Sybille Haeussler, University of Northern British Columbia

Forest Ecosystem Dynamics in a Non-Linear World

The Problem

- Forest ecosystems are changing in complex, non-linear ways due to the interacting effects of changing disturbance regimes, climates, and species distributions.
- How can we make better predictions about what those changes might be?

The Premise

- Forest ecosystems have emergent properties; they can not be modeled solely as the sum of the dynamics of their component parts (e.g., trees, insects).
- Models that treat forest ecosystems as individual, interacting agents are needed as part of a multi-scale framework to predict forest response to global change

Outline of Presentation

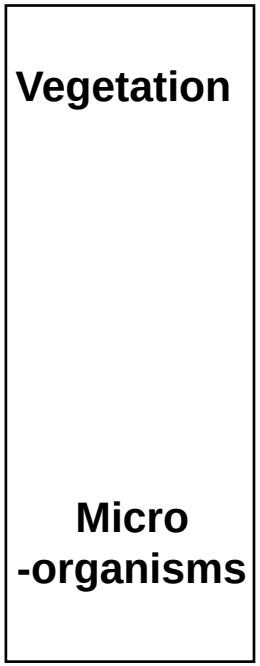
- Introduce a simple agent-based model of ecosystem response to global change.
- Apply this modeling approach to threatened pine-lichen ecosystems of central British Columbia

Ecosystems as Interacting Agents?

A unit of land with relatively uniform soil profile development that is capable of supporting relatively uniform vegetation.

A unit of land under the influence of a single successional attractor.

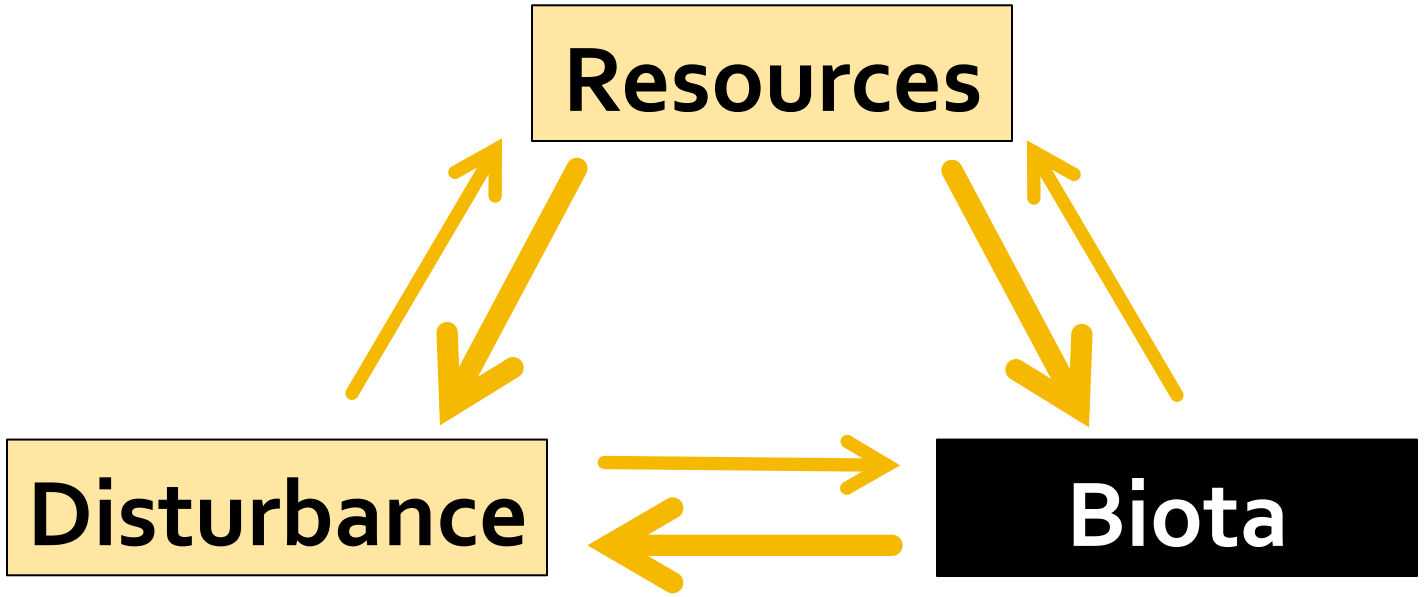
"*biogeocoenose*"
Sukachev 1945



Simplified state factor model

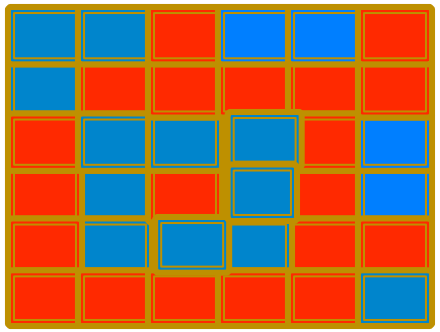
- Jenny 1941: *Soils or Ecosystems*
  = f (climate, organisms, topography, parent material, time)
- Ecosystem = *f(biota, resources, time)*

