Heterogeneity, legacies, and convergence: forest structure and function on Rocky Mountain landscapes

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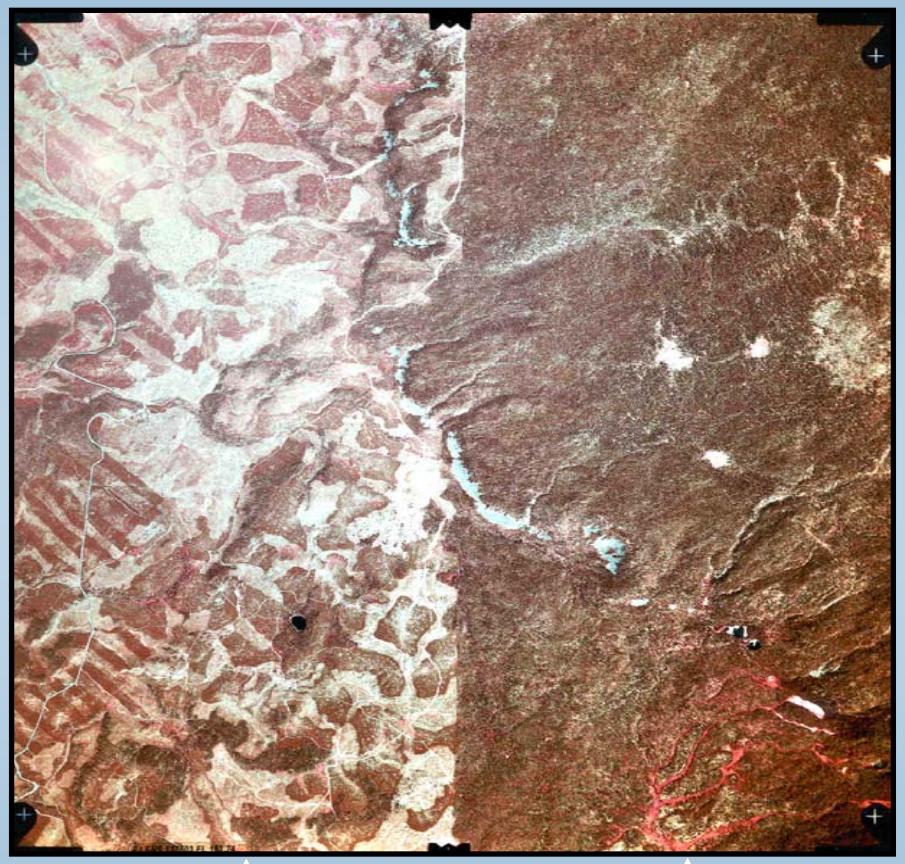
Defining landscape ecology

