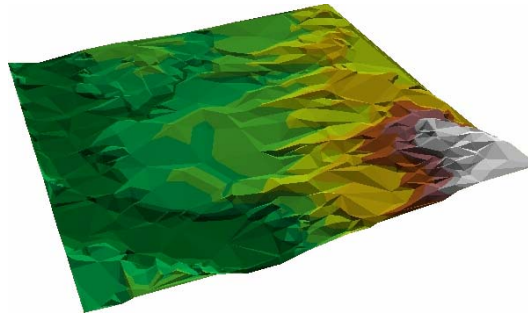


# Limits and Possibilities for Sustainable Development in Northern Birch Forests:

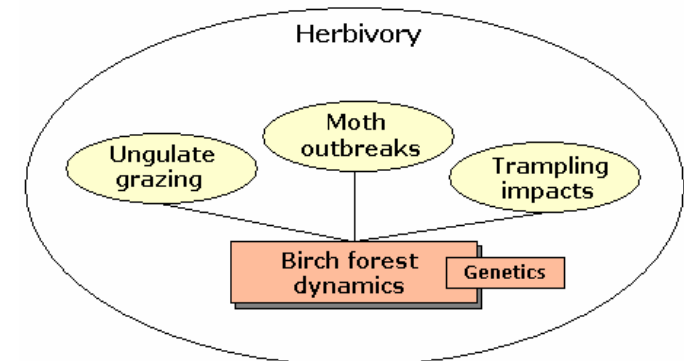
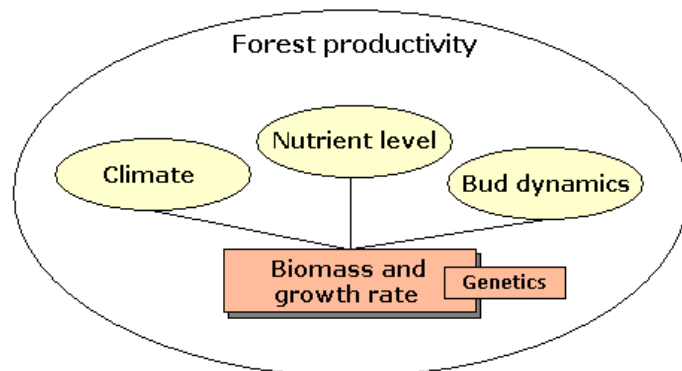
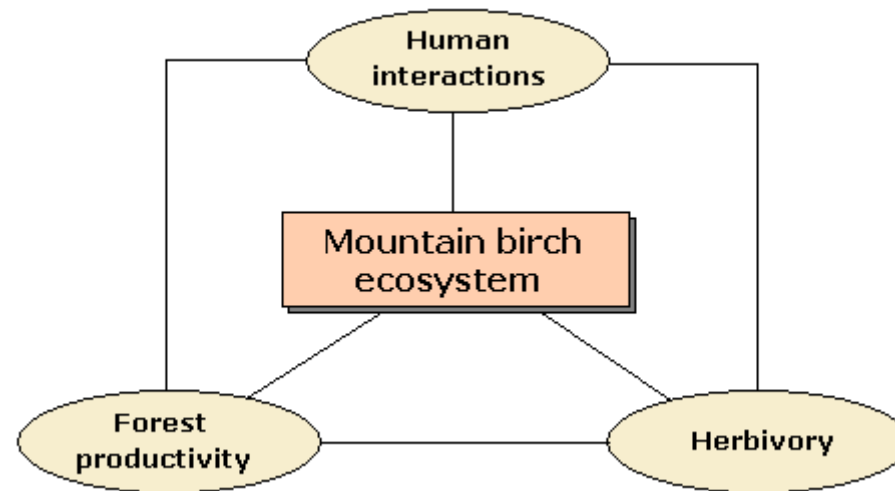
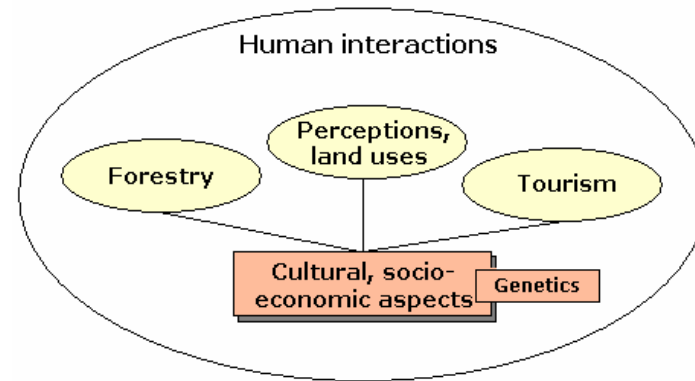
**A general landscape-scale model relating mountain  
birch forest dynamics to various anthropogenic  
influences, herbivory, and climate change**



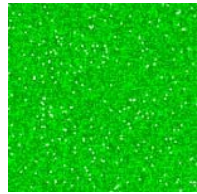
AO Gautestad, FE Wielgolaski\*, B Solberg\*\*, I Mysterud\*

\* Department of Biology, University of Oslo, Norway

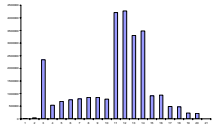
\*\* Agricultural University of Norway, Department of Forestry, Ås, Norway



# Outline



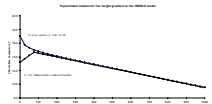
- **Introduction:** What can a model do for the HIBECO project?



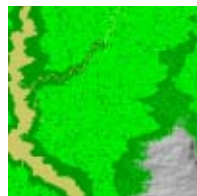
- **General model structure:** Exploring spatiotemporal birch forest dynamics under influence from forestry in a homogeneous environment



- **Adding realism I:** Age-structured forest dynamics at scale 1 Ha



- **Adding realism II:** Dynamics in a heterogeneous landscape



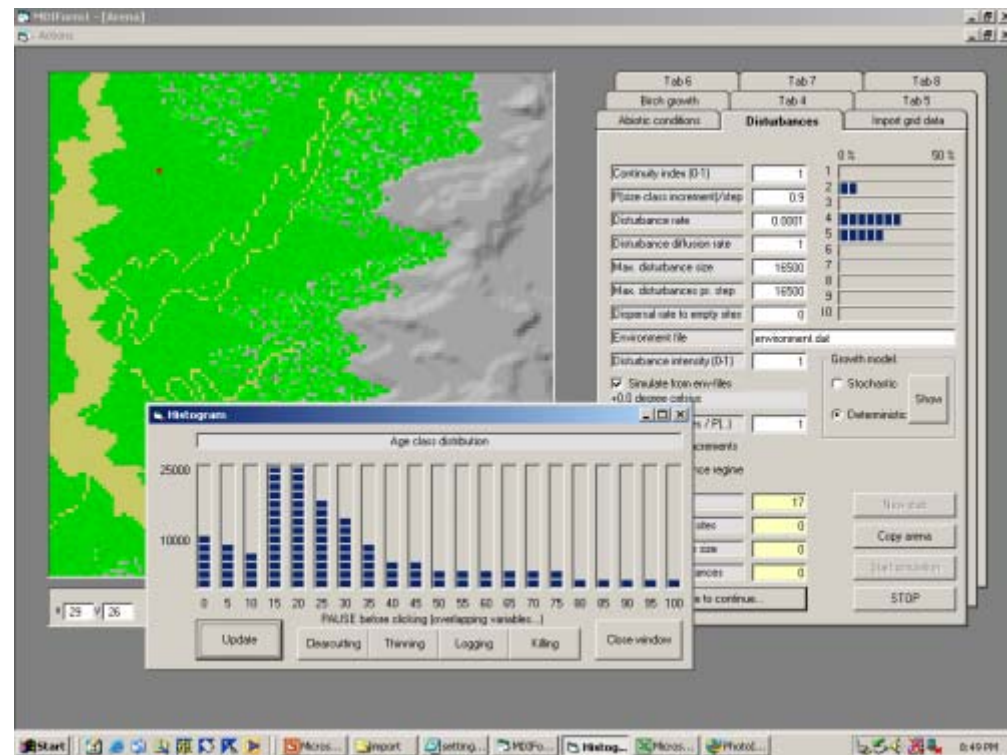
- **Adding realism III:** Climate change scenarios
- **Adding realism IV:** Influences from herbivores – grazing ungulates and leaf-eating insects

# Purpose of the model

- An instrument linking various aspects of the HIBECO project closer together
  - HIBECO is an interdisciplinary project
  - Proper modeling requires explicit qualitative and quantitative descriptions of essential variables and parameters and their dynamic interactions
- Exploring complex interactions in space and time:  
Scenarios
  - Basic scientific value
  - Practical value for management and politics: sustainable use of birch forest resources and maintenance of the northern birch forest ecosystem

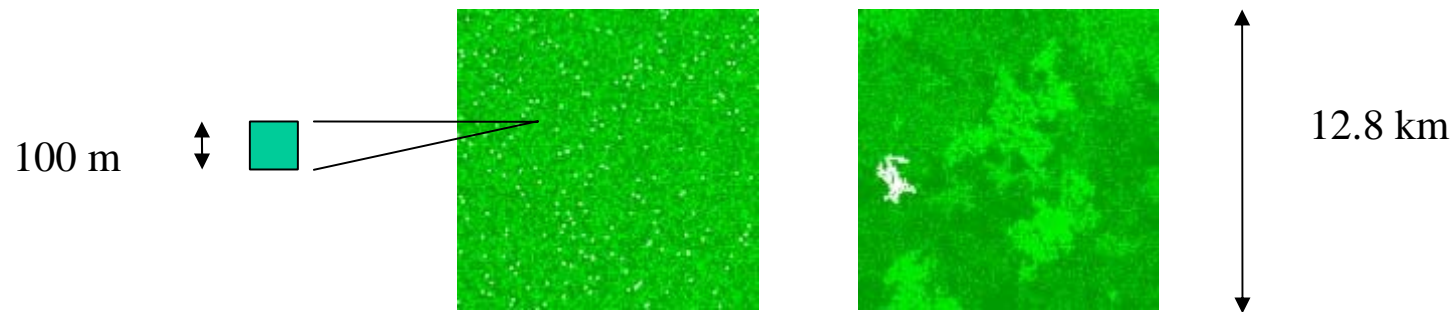
# Sustainable use of mountain birch: How can modeling make a contribution?

- Birch is a keystone species in many parts of the Northern terrestrial ecosystems
- Mountain birch forest ranges are expanding due to a warmer climate and changes in cultural use of the landscape
- Mountain birch may become an increasingly important resource in the future (forestry etc.)
- Expansion of the forest ranges also means a parallel contraction of the treeless landscapes (problems related to reindeer herding and grazing field availability).
- *Models may be used to explore long term interactions and consequences (“landscape behaviour”) under various hypothetical management regimes in virtual landscapes*



# Part 1: General Model Structure

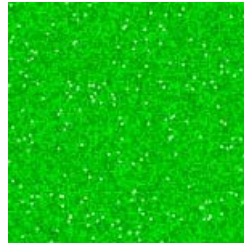
Exploring spatiotemporal birch forest  
dynamics and disturbances in a  
homogeneous environment



Pattern from intrinsic processes in  
a birch / forestry model system

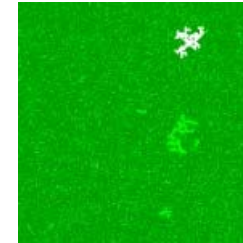
## Rules for local cell disturbances (logging events)

- Rule 1:



- At each time increment randomly choose 5% of the cells
- Reset all chosen cells dominated by old-growth stands to young stands (i.e., local logging event at 1 Ha scale)

- Rule 2:

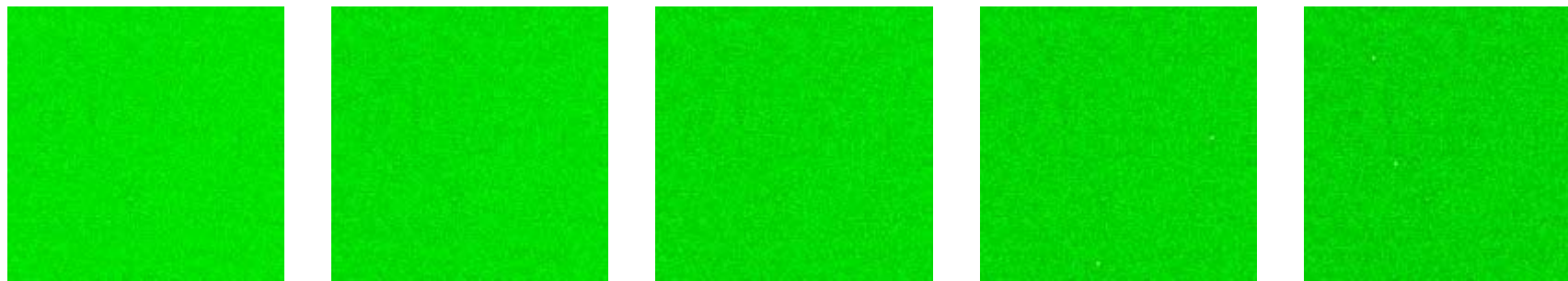


- At each time increment randomly choose **one** of the arena cells with old-growth stands
- Perform logging in this cell, and **all connected cells** with old-growth stands (i.e., logging with no spatial scale constraints up to arena size)

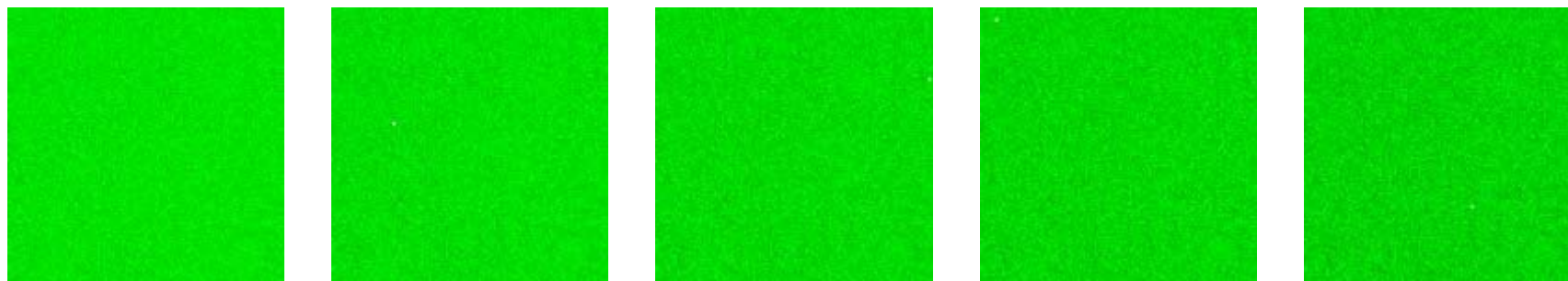


## Test: 150-year simulation

Rule 1:



Rule 2:



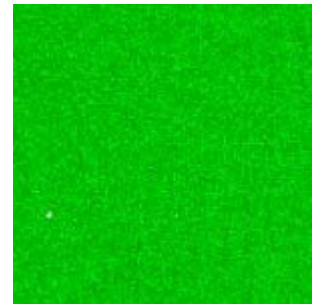
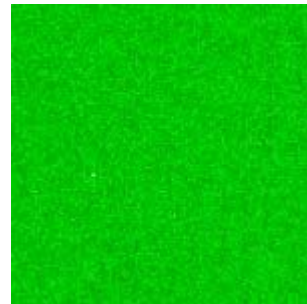
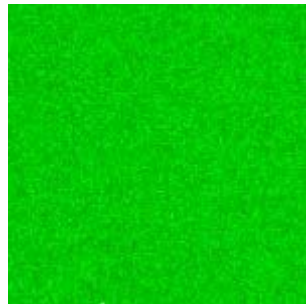
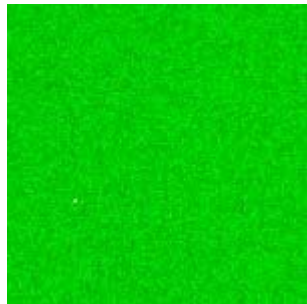
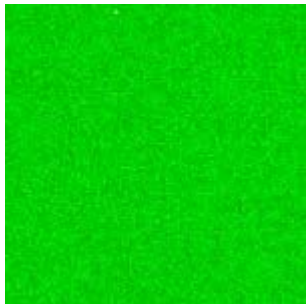
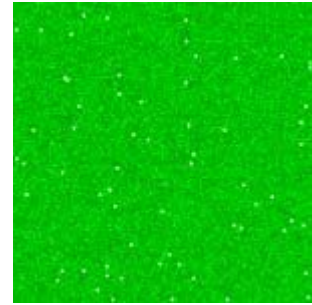
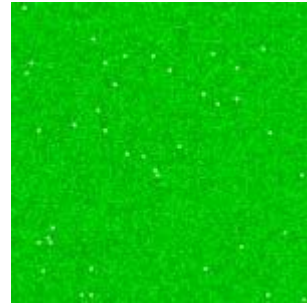
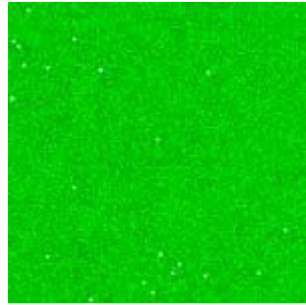
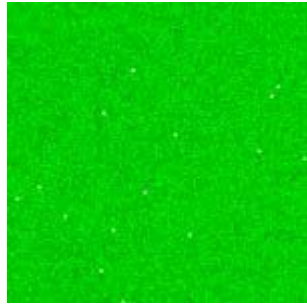
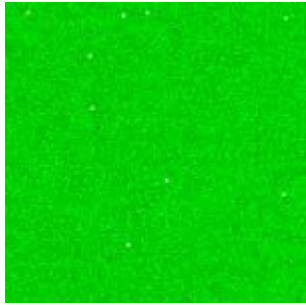
Time step: 10