Reductionist (linear) vs. Holistic (non-linear) approach



Simplified "Toy" model

- Agent-based model => emergent behaviour
- Lattice of cells = ecosystem units
- Biota: two plant-soil functional groups (alternative ecosystem states)



- Resources: single resource gradient (low to high)
- Disturbance: (disturbed, undisturbed) single gradient low to high probability & power law size distribution

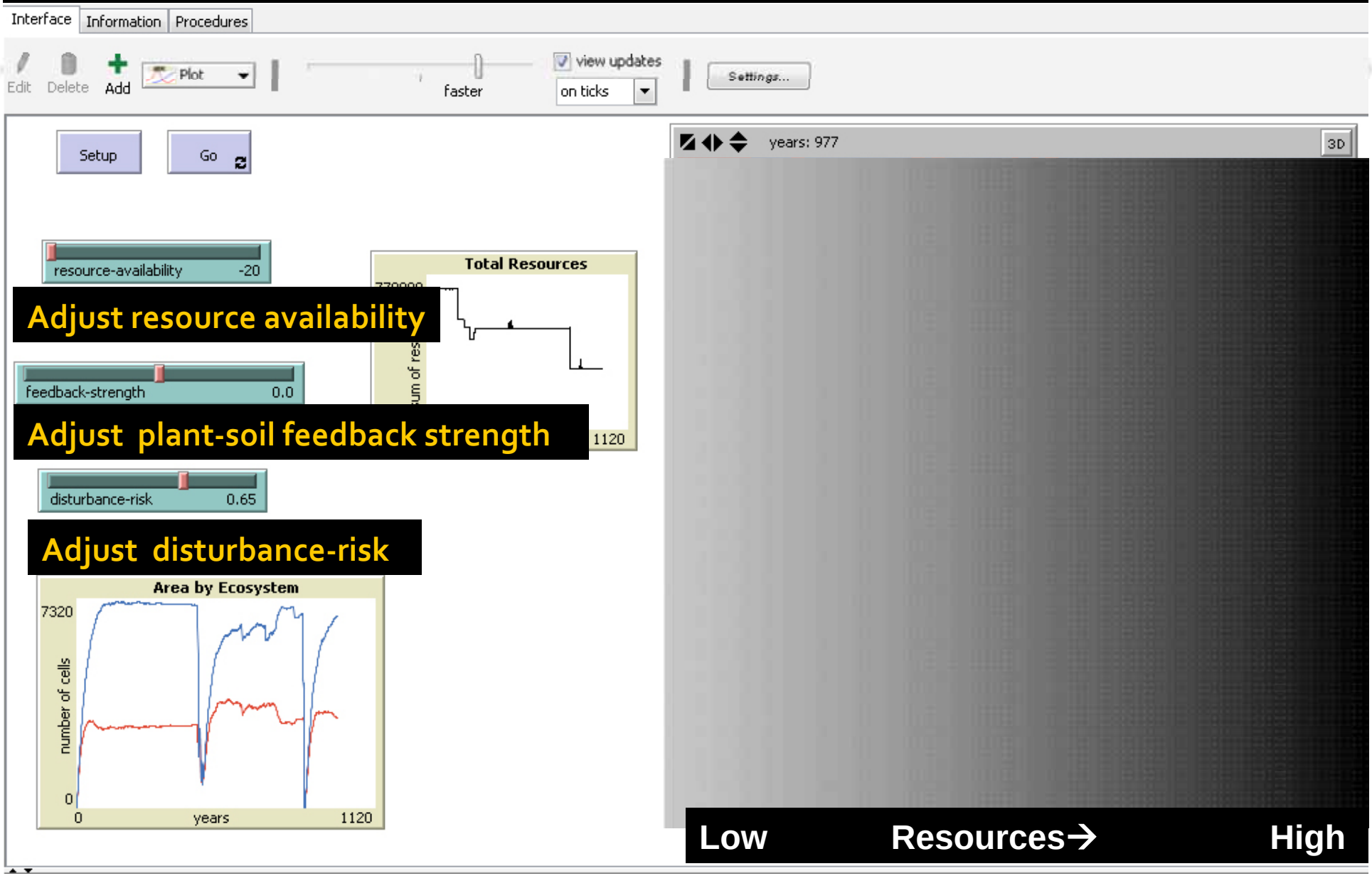
$$P(blue) = 0.5 + a\,(b/8 - 0.5)$$

b = number of blue cells in 8-cell neighbourhood

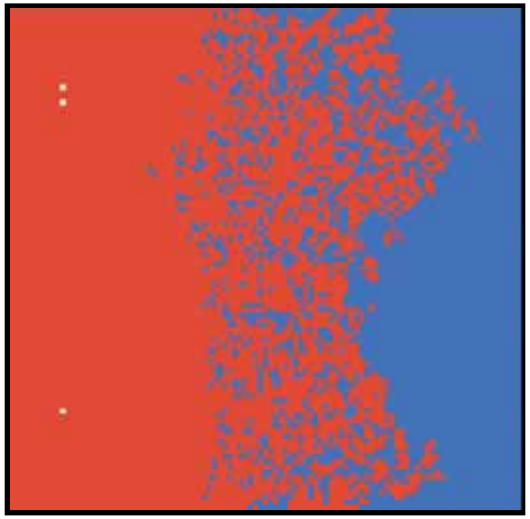
a = feedback strength $-1 < a < 1$

(Molofsky et al. 1999, 2001, 2002)