1. Broad spatial scales
2. Spatial heterogeneity
3. Pattern and process
4. The human role/impact



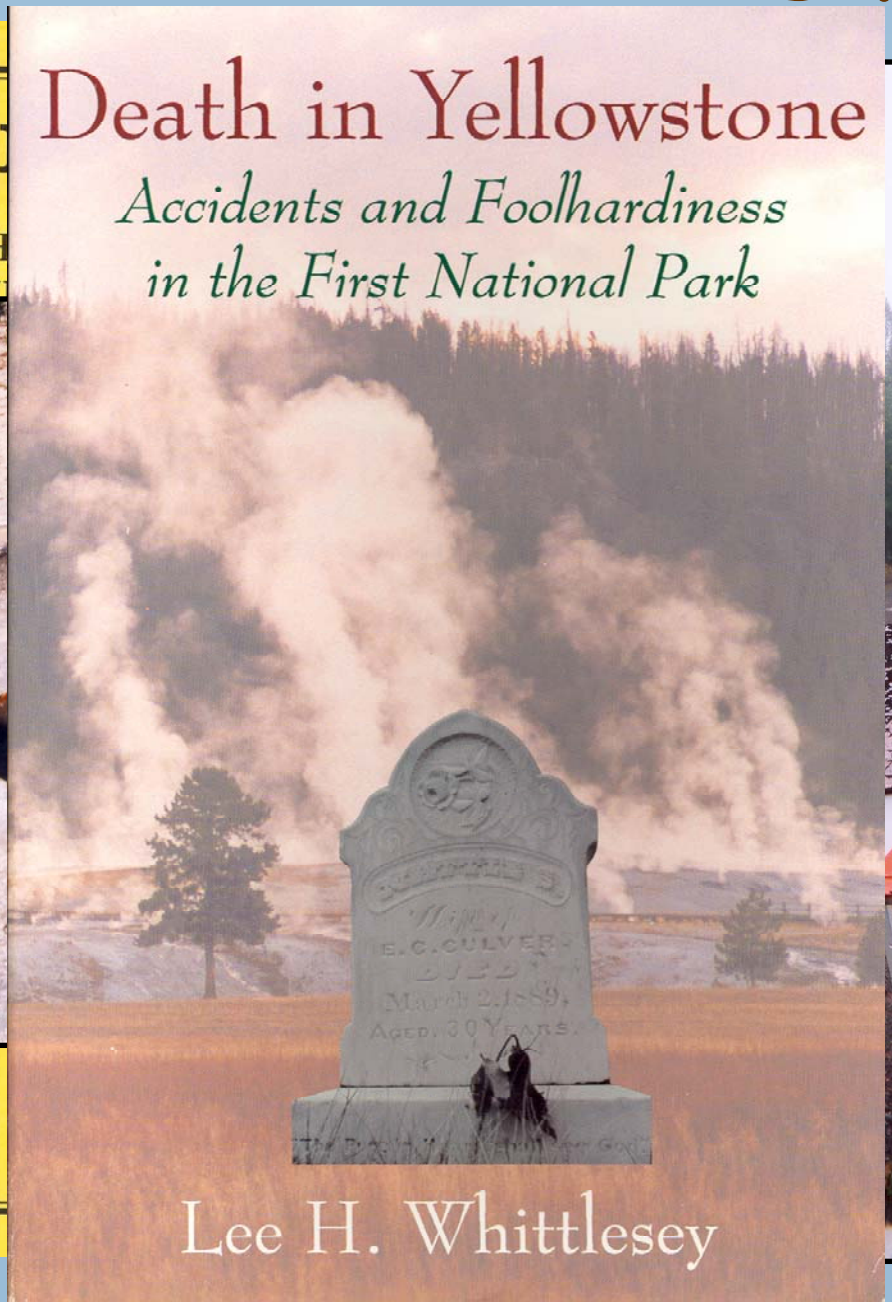
Targhee National Forest

Yellowstone National Park

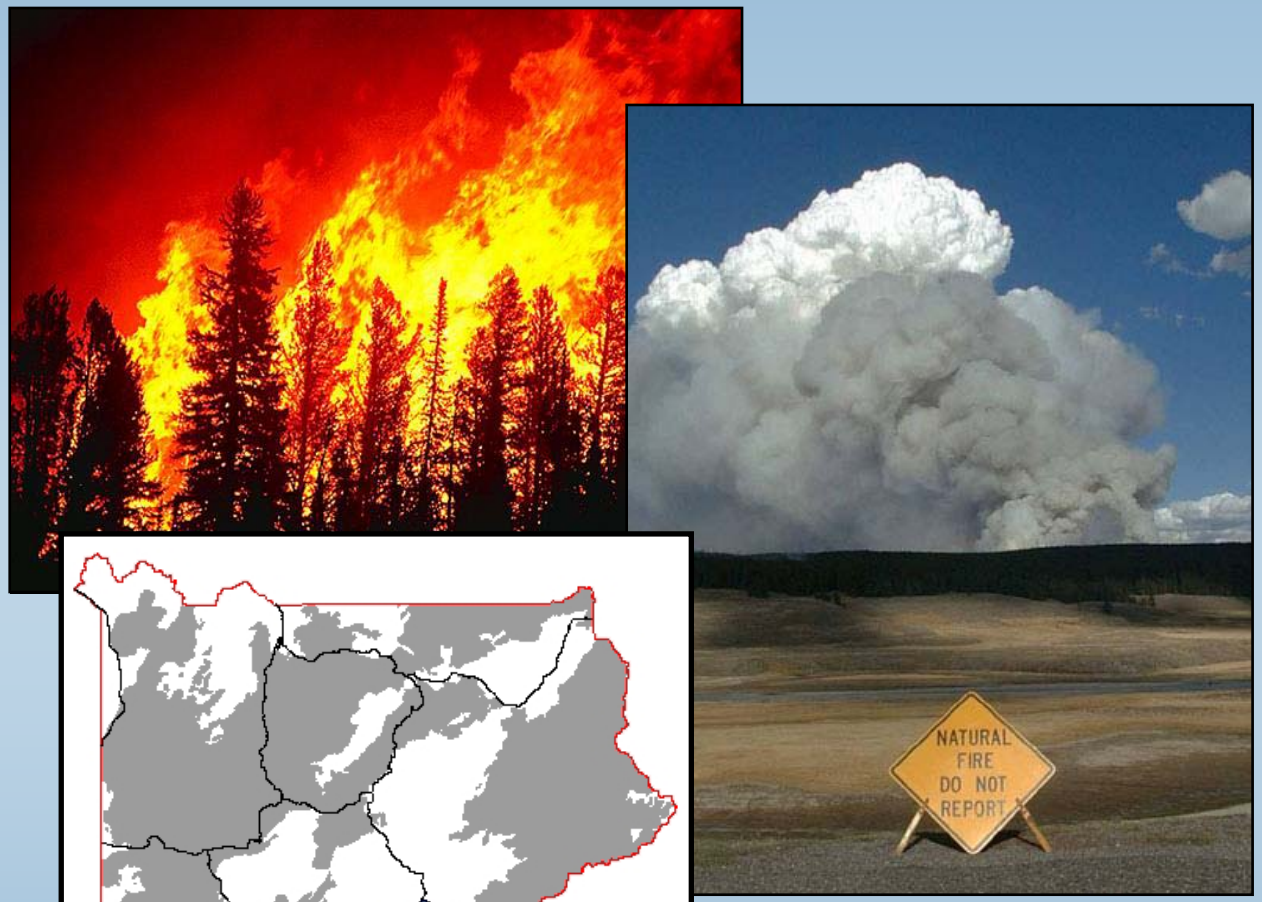
Outline

- **The 1988 fires in Yellowstone**
  - Post-fire heterogeneity in forest regeneration
- **Variability and convergence in forest structure**
- **Climate change and carbon cycling on the Yellowstone landscape**
- **Future directions**

Yellowstone: an exciting place!



