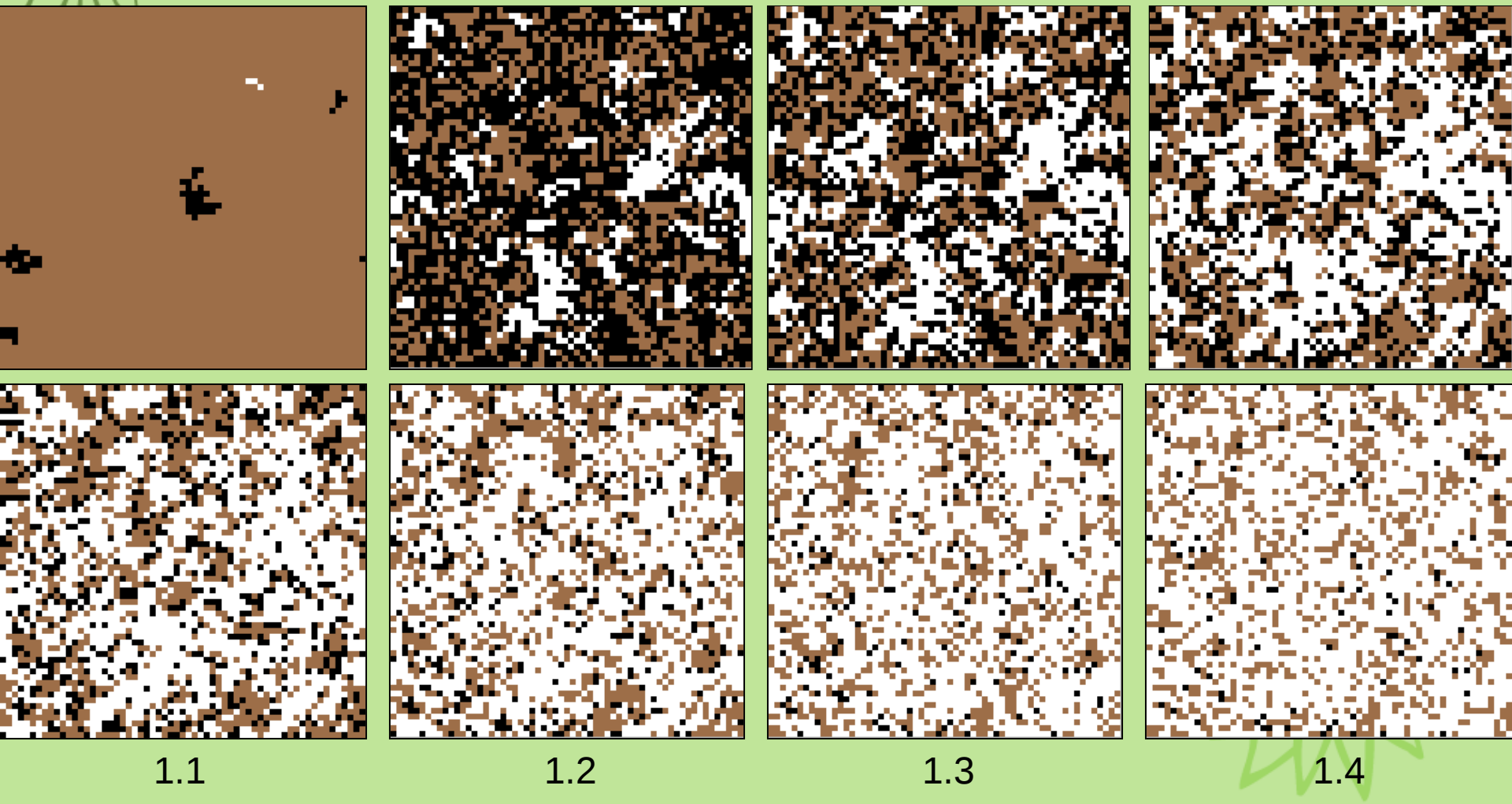


(Mathematical Model)

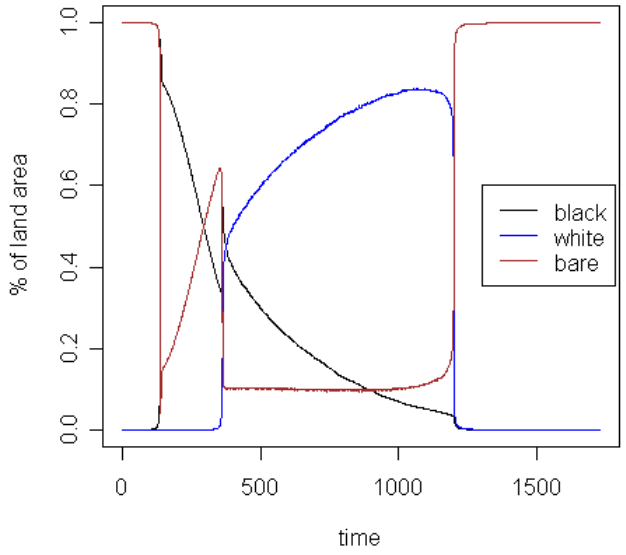


(Spatial Model)