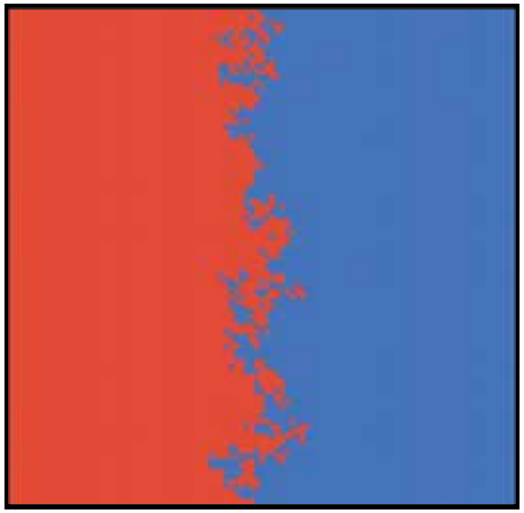
Toy model (Netlogo™)



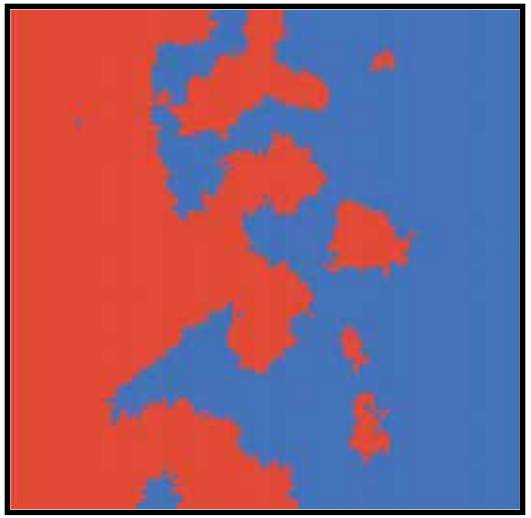
Varying feedback strength (a)



$a = -0.7$
moderately strong
negative feedback



$a = 0.0$
neutral



$a = 1.0$
strong positive
feedback

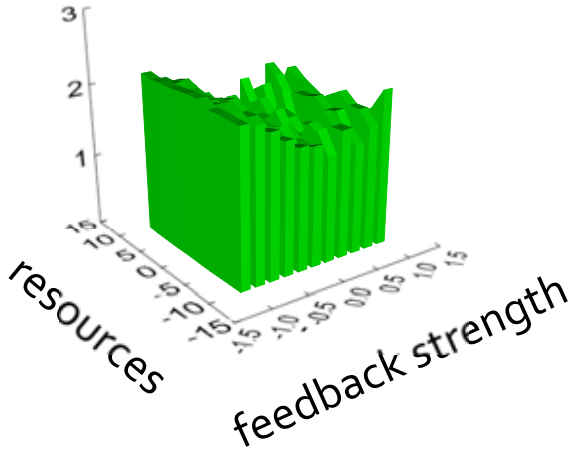
Probability of flip to blue state = 0.5 + a (# of blue neighbours)/8 - 0.5)
Probability of flip to red state = 0.5 + a (# of red neighbours/8 – 0.5)

Conducting modeling experiments

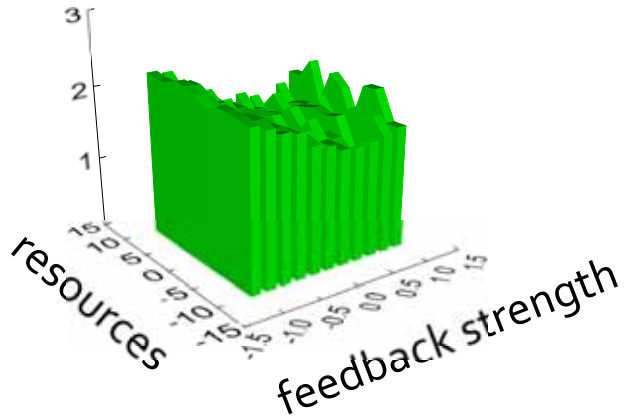
- Ecosystem diversity: *number and size distribution of red vs. blue polygons* (Shannon Index)
- Ecological resilience (Holling 1973): *amount of change (resources/disturbance) the system can absorb before it shifts to an alternative state* (before:after Similarity Index; look for thresholds).
- Landscape complexity: *the amount of hidden order in the pattern of blue and red polygons* (Excess Entropy – Feldman & Crutchfield 2003)