The Yellowstone landscape



- Stand-replacing fires
- 100-300 year fire interval
- Large, "natural" landscape

Variation in burn severity

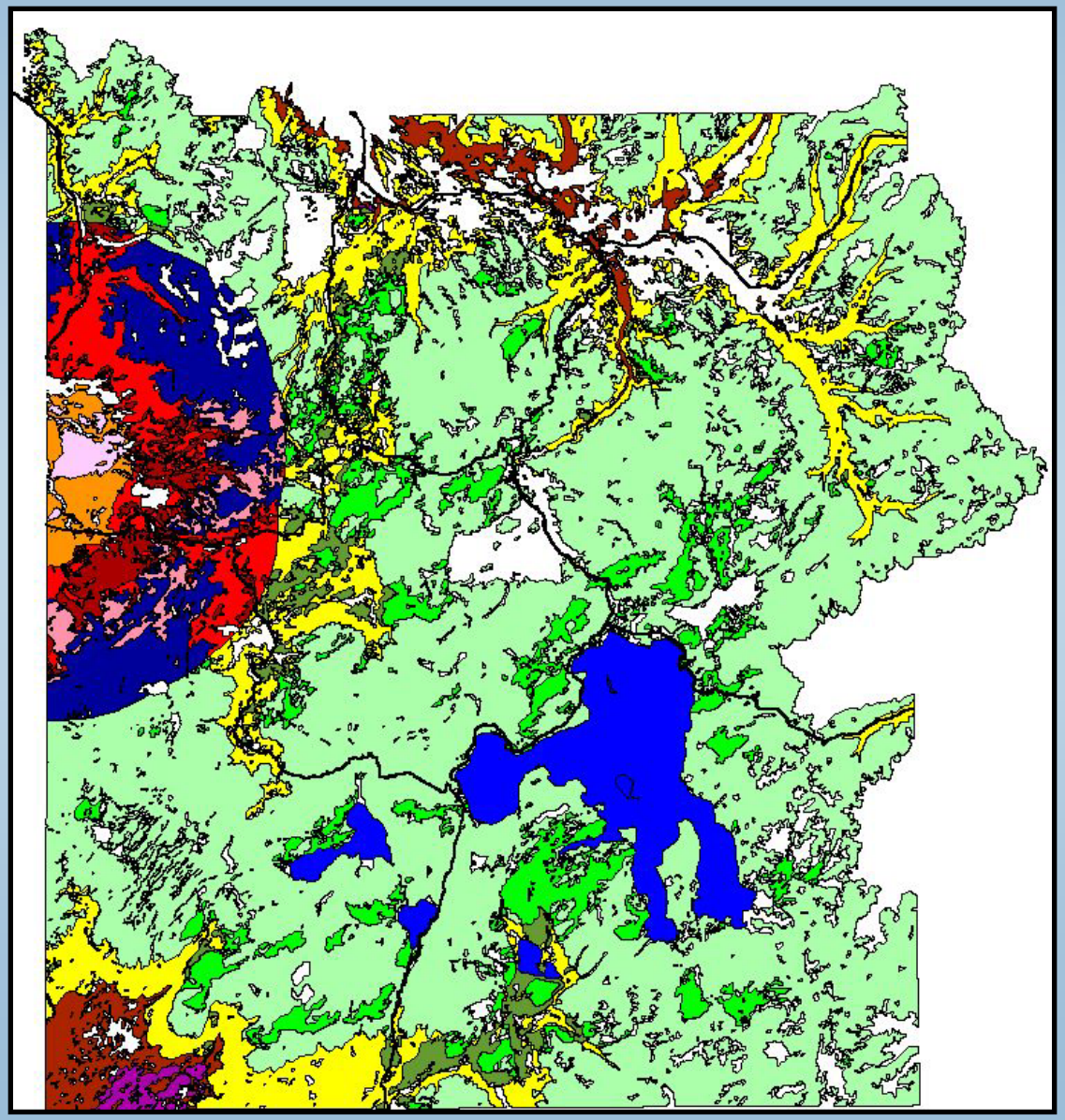
Yellowstone Burn Mosaic, 10/88

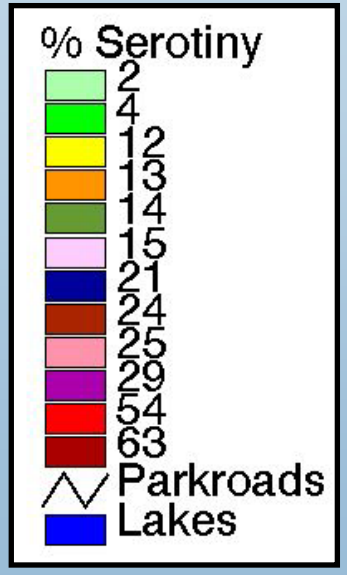
Light/Severe Surface Fire

Severe Surface/Crown Fire

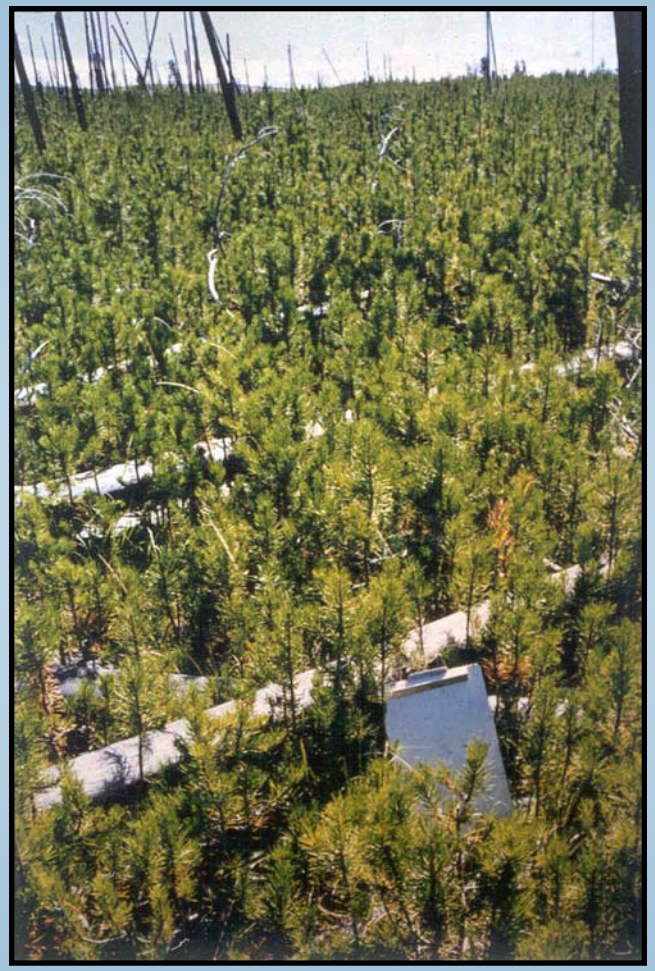
Serotiny in lodgepole pine