Effects of Solar Luminosity on Daisyworld

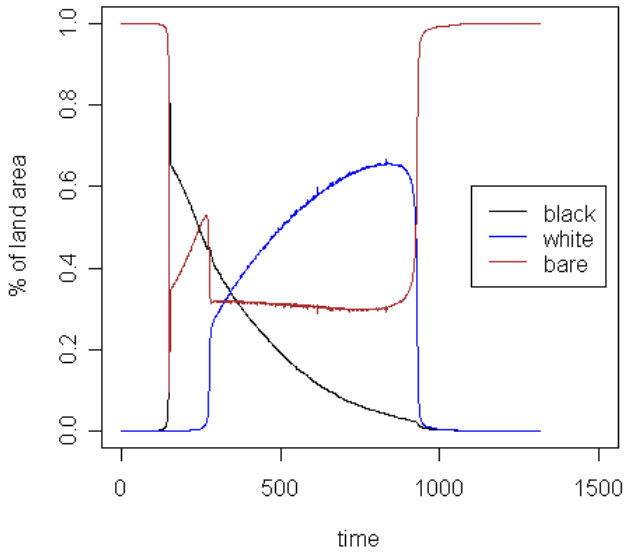


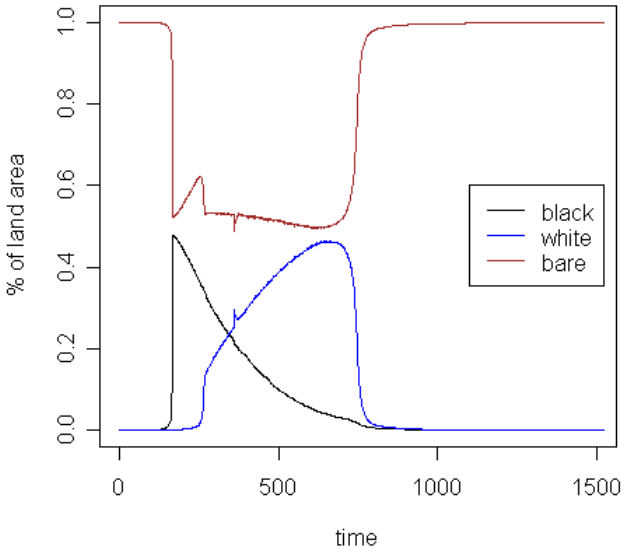
The Effects of Death Rate on Daisyworld



death-rate = 0.1

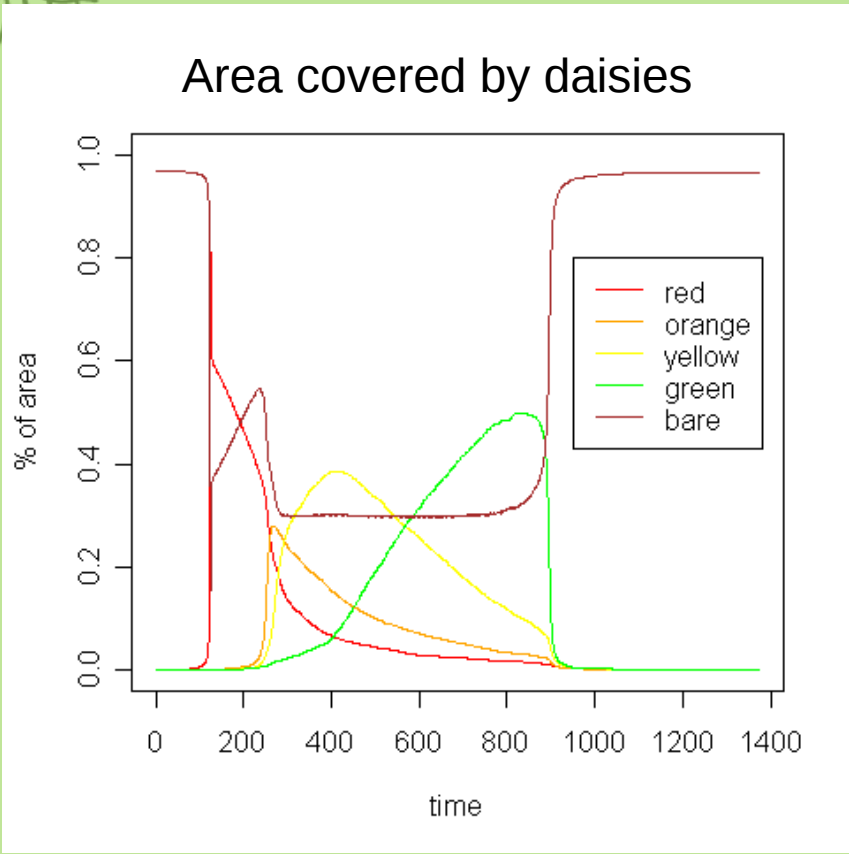
death-rate = 0.3

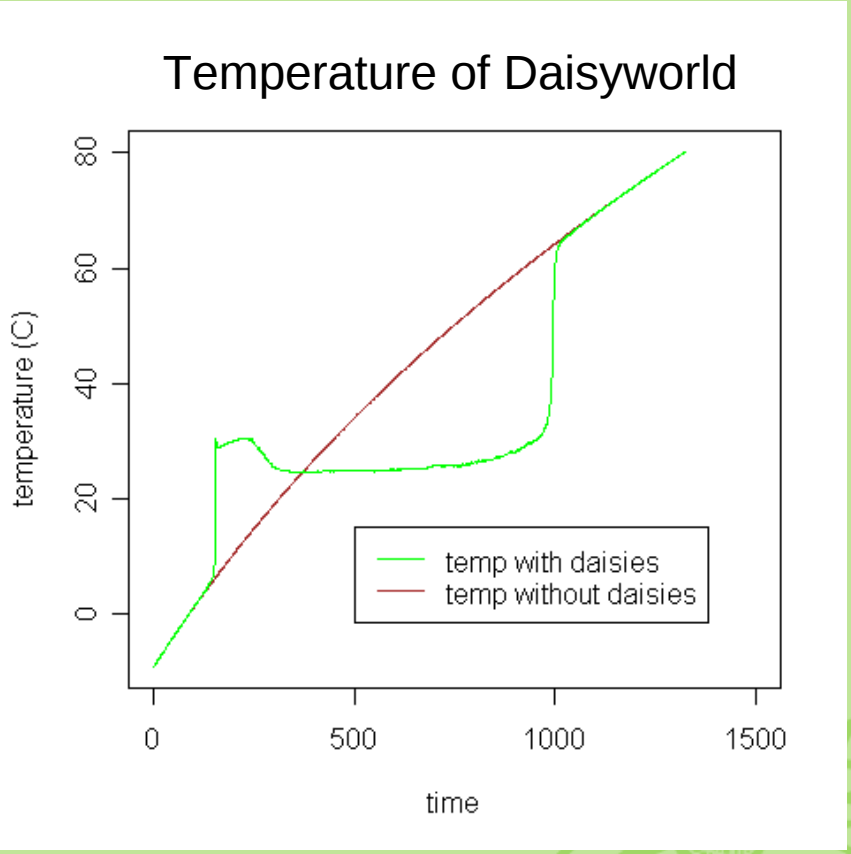




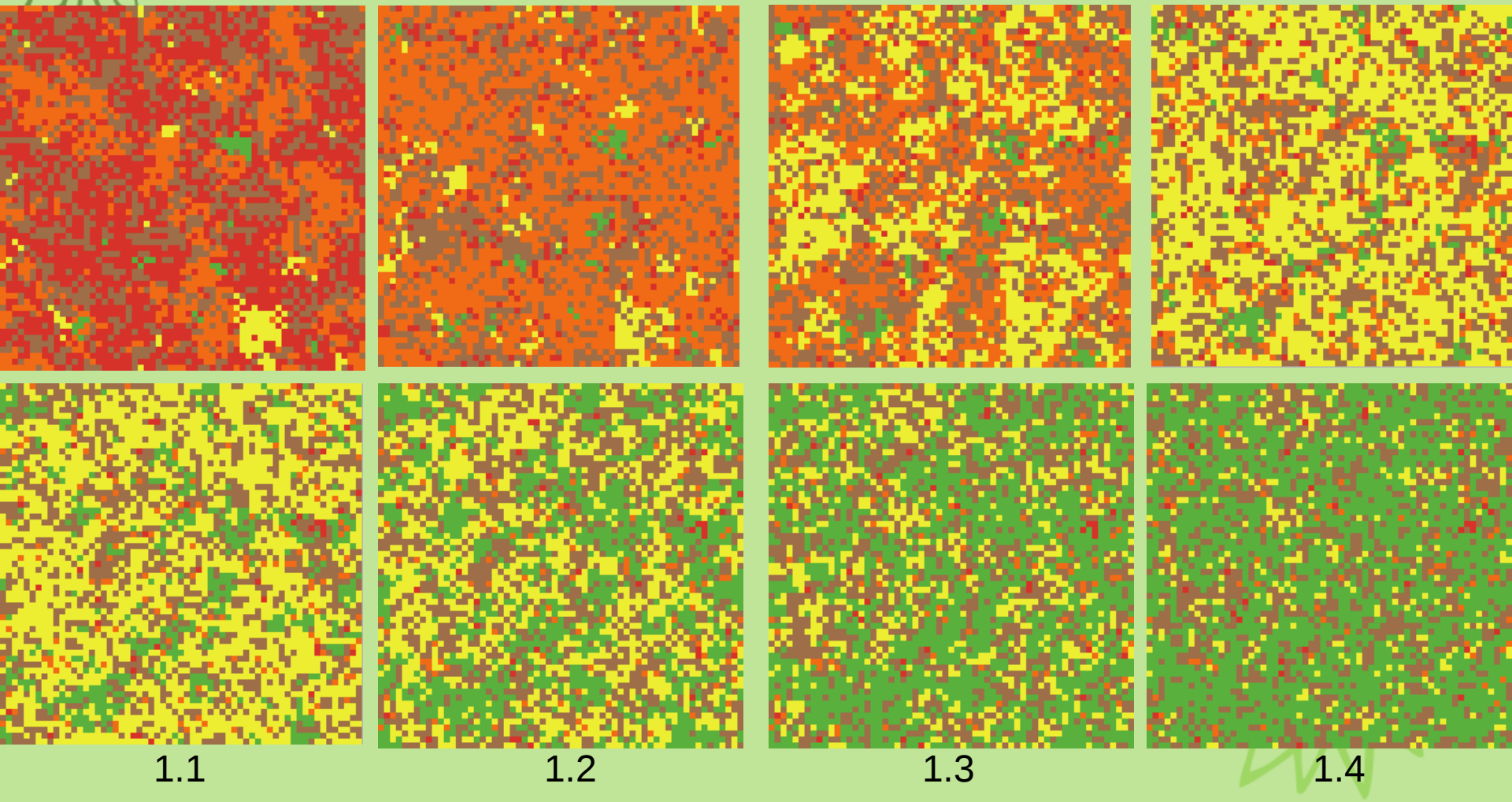
death-rate = 0.5

Daisyworld with Four Species of Daisies





Effects of Solar Luminosity on Daisyworld with Four Species



Future Directions

- Daisies with different optimal temperatures
  - Parameters for growth curve could be calculated dynamically to allow for a range of temperatures
- Evolutionary strategies for the daisies