Example of diversity experiment

No disturbance

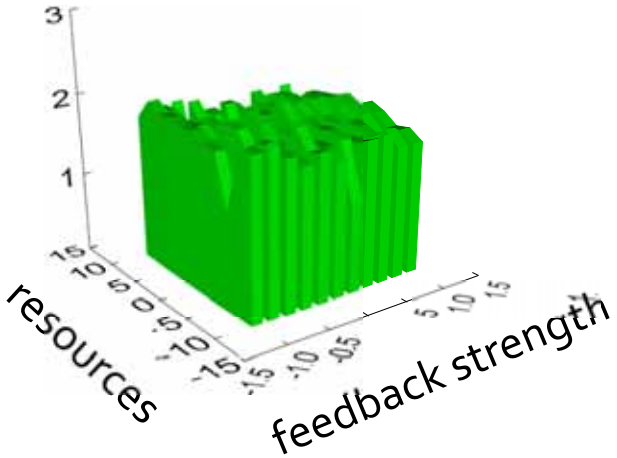


Few, mostly small, disturbances



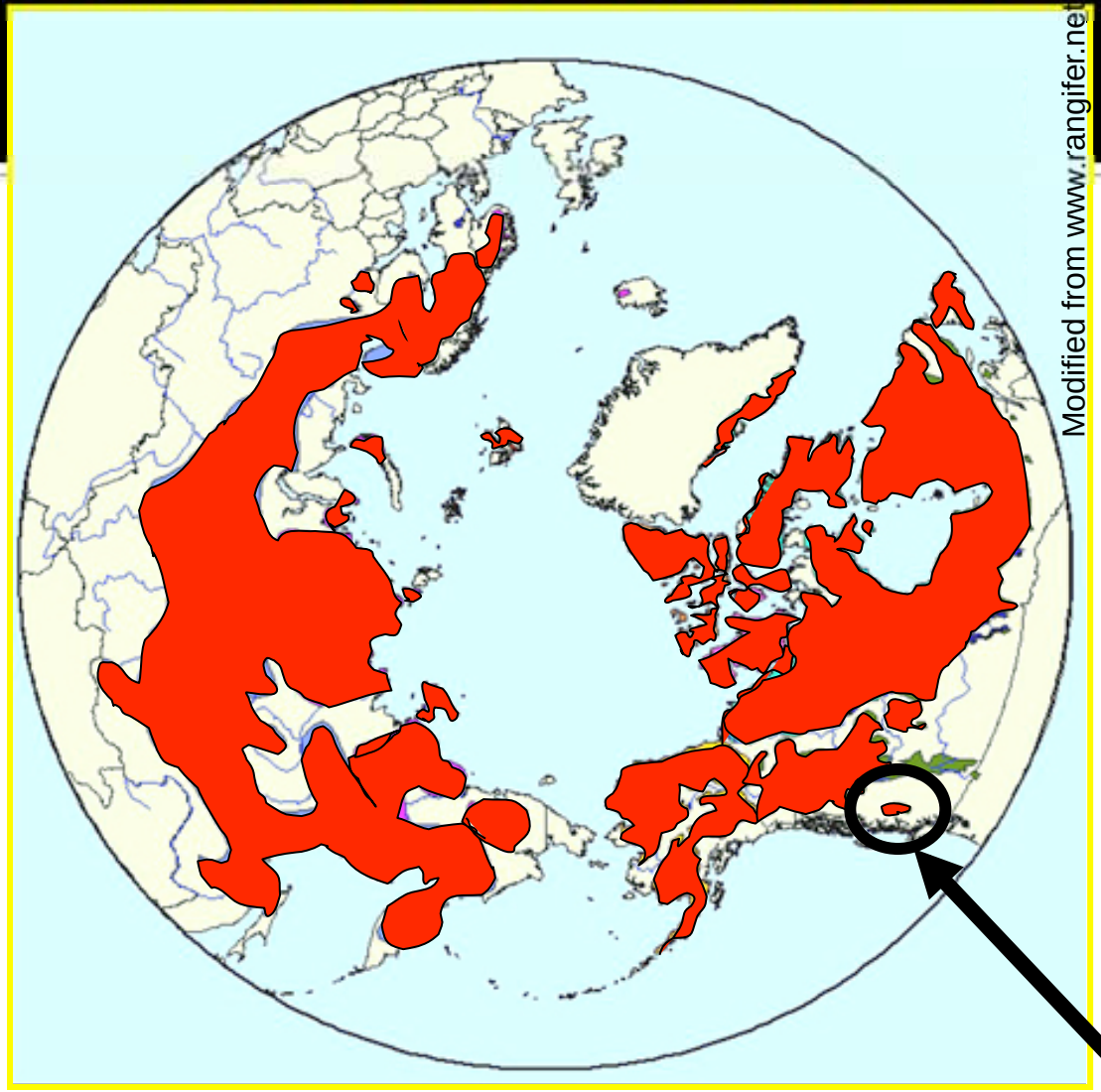
Many, small to large disturbances

Ecosystem Diversity



Part 2: A Real-World Example:
Pine-Lichen woodlands of central British Columbia

Bellwether of climate change?