Variation in lodgepole pine serotiny





Variation in regeneration density

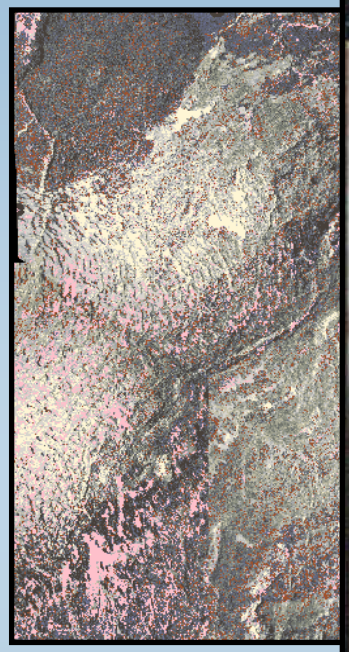


>50,000 stems/ha

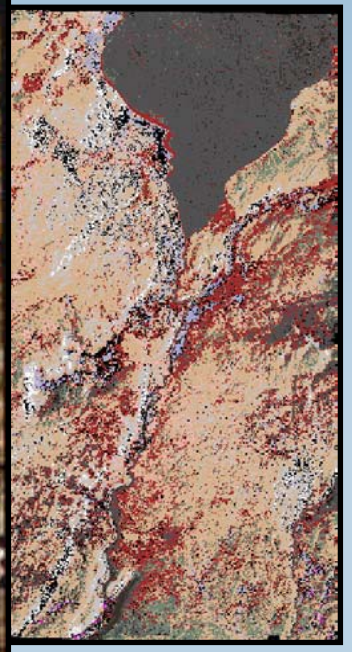
1,000 stems/ha

0 stems/ha

Mapping regeneration density



Orthore



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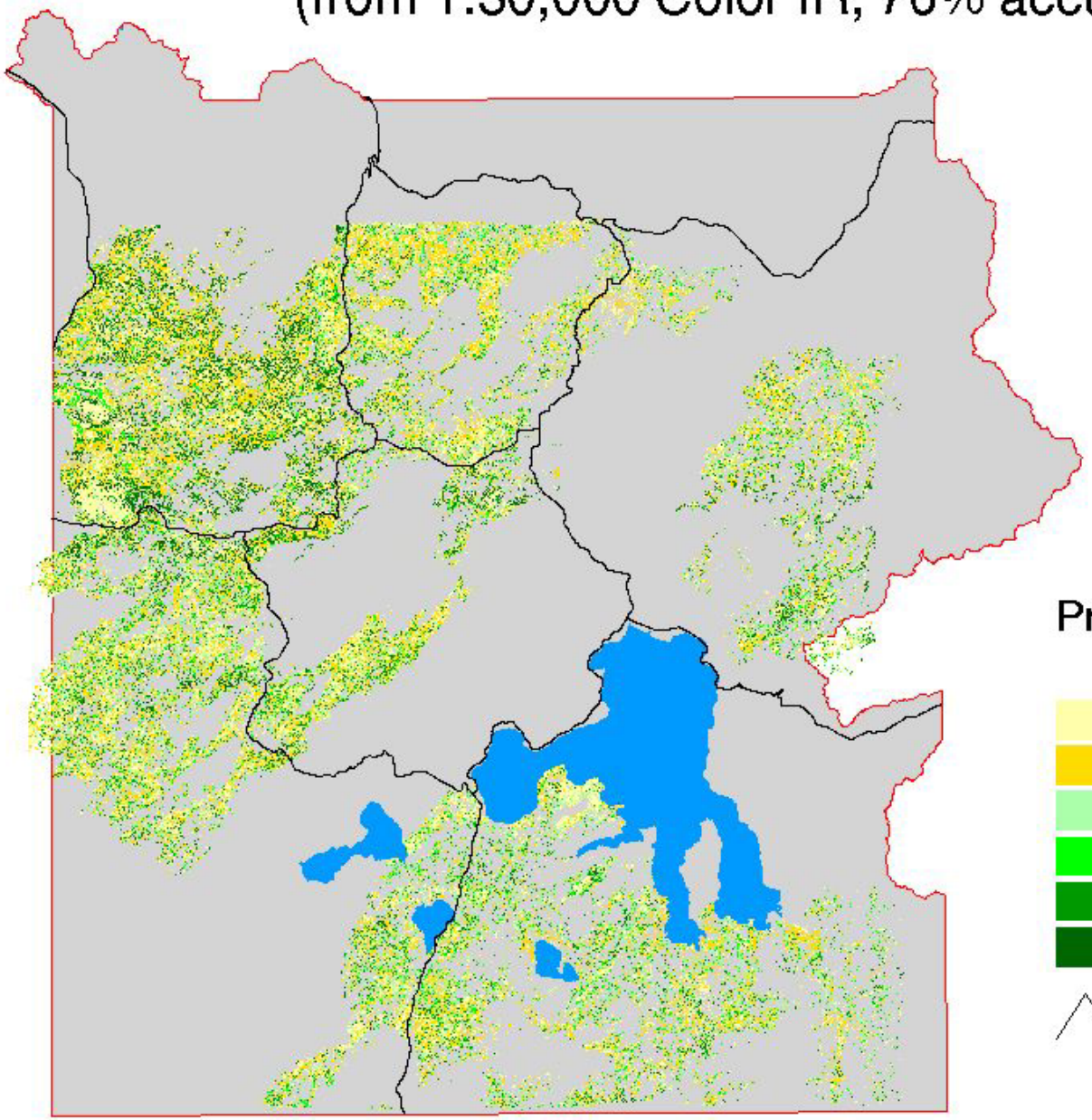
1998 Lodgepole Pine Sapling Density