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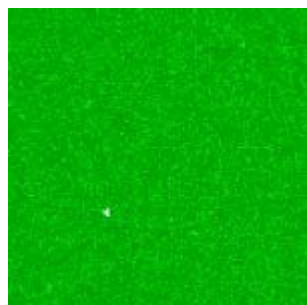
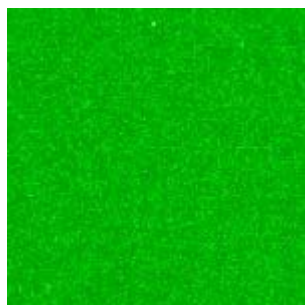
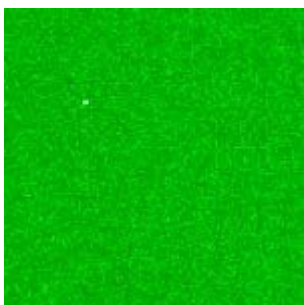
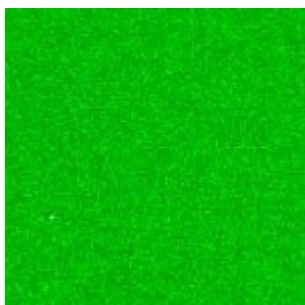
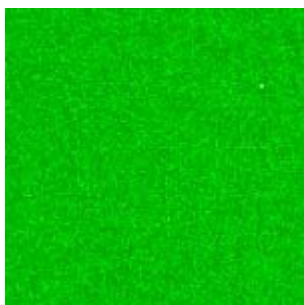
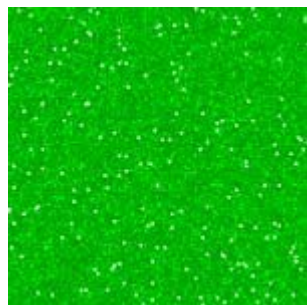
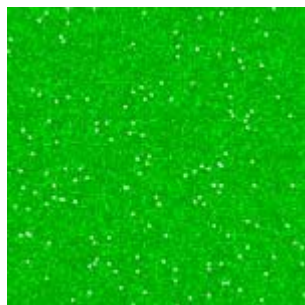
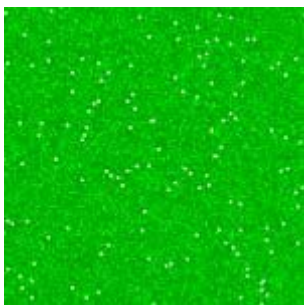
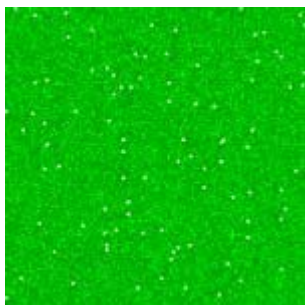
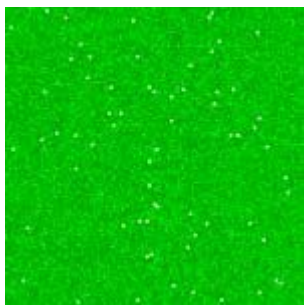
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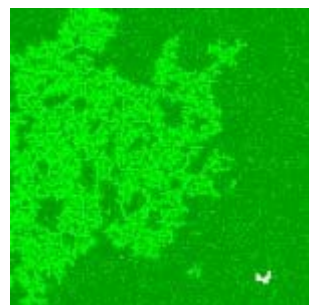
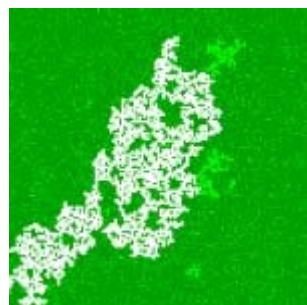
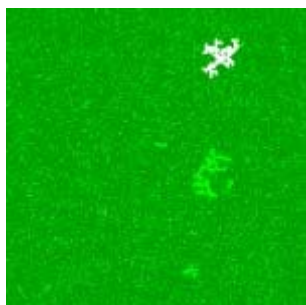
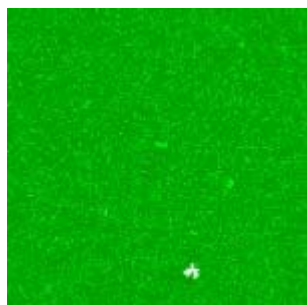
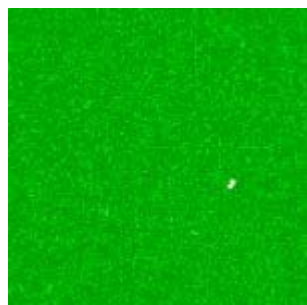
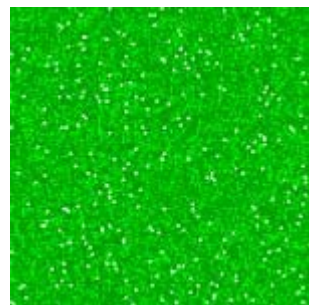
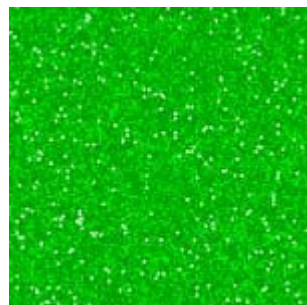
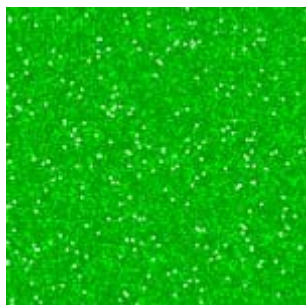
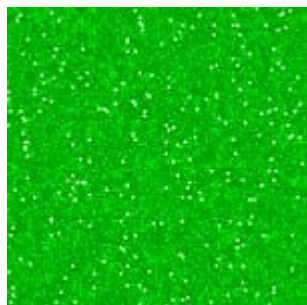
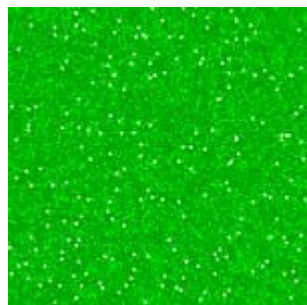
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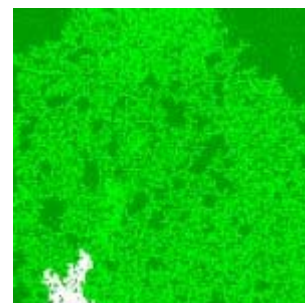
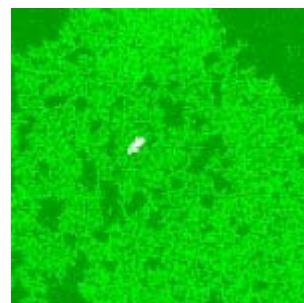
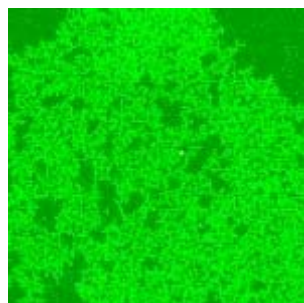
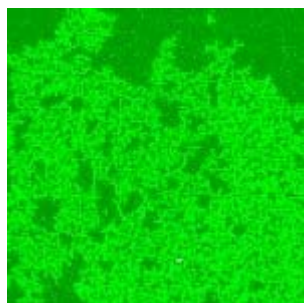
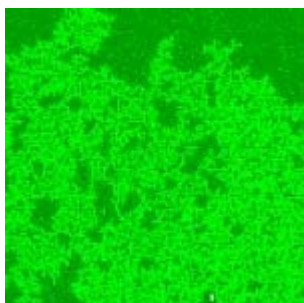
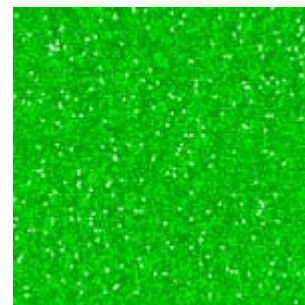
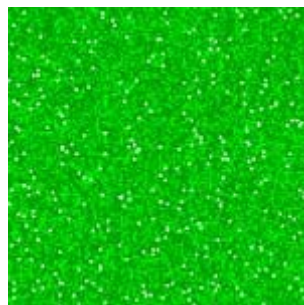
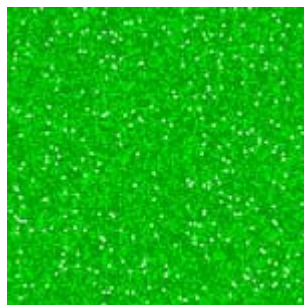
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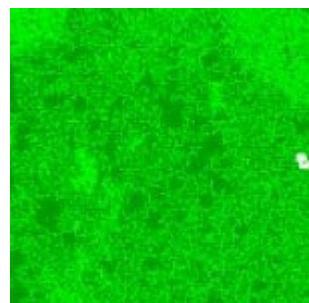
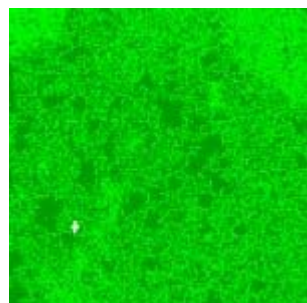
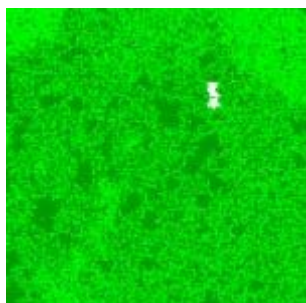
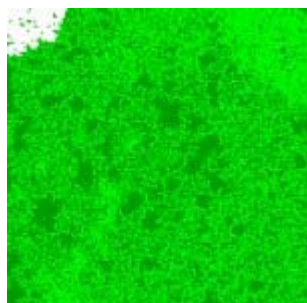
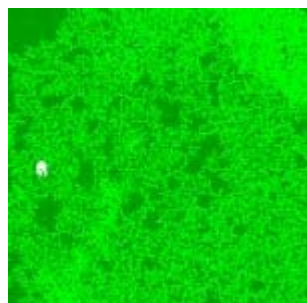
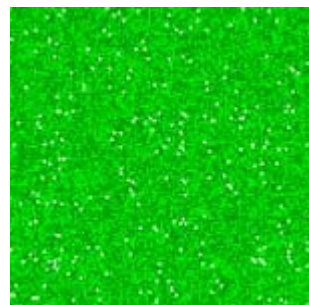
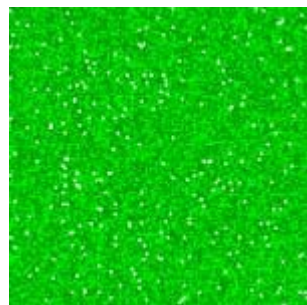
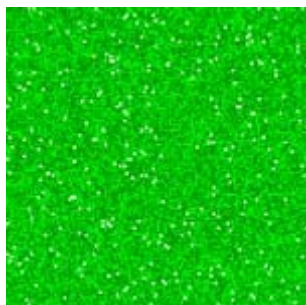
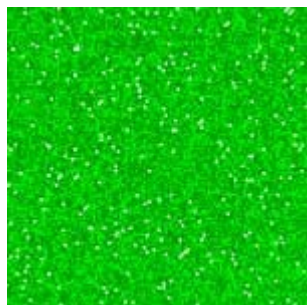
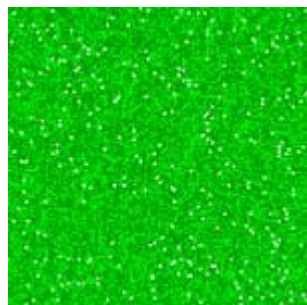
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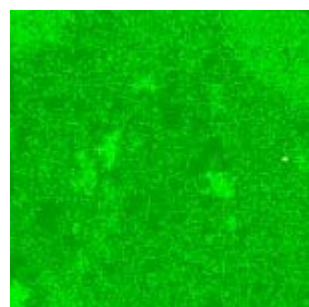
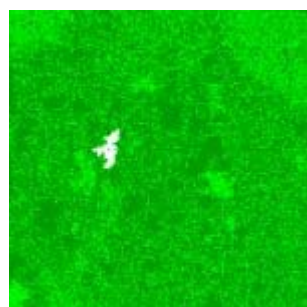
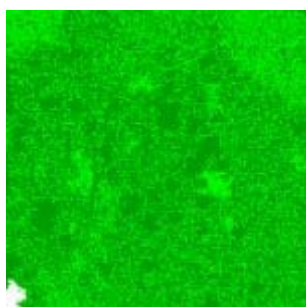
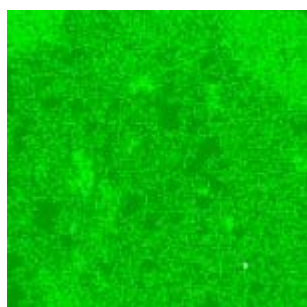
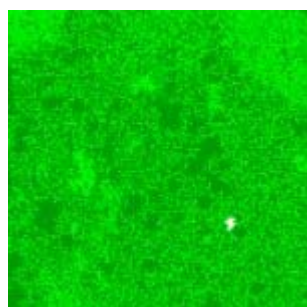
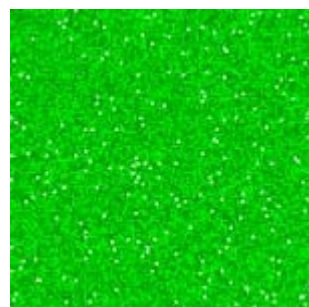
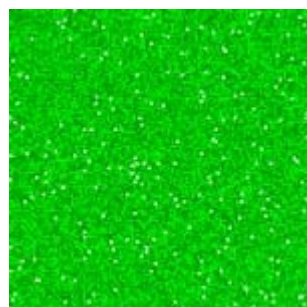
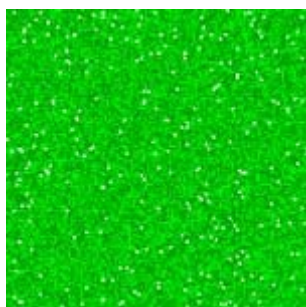
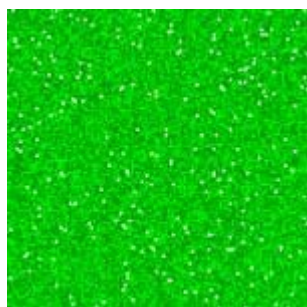
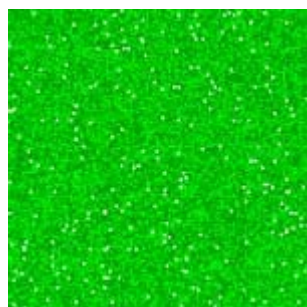
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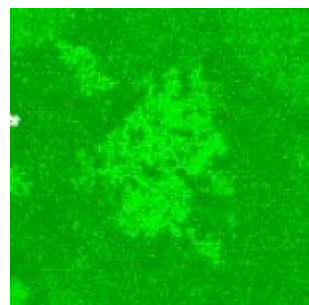
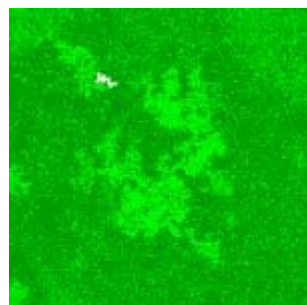
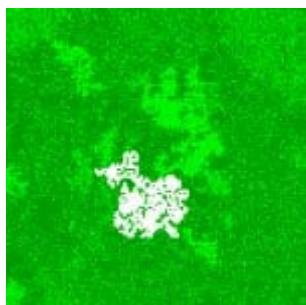
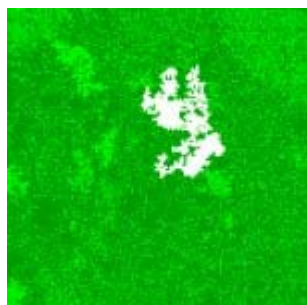
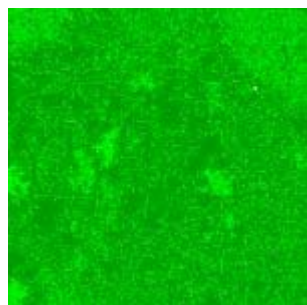
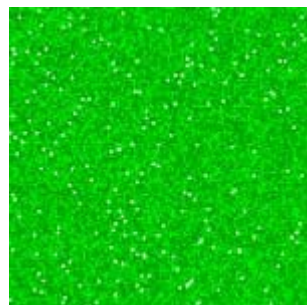
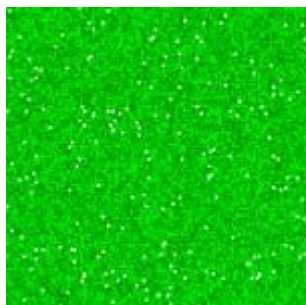
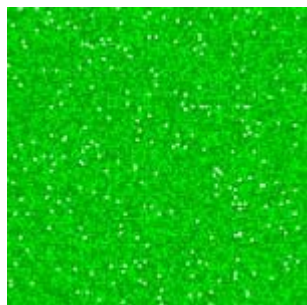
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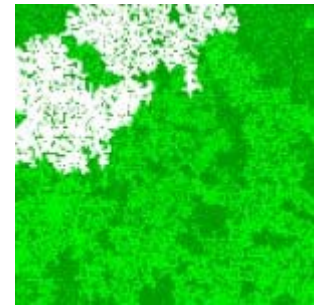
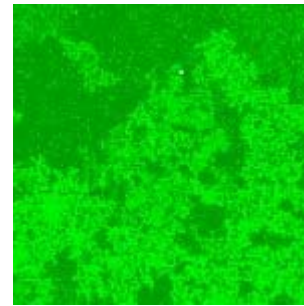
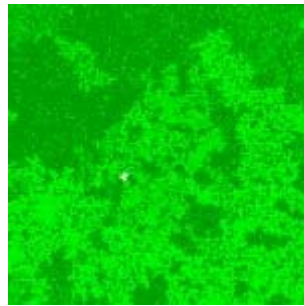
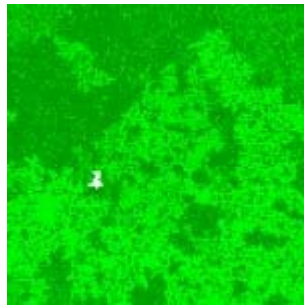
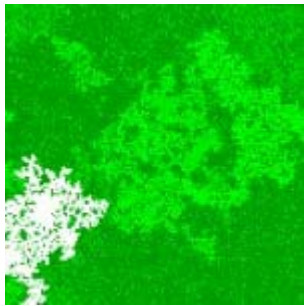
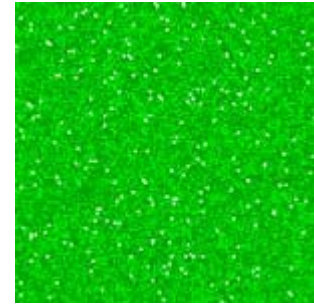
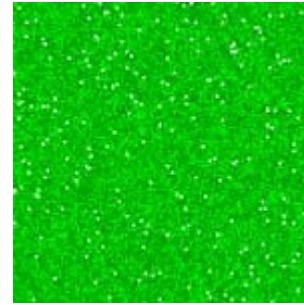
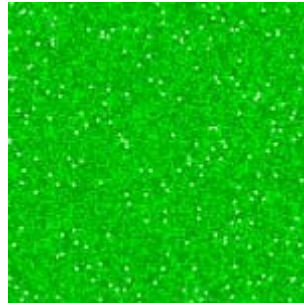
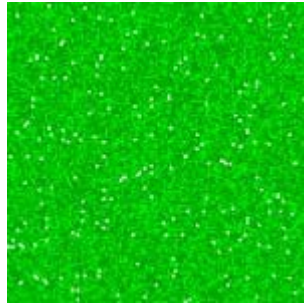
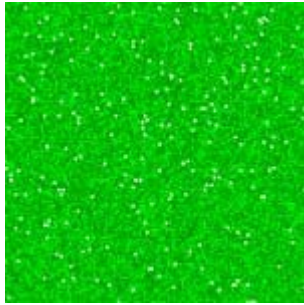
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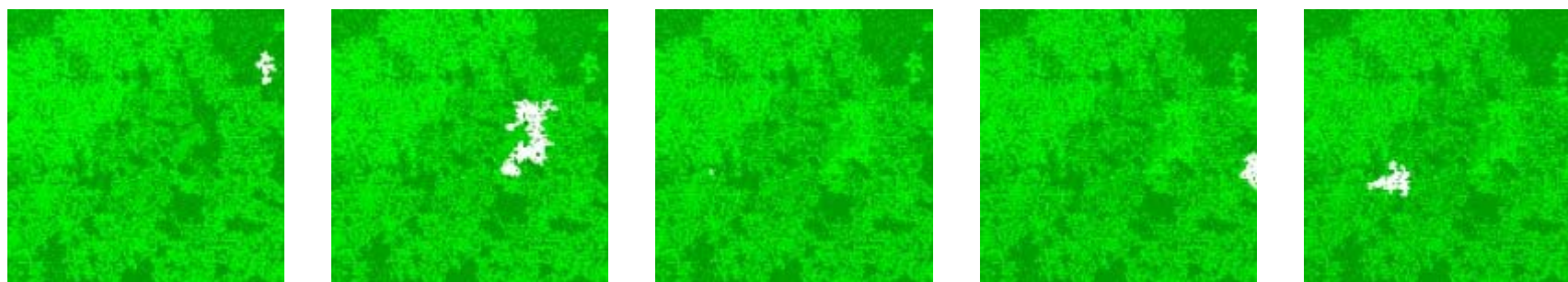
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92