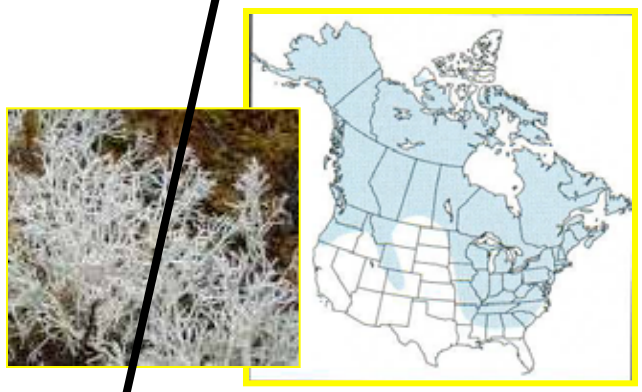


Modified from www.rangifer.net

Worldwide distribution of Caribou
(*Rangifer tarandus*)

Brodo et al.

Cladina stellaris



Brodo et al. 2001

Cladina rangiferina

West central BC

Are Pine- Lichen woodland ecosystems being replaced by mesic forest throughout central BC as a consequence of the interacting effects of changing climate and disturbance regimes?

The Wal-Mart hypothesis

mesophication (Nowacki & Abrams 2008)

D.Cichowski-near Ootsa Lake

Results of three field studies

- Lodgepole pine – lichen after Mountain Pine Beetle

  Cichowski et al.2008,2009; NAFEW 2007

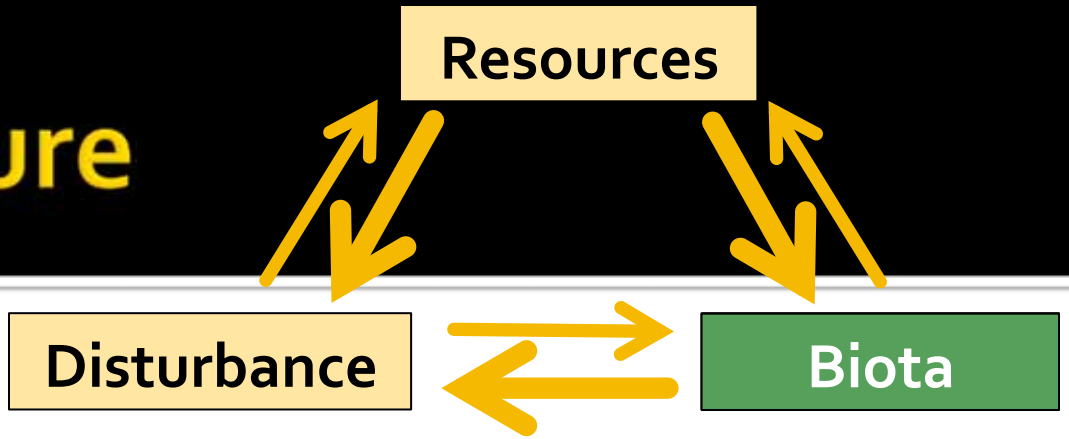
  - Tweedsmuir-Entiako herd –423 plots (2001-2008): **-38%**
  - Itcha-Ilgatchuz herd –300 plots (2005-2008): **-21%**

- Whitebark pine – lichen ecosystem resilience

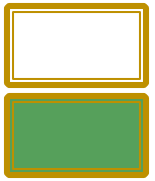
  Haeussler et al. *in review;* Alana Clason MSc

  - revisiting 25-30 yr-old plots & spatial pattern analysis

Model Structure



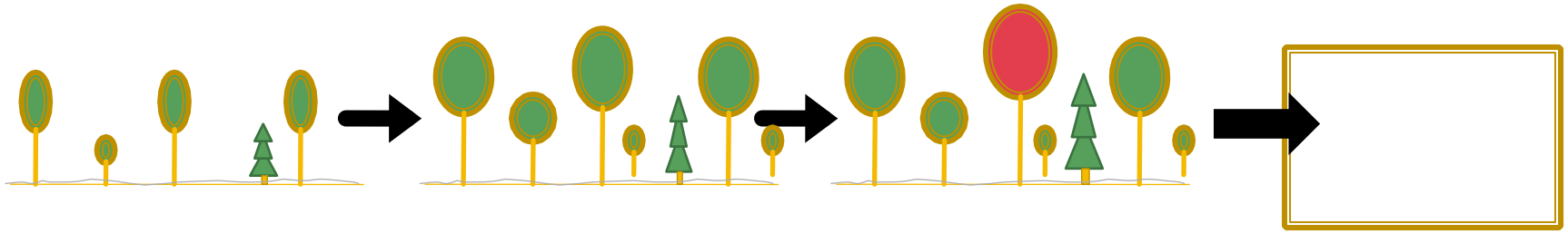
- Two Successional Attractors (alternative states)
  - Pine-Lichen woodland (dwarf ericaceous shrubs)
  - Spruce-Fir – Moss mesic forest (Vaccinium)