(from 1:30,000 Color IR, 76% accuracy)



N

5 0 5 10

Kilometers

Predicted Sapling Density
(stems/ha)

- 0-1000
- 1001-5000
- 5001-10000
- 10001-20000
- 20001-50000
- >50000

Park Roads

Do initially dissimilar stand structures eventually converge?

???

???

Stand structure: Methods

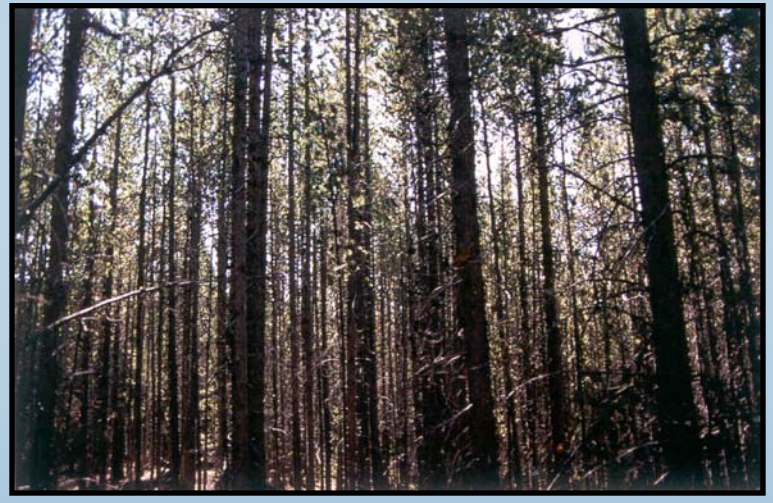
- Chronosequential measurements of unburned stands across the landscape.

- Analyses of size and age structures and spatial patterns

- Regression analyses to reconstruct past density of stands using tree ring widths.