94

96

98



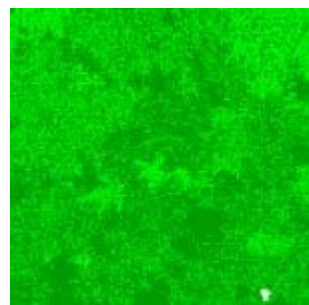
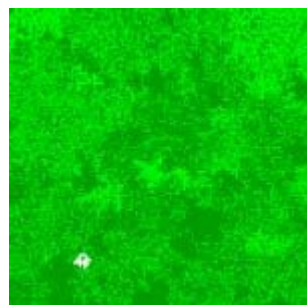
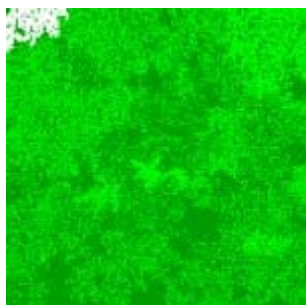
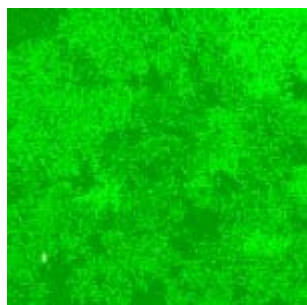
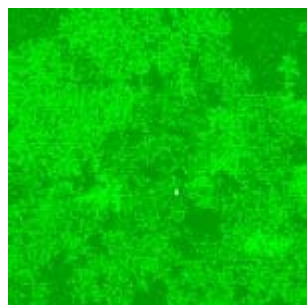
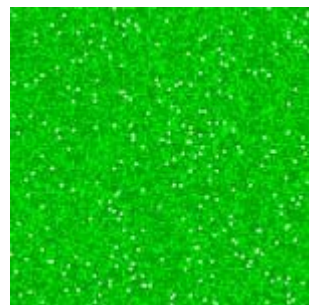
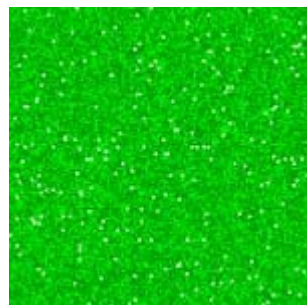
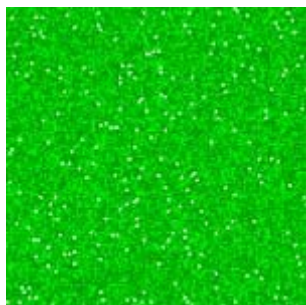
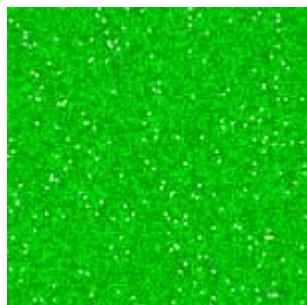
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110

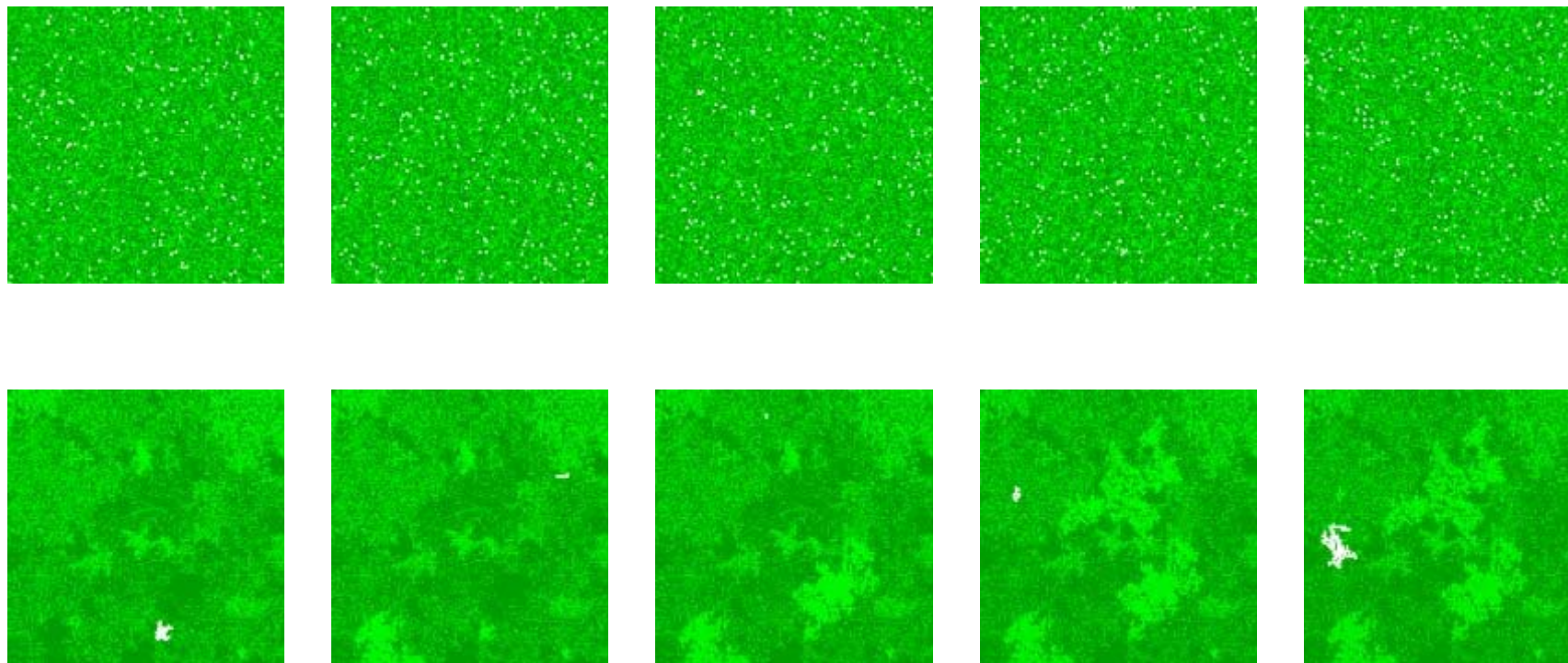
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114

116

118





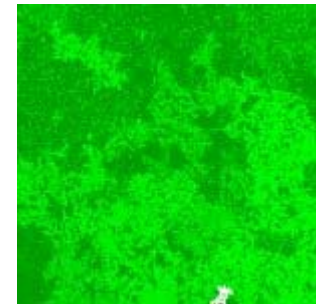
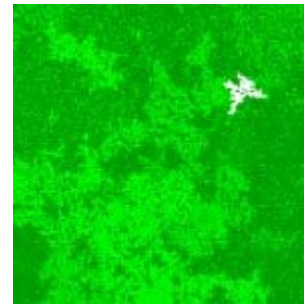
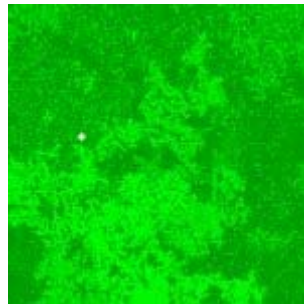
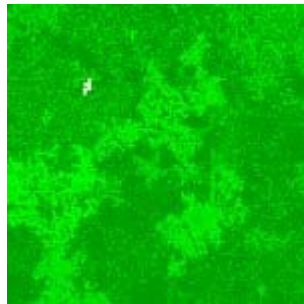
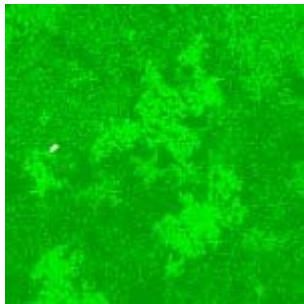
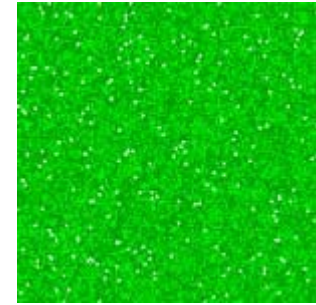
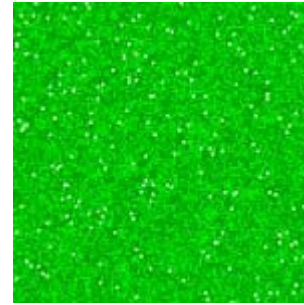
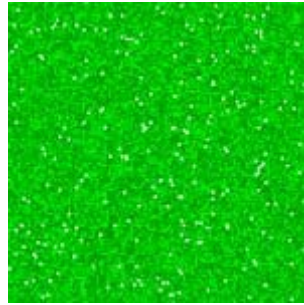
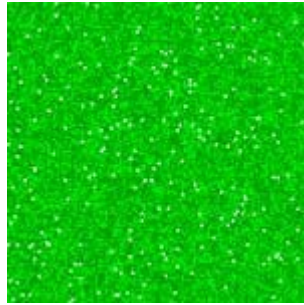
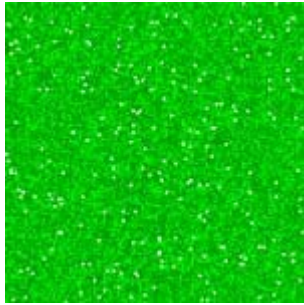
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128