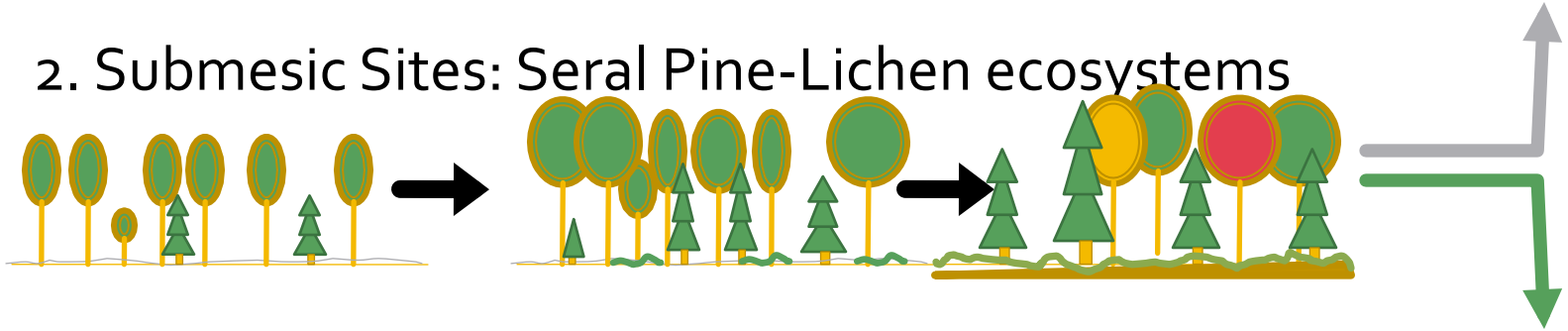
- Changing Resources
  - General climate warming: temp ↑; precipitation ↑ ?
  - PDO regime shifts (Negative-Cold phase: cold snowy winter, dry summer; Positive-Warm phase: warm dry winter, cool moist summer)
- Changing Disturbance Regimes
  - Fire suppression, fewer fires in warm PDO phase
  - Mountain pine beetle (favoured by warmer temps & older stands)
  - Clearcut Logging (ubiquitous in lodgepole pine landscape)
  - White pine blister rust (ubiquitous in whitebark pine landscape)
  - ??????

Classical Forest Succession

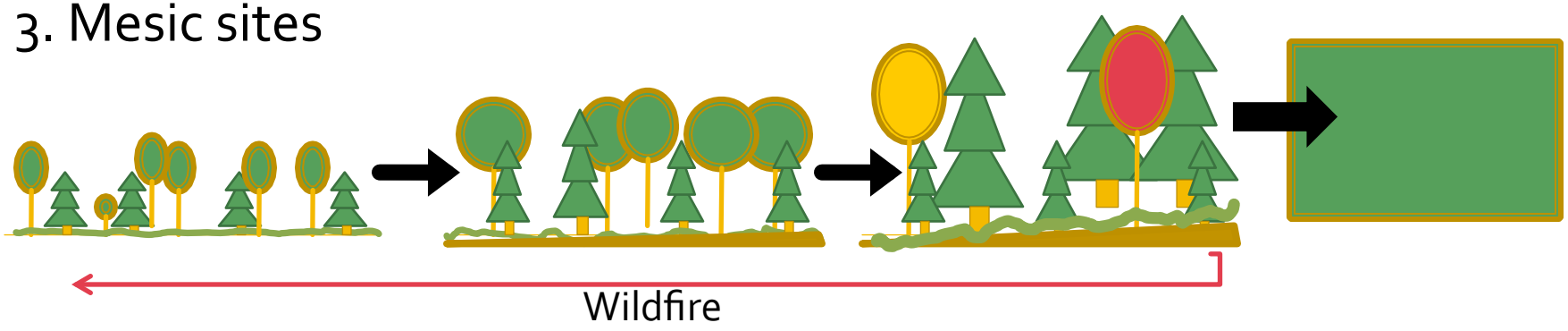
1. Xeric sites: Persistent (non-successional) Pine-Lichen