Variation in Stand Density

Stands shown are in the 50-100 year age class

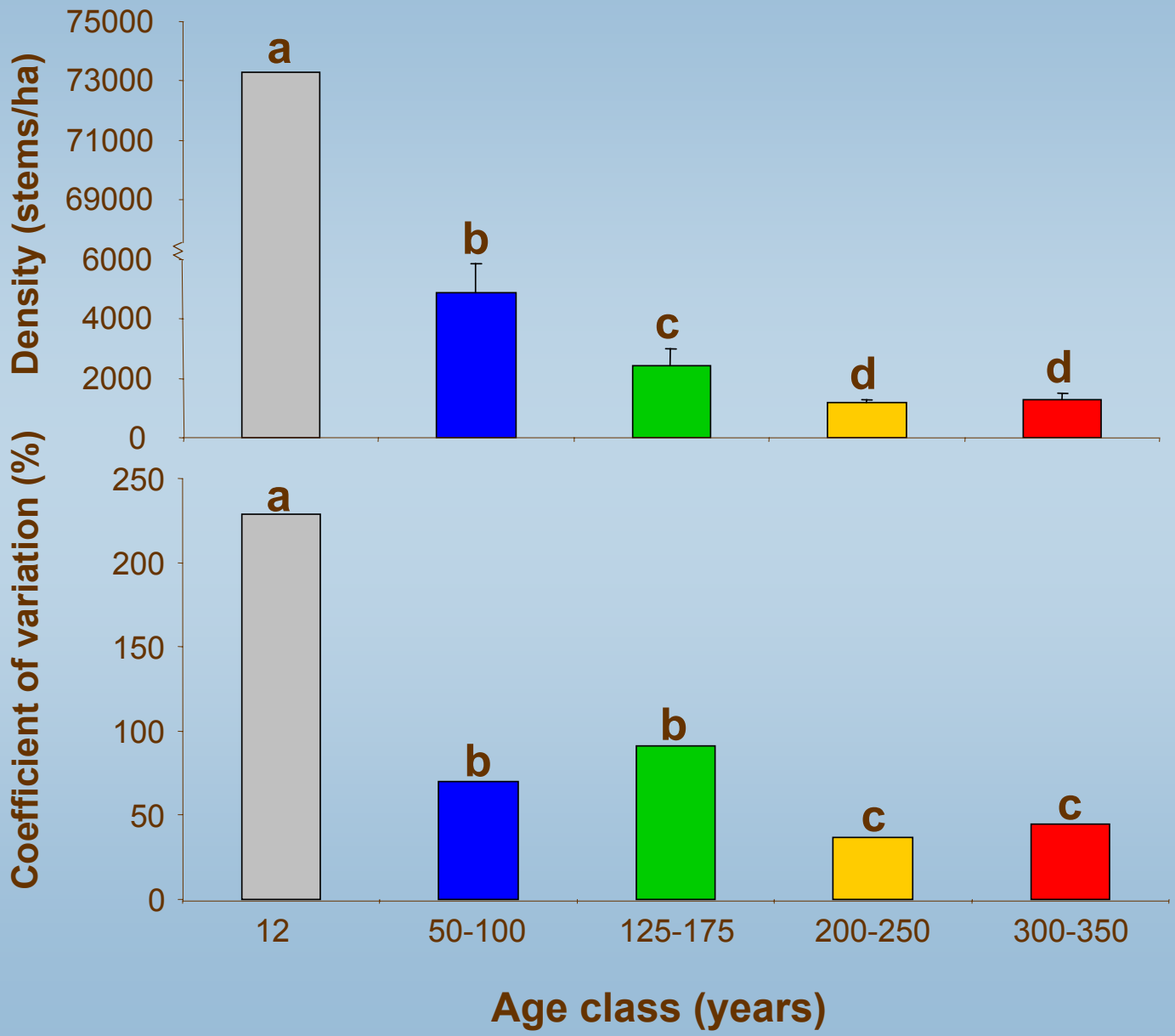


11,000 stems/ha

3,000 stems/ha

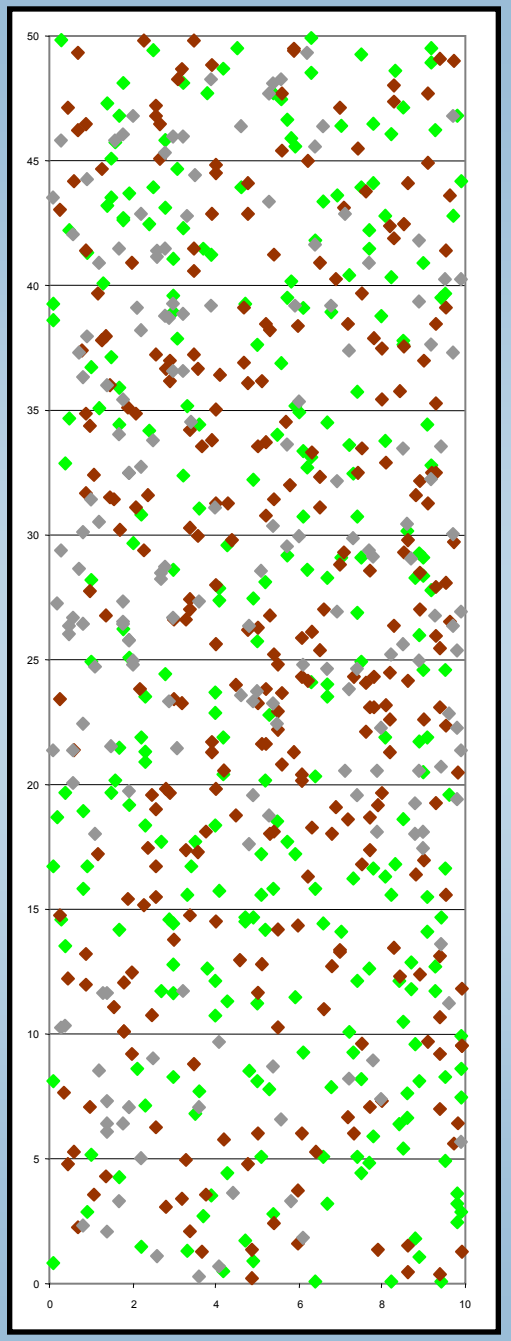
1,100 stems/ha