  - Fitness based on how close their local temperature is to their optimal temperature
  - Albedo could be modified to bring the local temperature closer to the optimal temperature
- Introduction of habitat fragmentation in the form of uninhabitable patches
- Use a Moore neighborhood with r>1 to allow daisies to influence daisies further away from them

Conclusions

- 2D CA model of Daisyworld provides more insights into the effects of species on their environment
- Despite being regulated by simple feedback loops and growth rules the daisies are able to have an impact on their environment, keeping it in a state that is ideal for life

References

- [1] D. Bice. Modeling Daisyworld. http://www.carleton.edu/departments/geol/DaveSTELLA/Daisyworld/daisyworld_ . Accessed on: 01/16/2006.
- [2] W. von Bloh, A. Block, M. Parade, H.J. Schellnhuber. Tutorial Modeling of geosphere-biosphere interactions: the effect of percolation-type habitat fragmentation. *Physics A,* 266: 186-196, 1999.
- [3] G. Booth.Lovelock's DaisyWorld & the Gaia Hypothesis. http://gingerbooth.com/courseware/pages/demos.html\#daisy . Accessed on: 01/16/2006.
- [4] J. Lovelock. Gaia: A New Look at Life on Earth. Oxford University Press UK, 2000.
- [5] A. Watson, J. Lovelock. Biological homeostasis of the global environment: the parable of Daisyworld. *Tellus*, **35B**:284--289, 1983.
- [6] Wikipedia. Gaia Theory.http://en.wikipedia.org/wiki/Gaia_hypothesis

Questions?