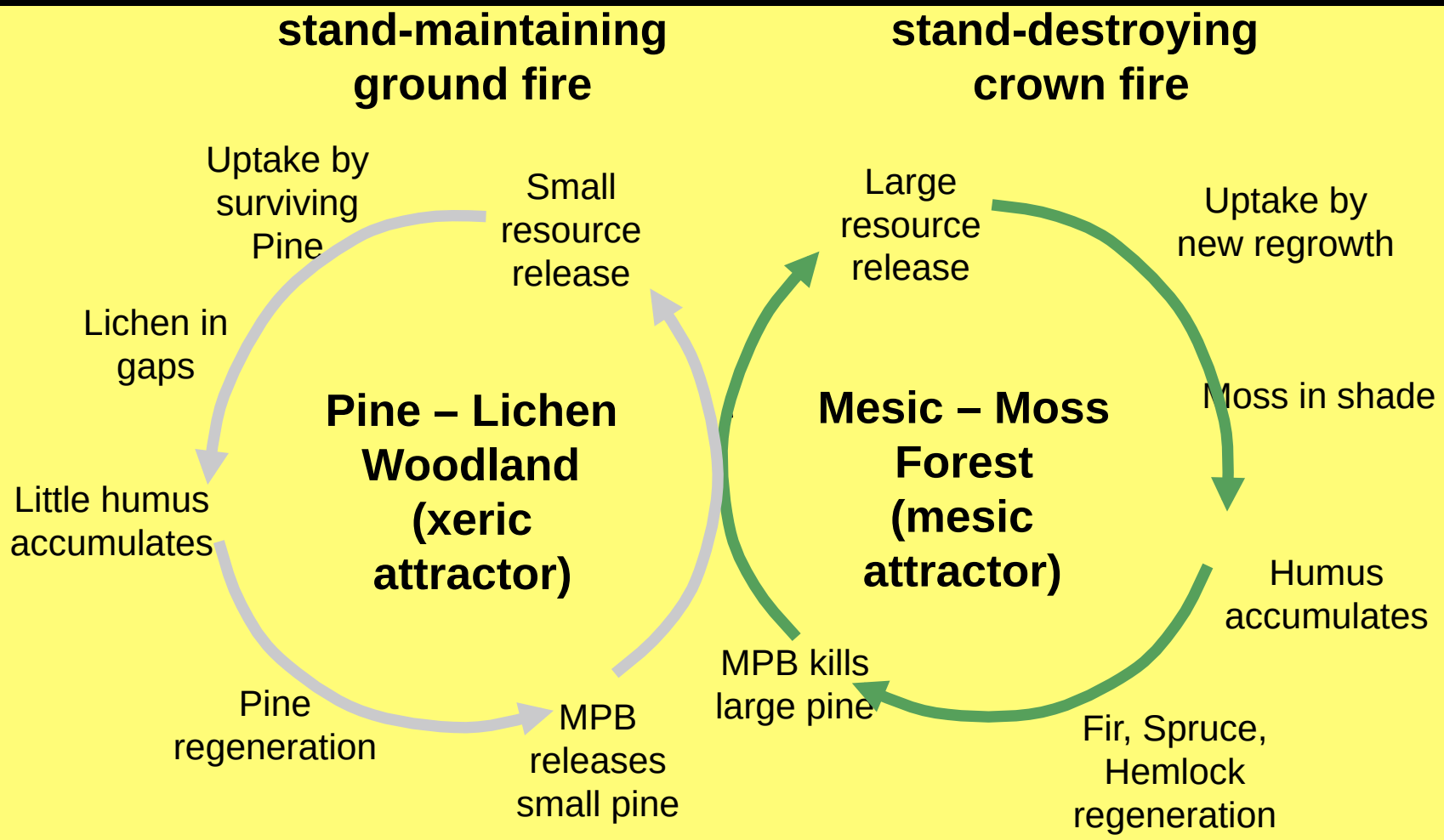
2. Submesic Sites: Seral Pine-Lichen ecosystems