Variation and change in stand density with age



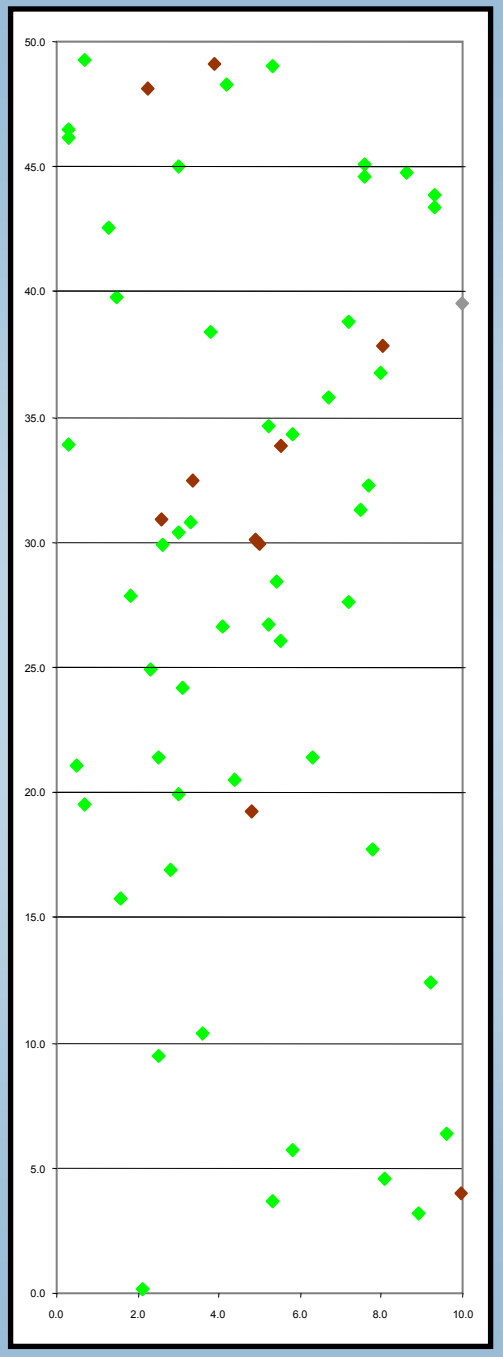
Stand A: Initially dense

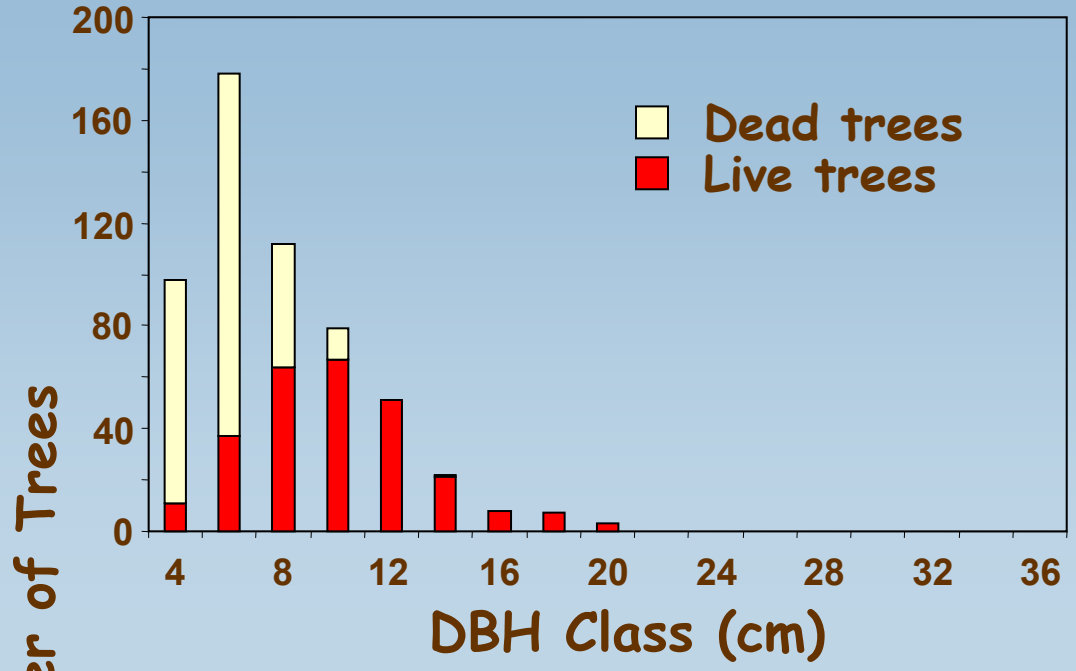
Age: 130 years
Density: 5,400 stems/ha

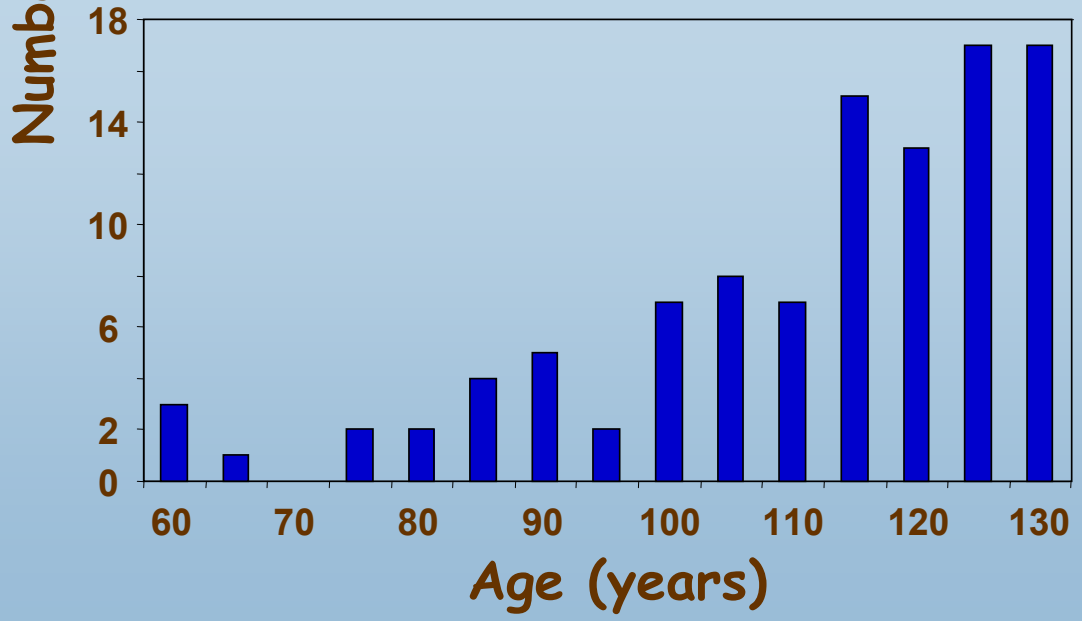


Stand B: Initially sparse