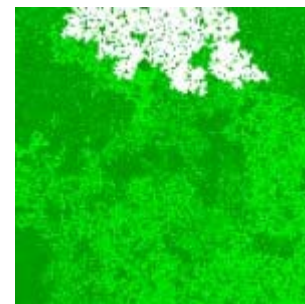
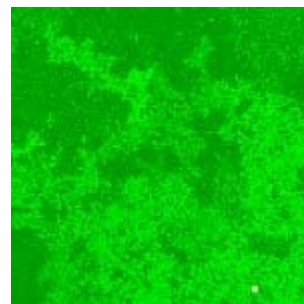
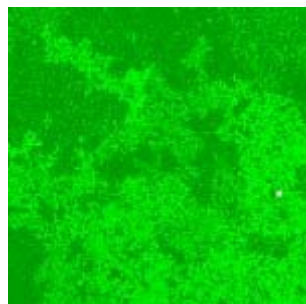
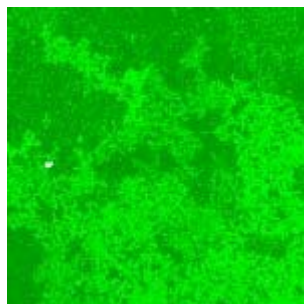
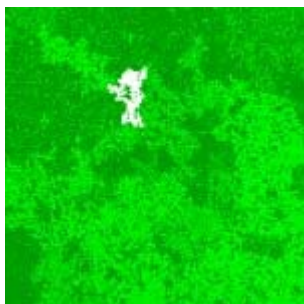
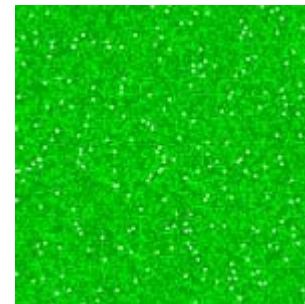
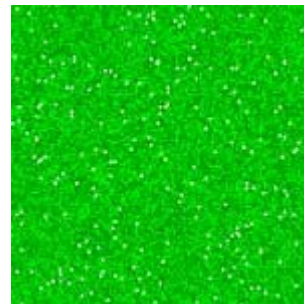
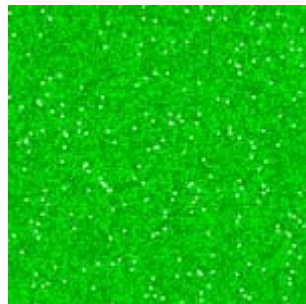
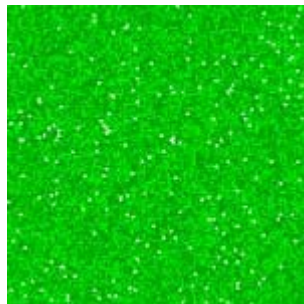
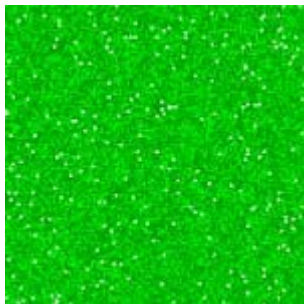
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134

136

138



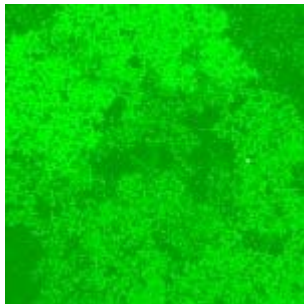
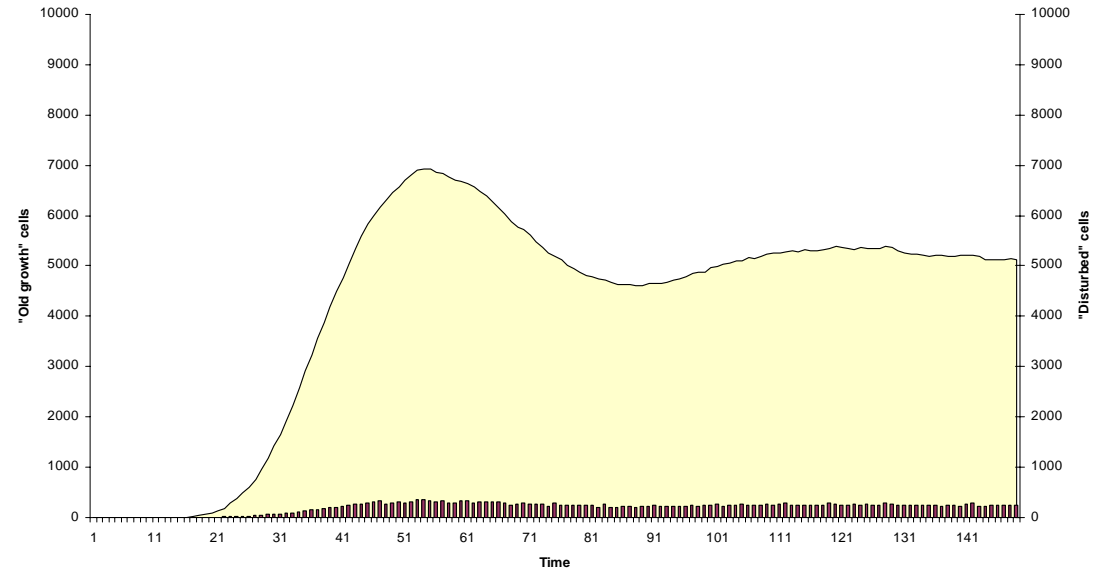
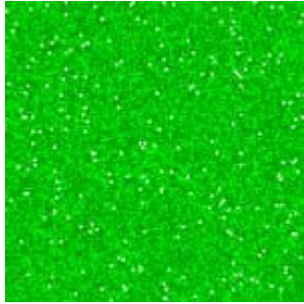
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142

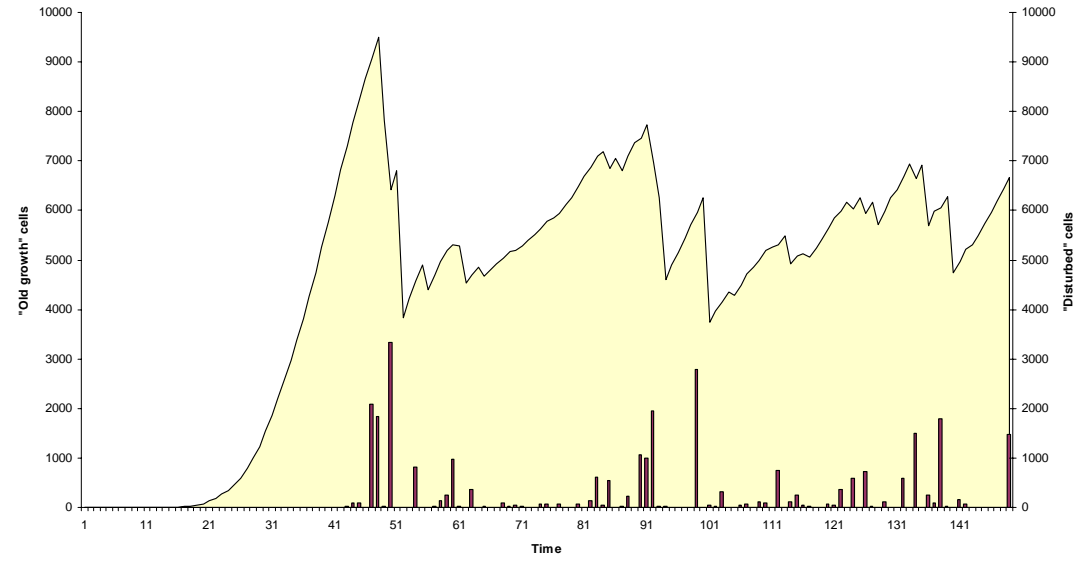
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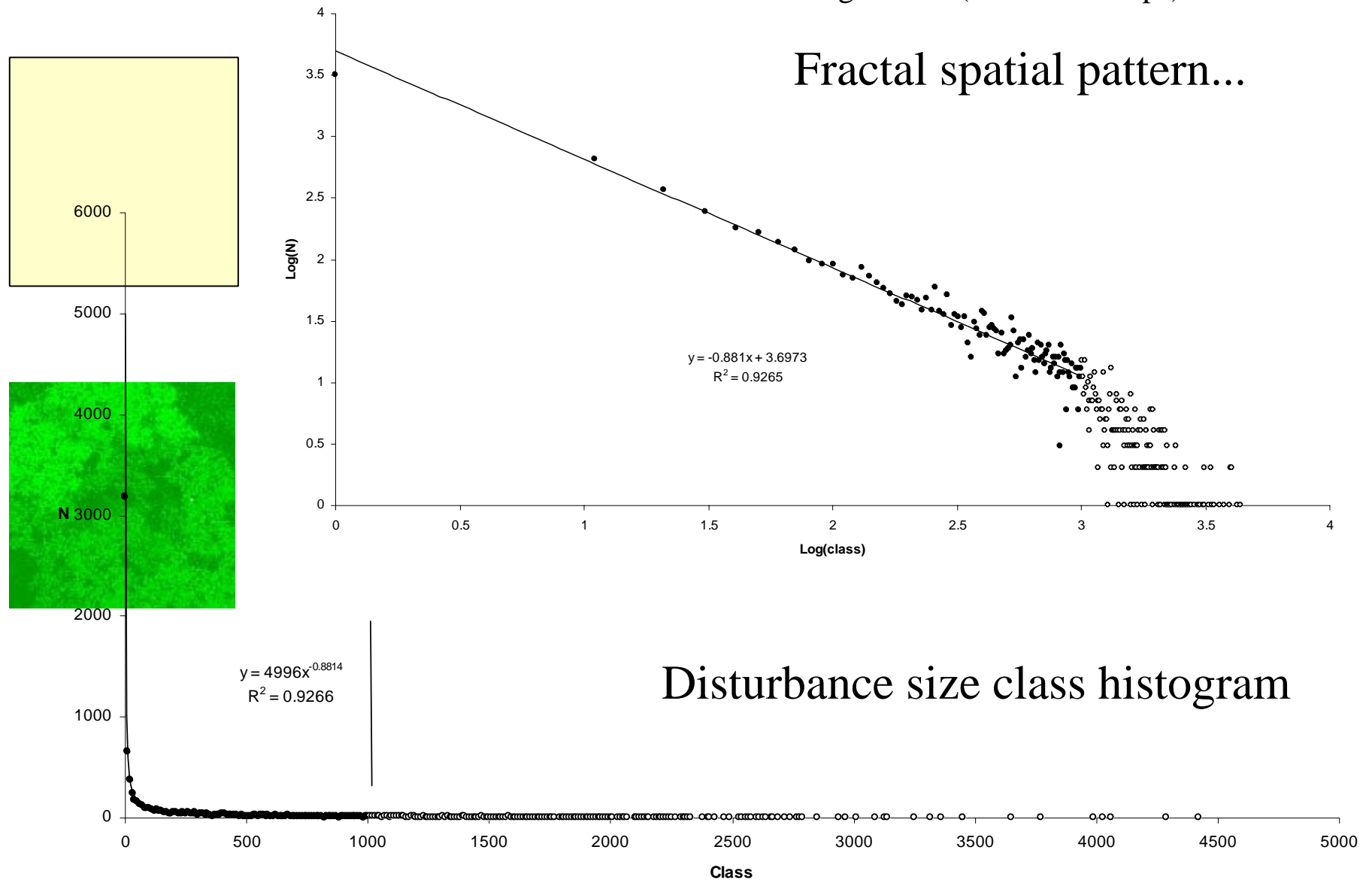




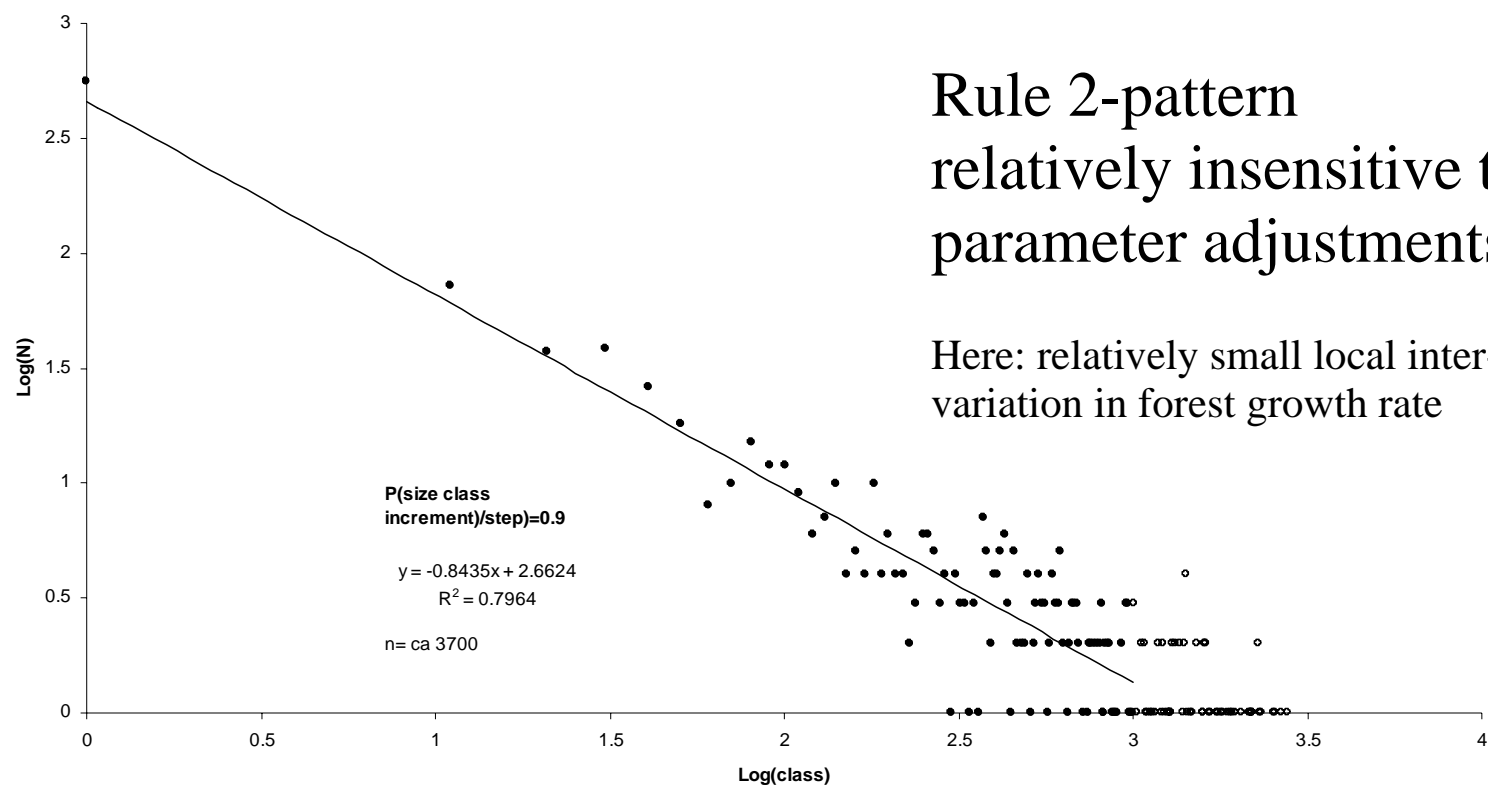
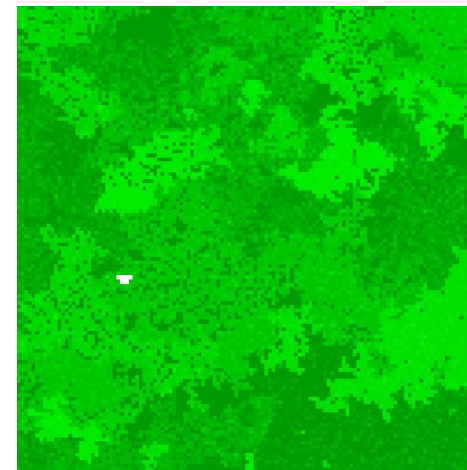
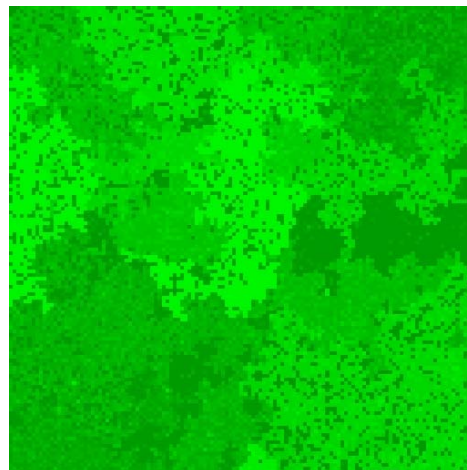
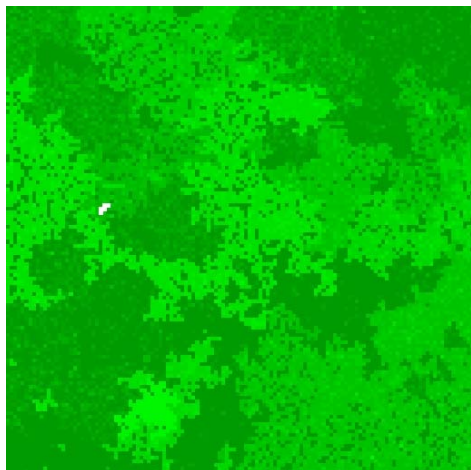
Time series analysis of rule 2:

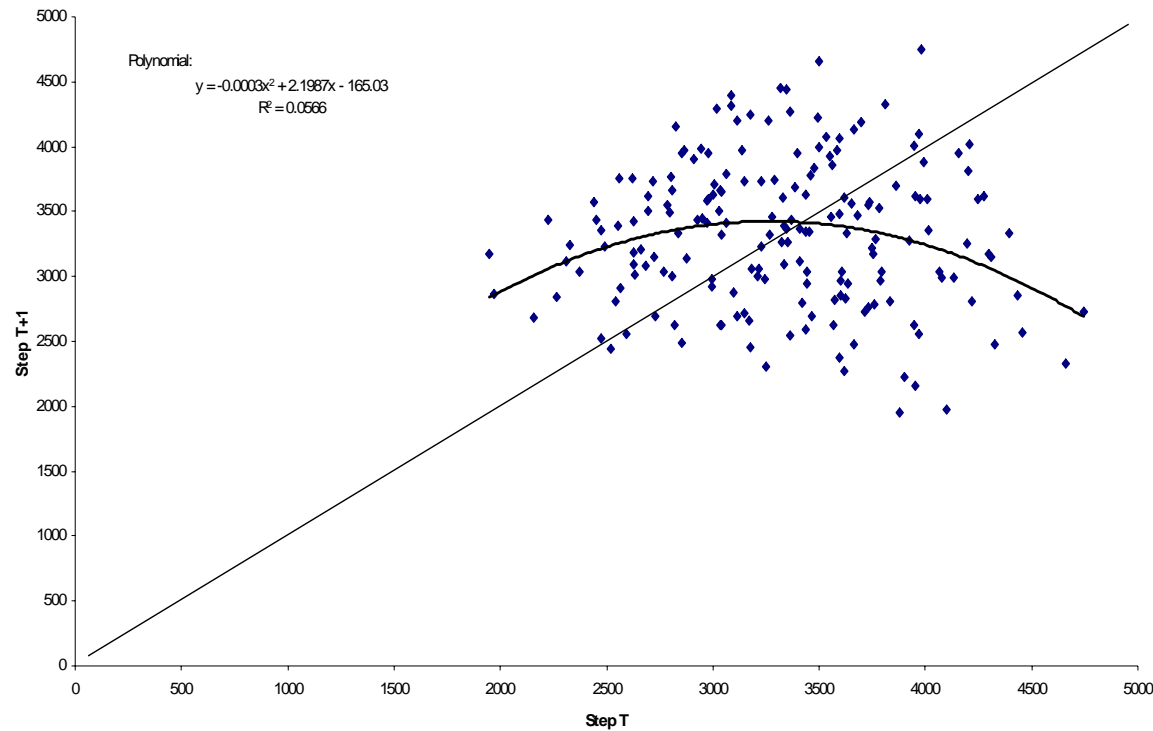
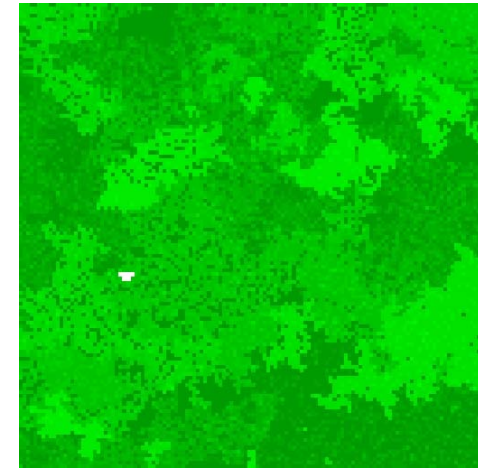
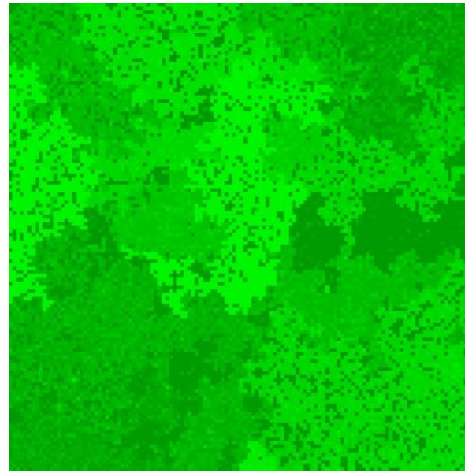
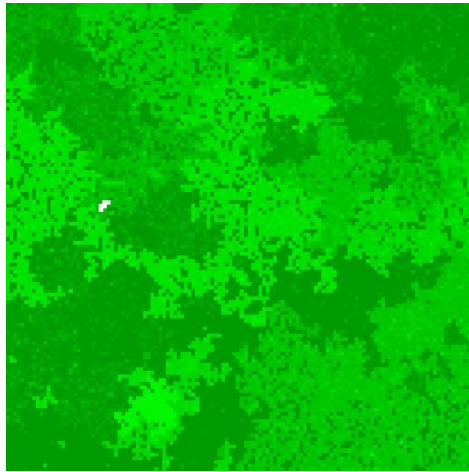
Large series (9200 time steps)

Fractal spatial pattern...









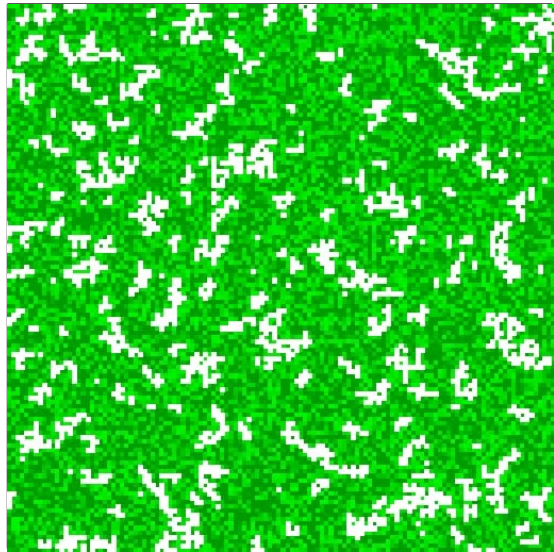
Rule 2-pattern shows  
 “mild chaos” on a return  
 map of order 1

Comparing cover of old forest at  
 time T (x-axis) with T+1 (y-axis)

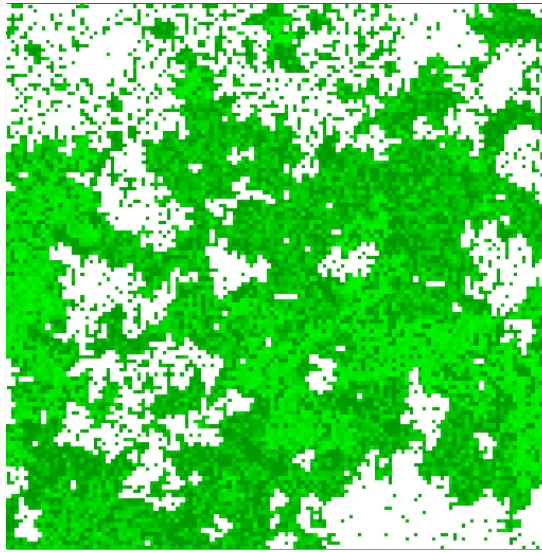
Statistical mechanics: Self-  
 organized critical state...

Landscape ecology:  
 Shifting mosaic

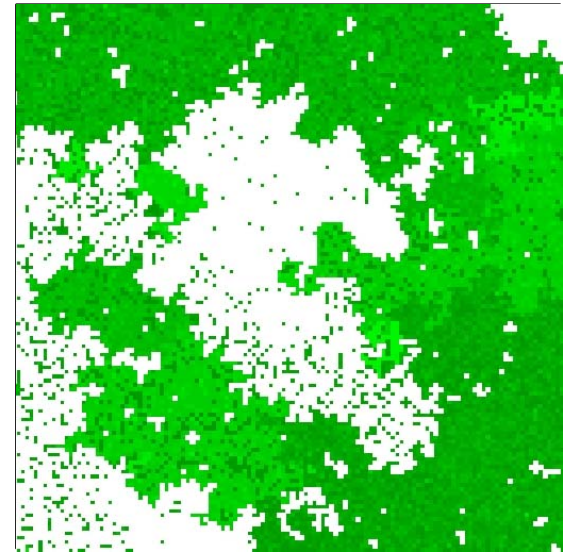
## Disturbance rules vs. landscape element connectivity



Rule 1 (scale-specific)



Rule 2, less synchronized

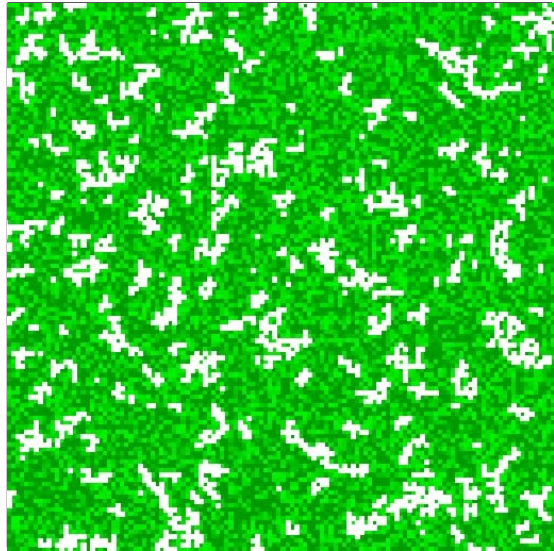


Rule 2, relatively synchronized

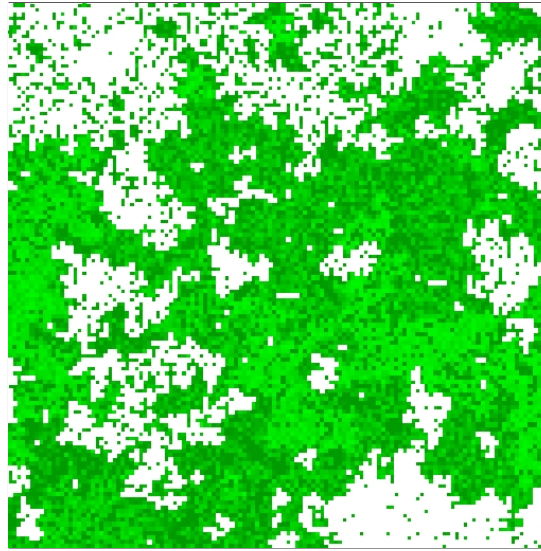
- Stop series at a random point where overall cover of old-growth cells is approximately 6500 cells
- For the next time step, set disturbance intensity to 0.05 (every 20<sup>th</sup> cell expected to be perturbed), and let all local disturbances spread to all connected old-growth cells (Rule 2)
- Result: Fractal patterns show better overall connectivity between similar growth phase elements, both for young and old age classes.



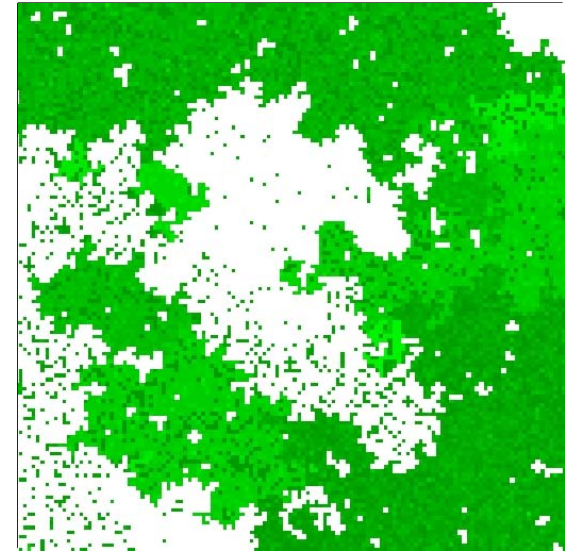
## Disturbance rules vs. landscape element connectivity



Rule 1 (scale-specific)



Rule 2, less synchronized

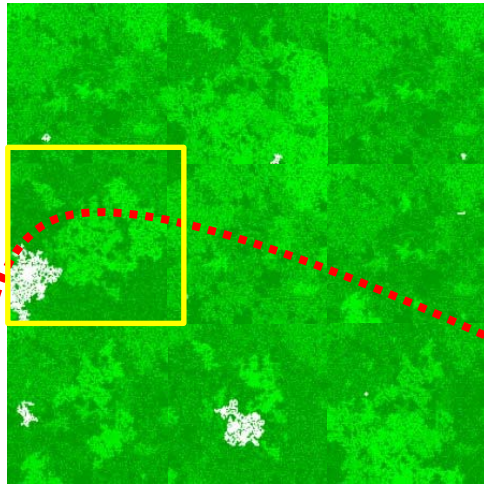


Rule 2, relatively synchronized

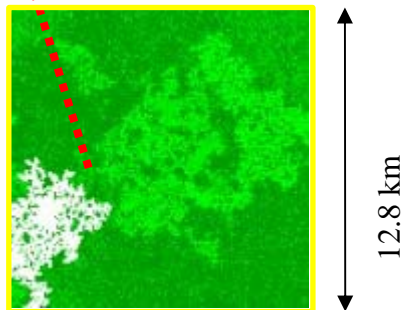
All three landscape patterns above offer the same overall logging output in the long run.