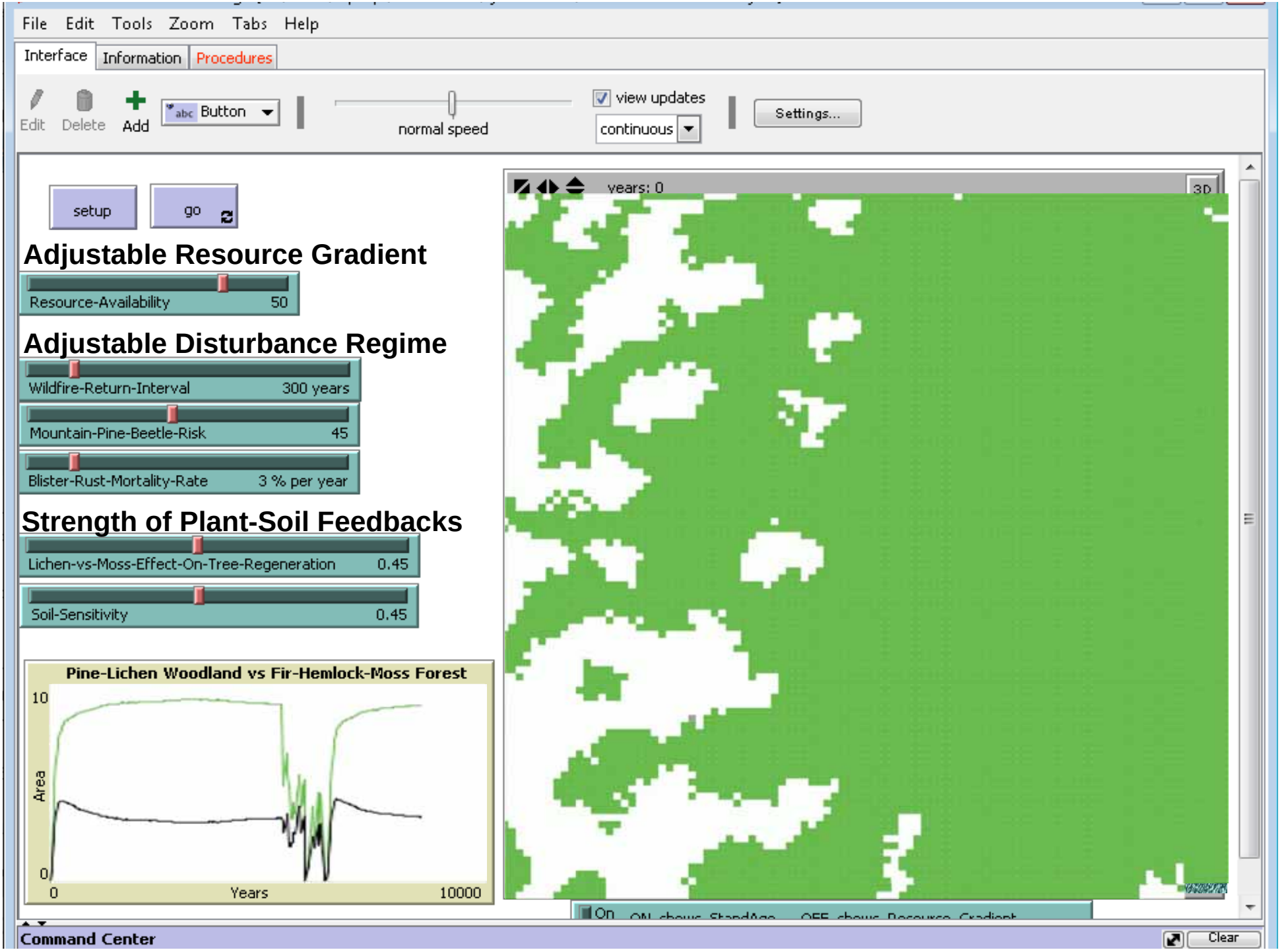
3. Mesic sites



Plant-Soil Feedbacks



(modified from Sedia & Ehrenfeld 2003, Jasinski & Payette 2005)


File Edit Tools Zoom Tabs Help
Interface Information Procedures
Edit Delete Add Button
normal speed
view updates
continuous
Settings...
setup
go
Adjustable Resource Gradient
Resource-Availability 50
Adjustable Disturbance Regime
Wildfire-Return-Interval 300 years
Mountain-Pine-Beetle-Risk 45
Blister-Rust-Mortality-Rate 3 % per year
Strength of Plant-Soil Feedbacks
Lichen-vs-Moss-Effect-On-Tree-Regeneration 0.45
Soil-Sensitivity 0.45
Pine-Lichen Woodland vs Fir-Hemlock-Moss Forest
10
Area
0
0
Years
10000
years: 0
3D
Command Center
Clear

Linear Assumptions

1) Under a stable climate, successional pathways & disturbance regimes are fixed properties of the ecosystem.
2) Climate envelope model: as the climate warms, higher elevation ecosystems take on the characteristics of lower elevation ecosystems
3) "Enduring" site features determine the pattern of ecosystems across the landscape

Non-linear Assumptions

1) Climate was never stable but oscillated between Positive & Negative PDO phases as well as longer/shorter trends (Little Ice Age/El Niño)
2) Successional pathways and disturbance regimes are not fixed, resulting in shifting attractors through time
3) Historical contingency and self-organization strongly influence the pattern of ecosystems across the landscape

Acknowlegements

- UBC Forest Sciences, BV Research Centre Smithers
- Suzanne Simard, UBC
- Evelyn Hamilton & Elizabeth Campbell, MFR
- Debbie Cichowski , Caribou Ecological Consulting
- John Youds, Harold Armleder, Michaela Waterhouse – Itcha-Ilgatchuz study
- Alana Clason, Ellen Macdonald U. of Alberta
- Leanne Helkenberg, Anita Norman
- Allen Banner & crew, Alex Woods, Phil LePage, Ken White, BC Forest Service Smithers
- BC Forest Science Program – research funding
- Santa Fe Institute – summer school funding