Parameter-sensitive connectivity pattern, in particular “Rule 1”-based management

Local management areas define upper scale range for age class pattern even for “scale-free” logging rules



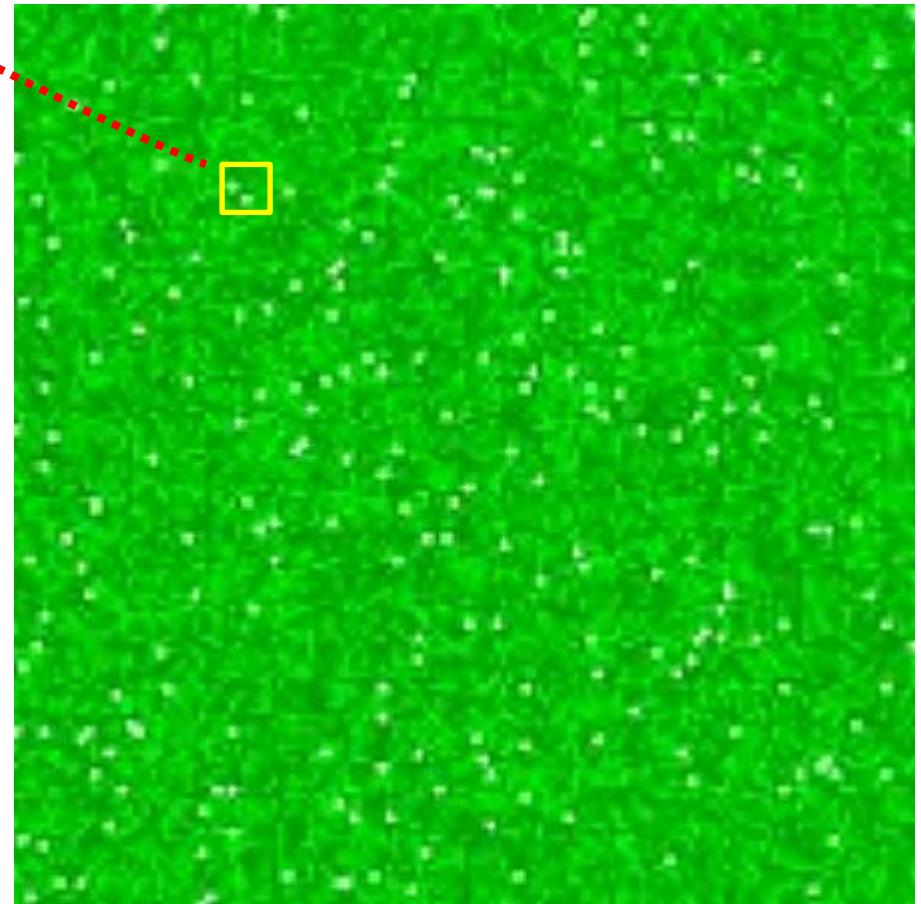
Extent:  $9 * 16,384 \text{ Ha} = 147,456 \text{ Ha}$



12.8 km

Grain: 1 Ha

Extent:  $128 * 128 = 16,384 \text{ Ha}$



768 km

Extent:  $400 * 147,456 \text{ Ha} = 58,982,400 \text{ Ha}$

# Part 2

**Adding realism I: Age-structured forest  
dynamics at scale 1 Ha**

Time



1

2

3

4

5

6

7

8

9

10

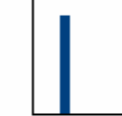
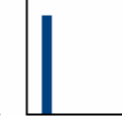
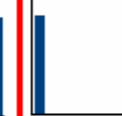
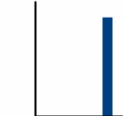
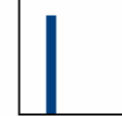
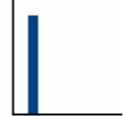
1

2

3

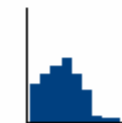
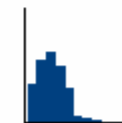
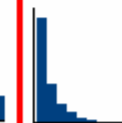
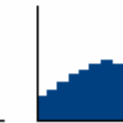
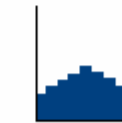
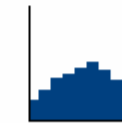
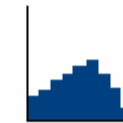
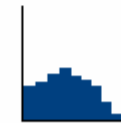
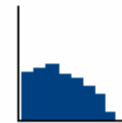
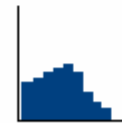
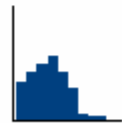
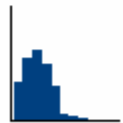
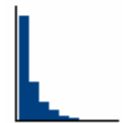
Ten size classes at 1 Ha pixel size

Basal  
area



Size  
class

Simplified model ("stochastic growth")

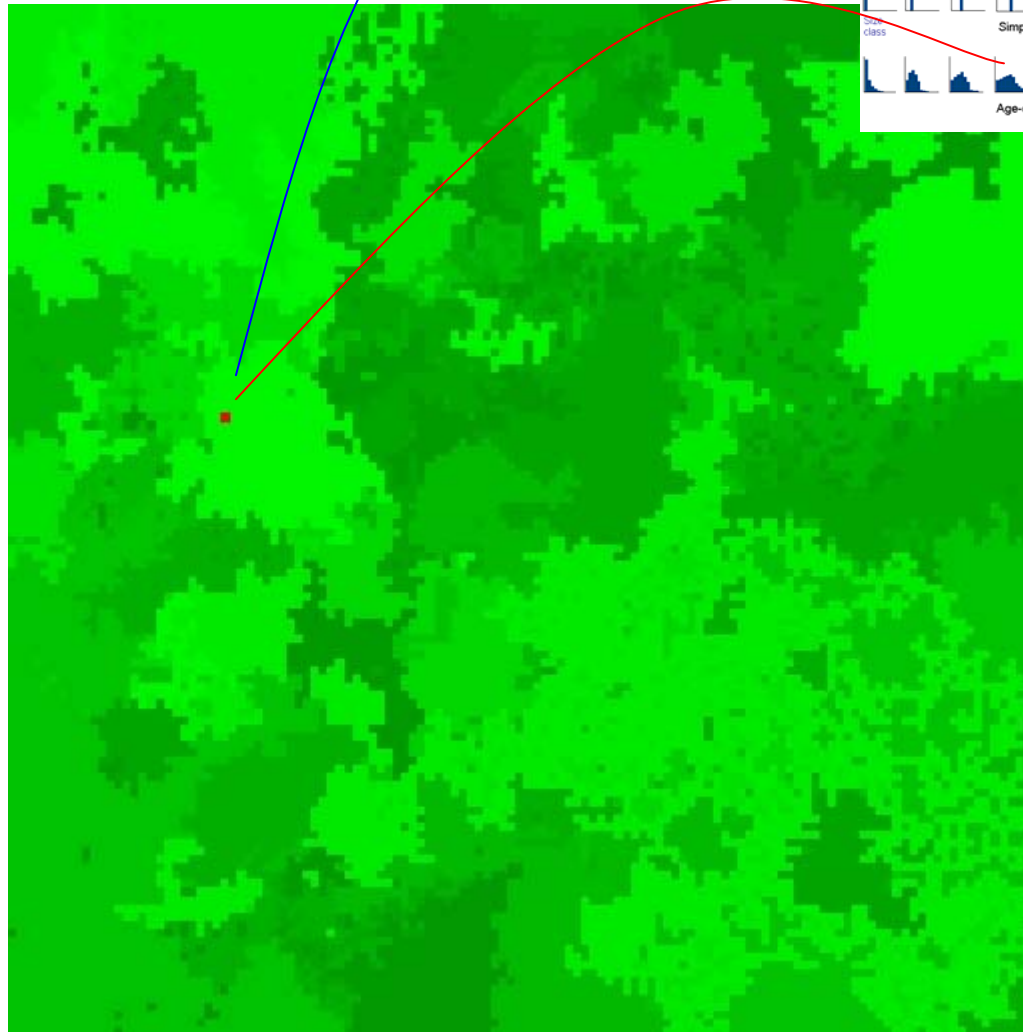


Age-class structured model ("deterministic growth")

Logging event

## Intense computation:

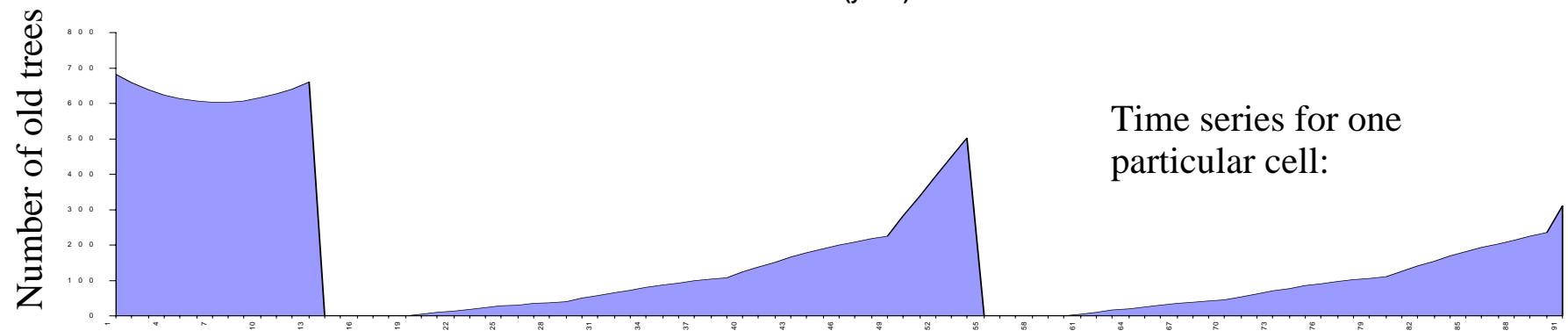
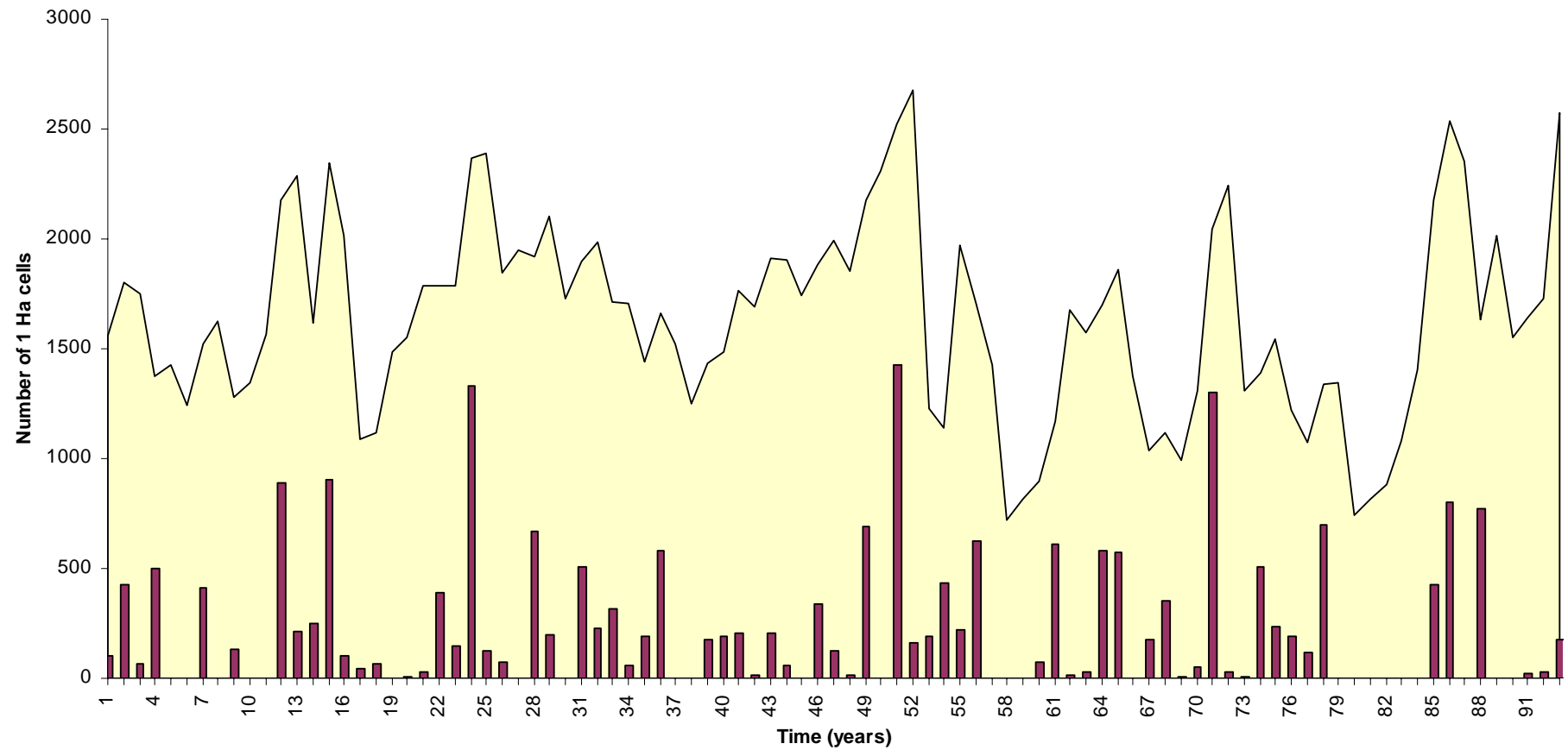
For each time increment, update more than 100 year classes for each of the arena's 16384 1 Ha pixels (cells)...



Example from a “Rule 2” type of logging regime

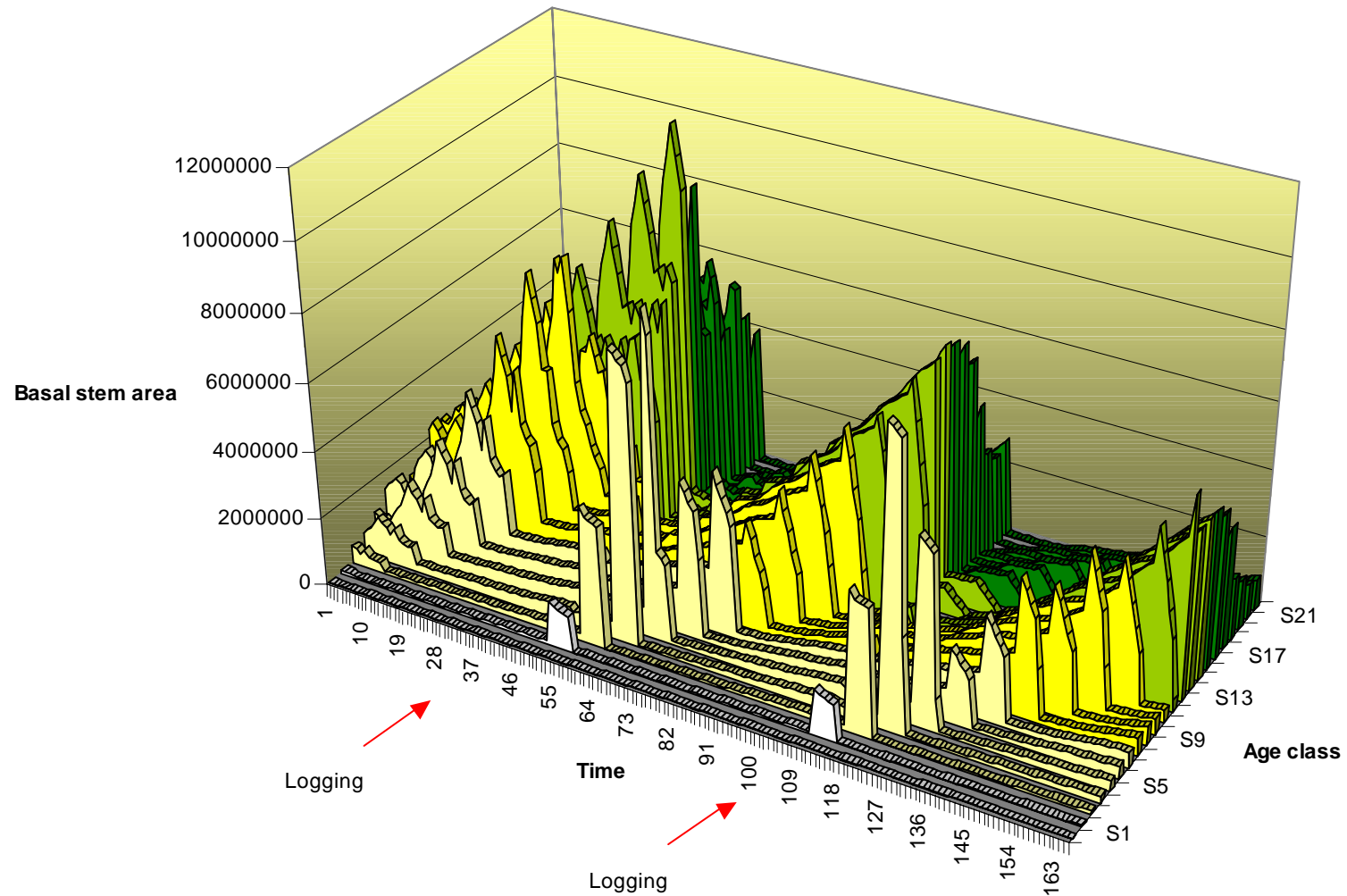


Time series for arena: Old growth forest cover (upper line) and logging intensity (bars)



Time series for one particular cell:

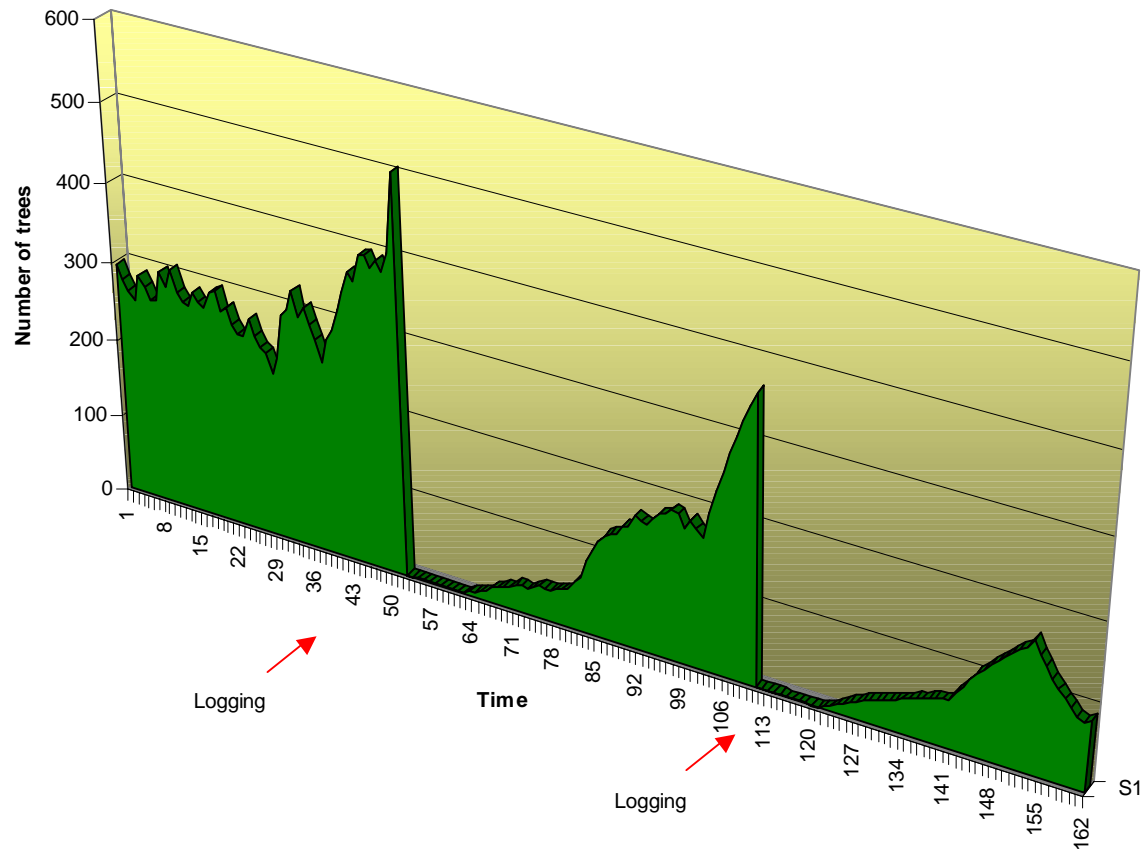
# Intra-cell dynamics



# Model behaviour needs careful validation

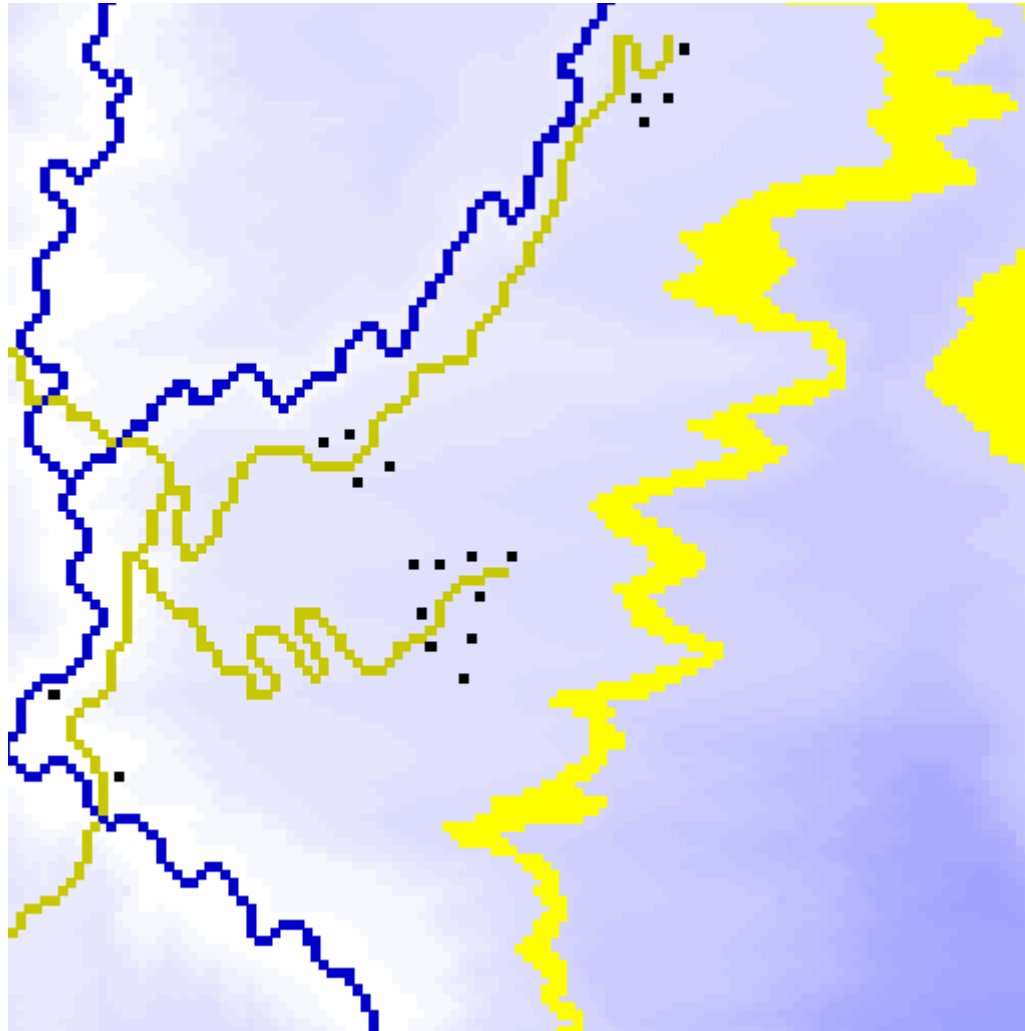
Example: Time series for oldest age class ( $\geq 100$  years) in a given 1 Ha cell

Time series for oldest age class  $>100$  years

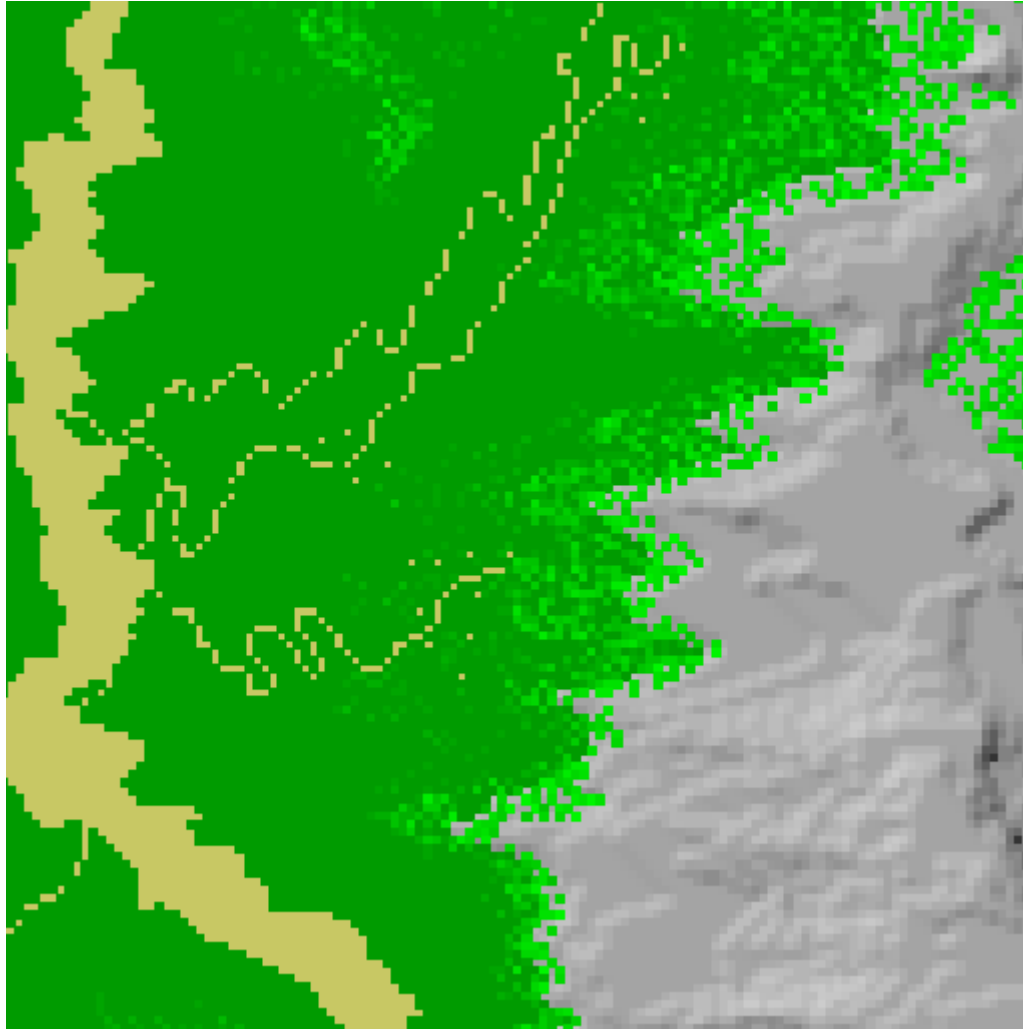


# Part 3

**Adding realism II:** Dynamics in a  
heterogeneous landscape



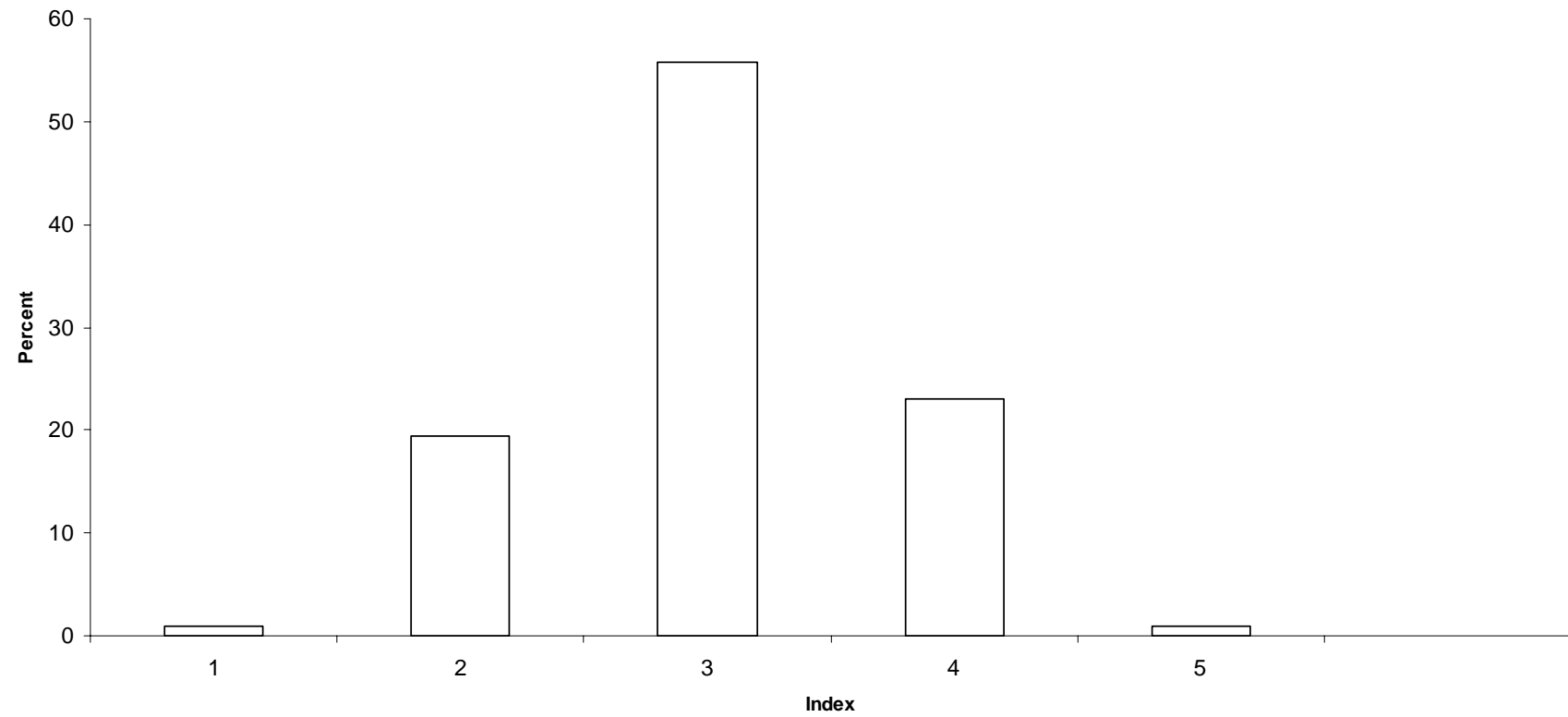
Adding GIS  
layers for local  
abiotic  
conditions

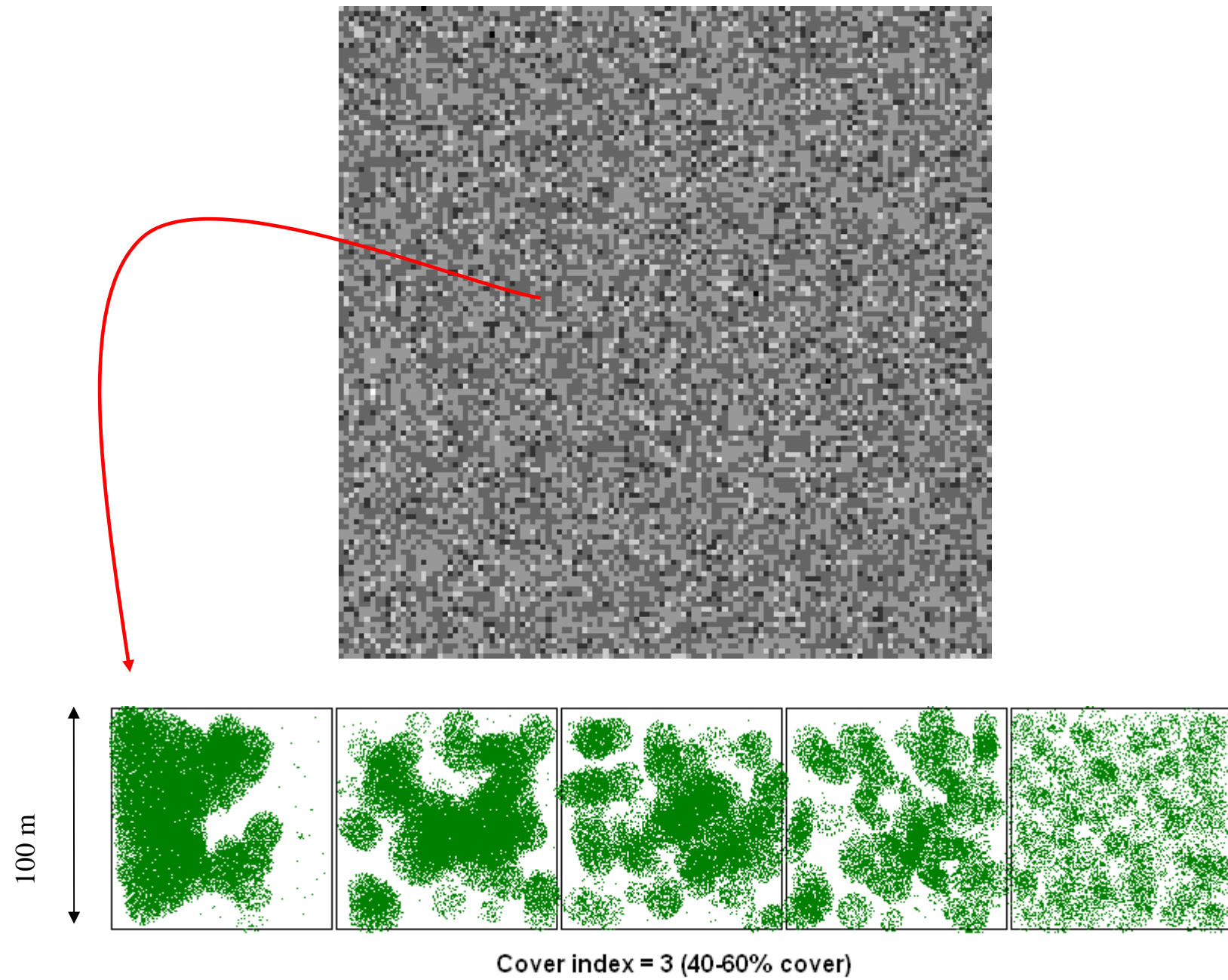


Relative growth  
rate smaller  
close to tree line:

A function of  
altitudal summer  
temperature  
gradient

Frequency histogram template for potential or actual birch forest substrate at 1 Ha scale from index 0 (no potential for birch) to 5 (full cover)



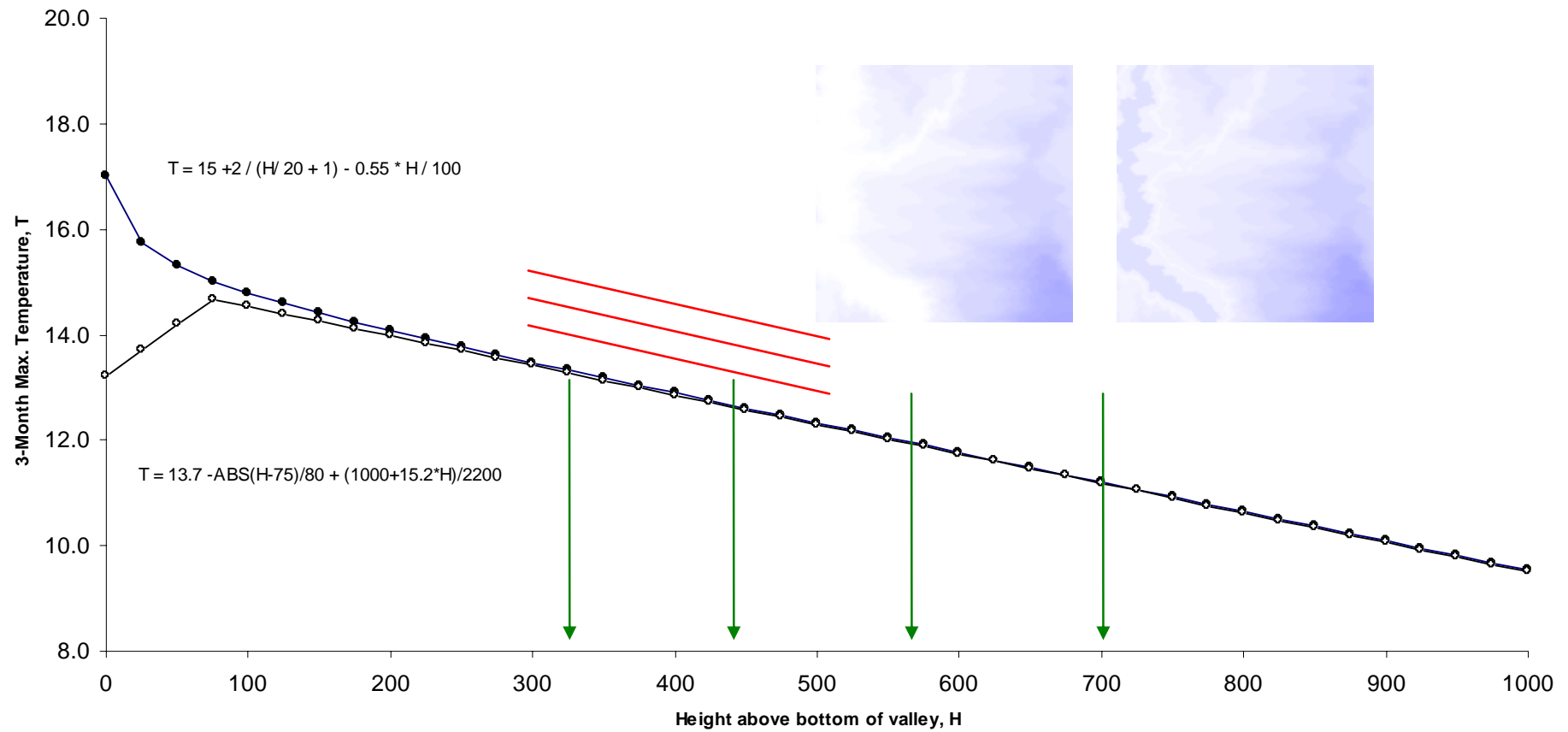




# Part 4

## **Adding realism III: Climate change scenarios**

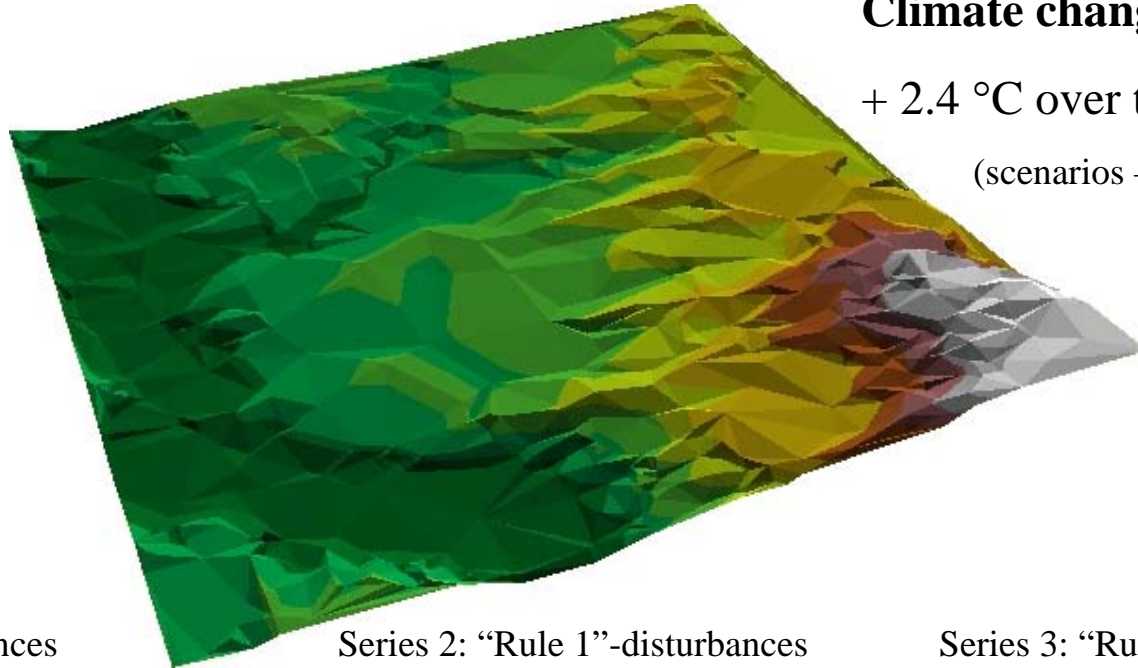
### Topoclimatic models for the height gradient in the HIBECO model



## Climate change scenarios:

+ 2.4 °C over the next 120 years

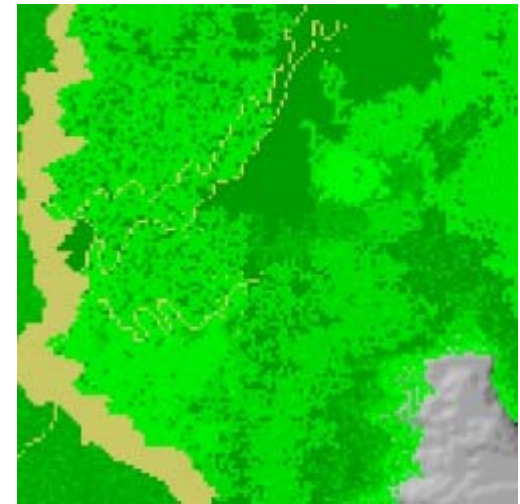
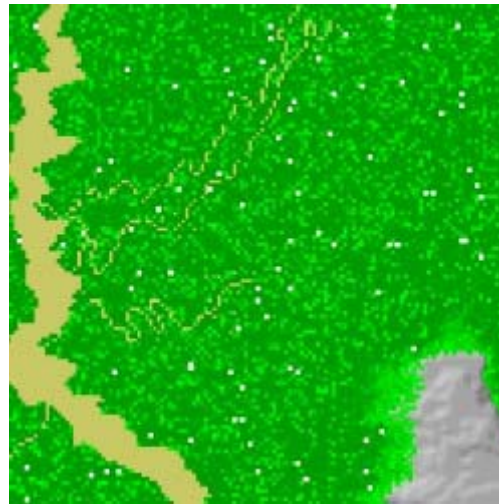
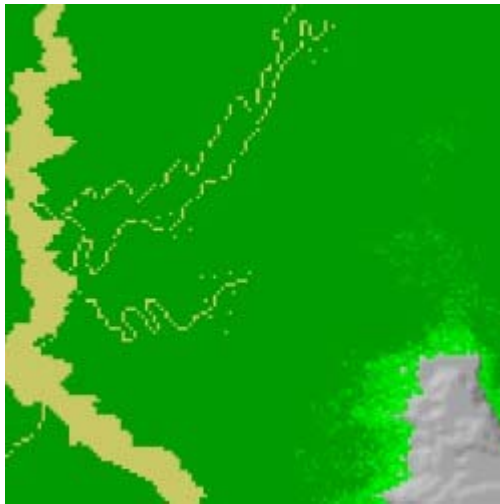
(scenarios – not prognoses!)



Series 1: No disturbances

Series 2: “Rule 1”-disturbances

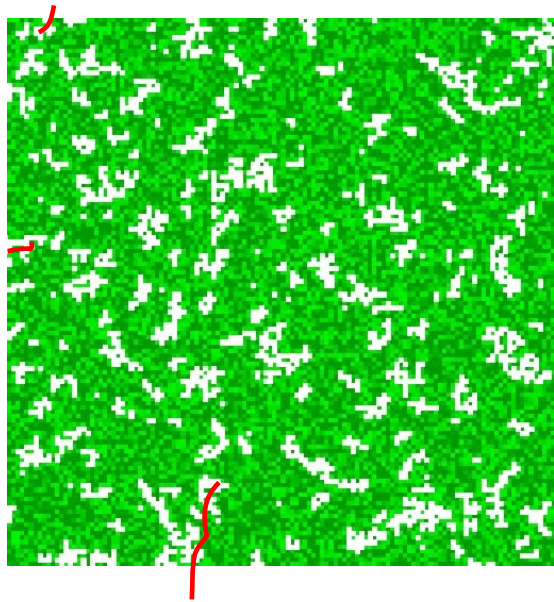
Series 3: “Rule 2”-disturbances



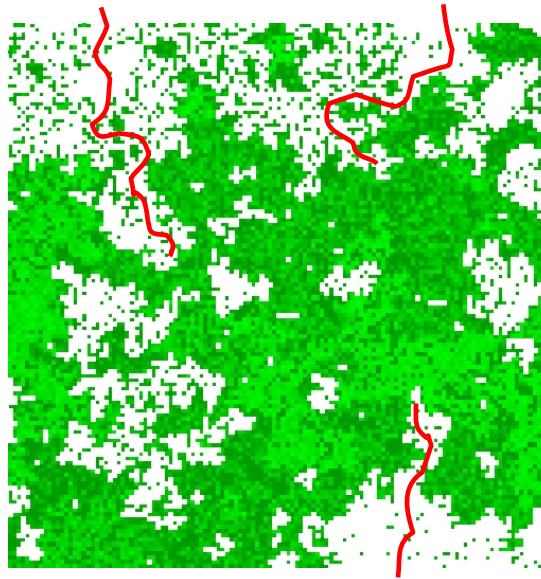
# Part 5:

**Adding realism IV:** Influences from herbivores – grazing ungulates and leaf-eating insects

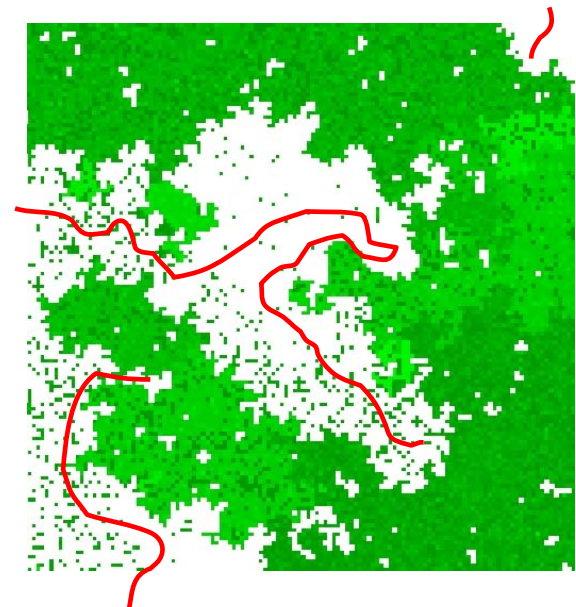
## Grazing ungulates (sheep, reindeer) and forest structure



“Rule 1”-generated pattern



“Rule 2”-generated patterns



### Sustainable pluralistic utilization of birch forest:

Logging rules (“policy”) can significantly influence the overall quality and availability of forest elements for other uses, like grazing habitat for sheep and reindeer, hiking/tourism, etc.



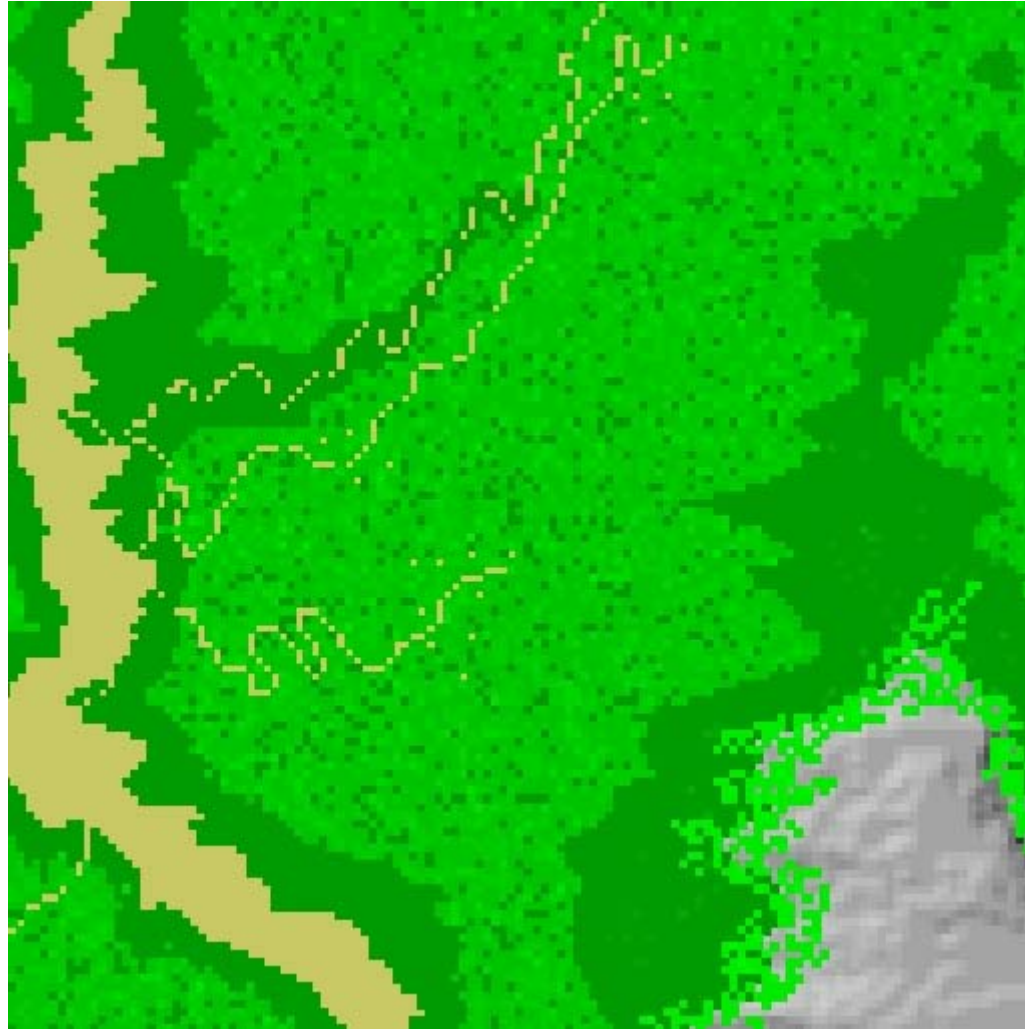
## Leaf-eating moth outbreaks (*Epirrita*, *Operopthera* etc.)

### Outbreak constraints:

Lower limit: 100 m above bottom of valley

(Winter inversion)

Upper limit: 13.5 °C isotherm for 3-month max summer temperature



In this preliminary and hypothetical 120-year scenario insects have tree-killing pseudoperiodic outbreaks every 8-12 years

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