Age: 130 years
Density: 1,020 stems/ha

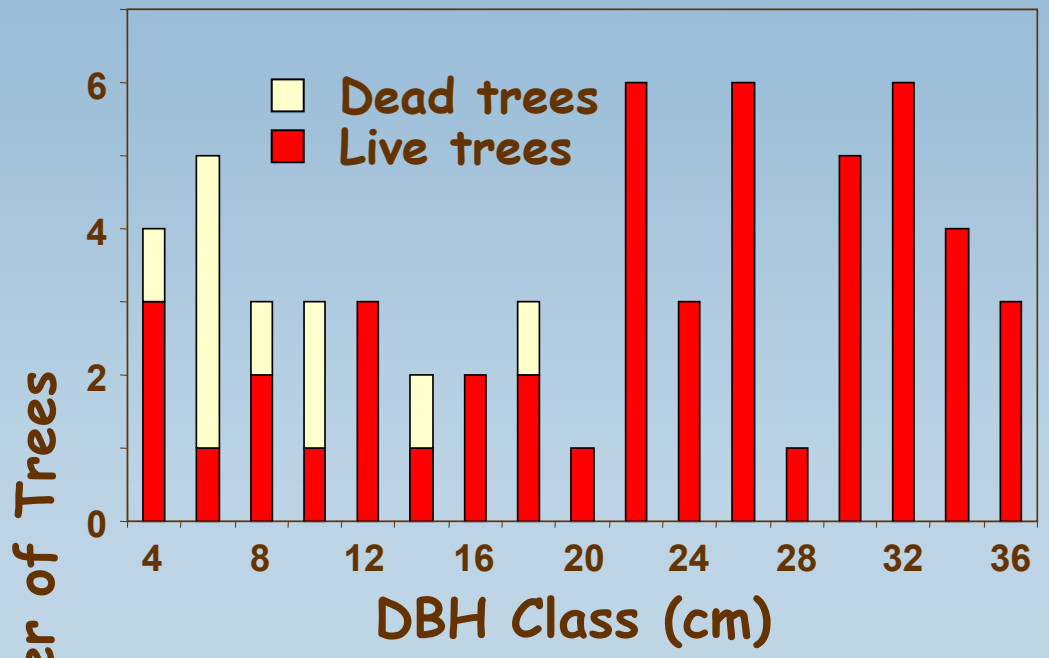


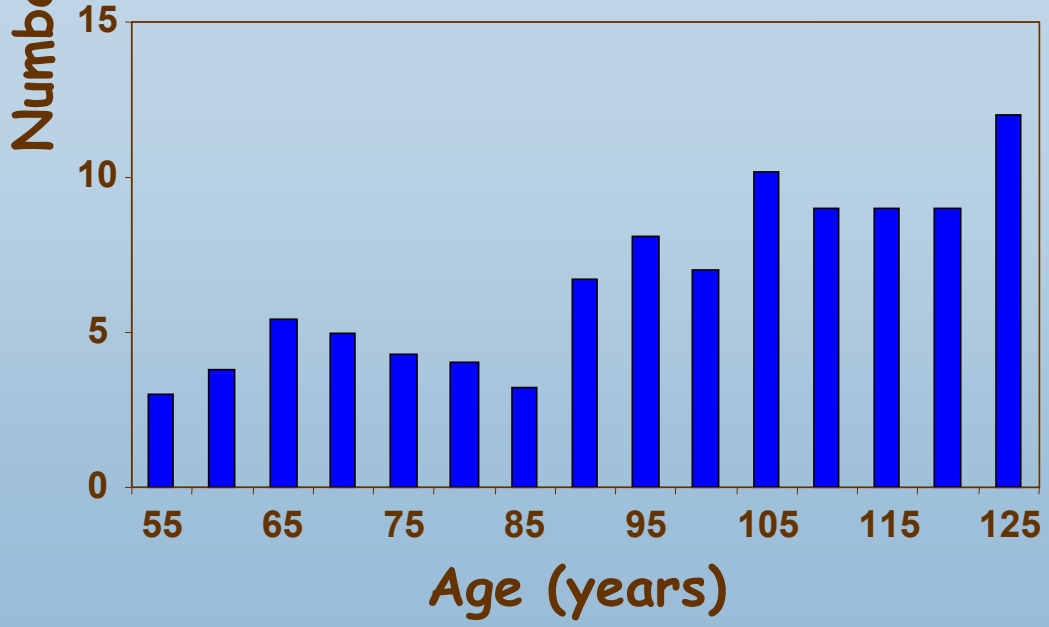




Initially dense stand

- Unimodal, steep distributions
- Dead trees common and small





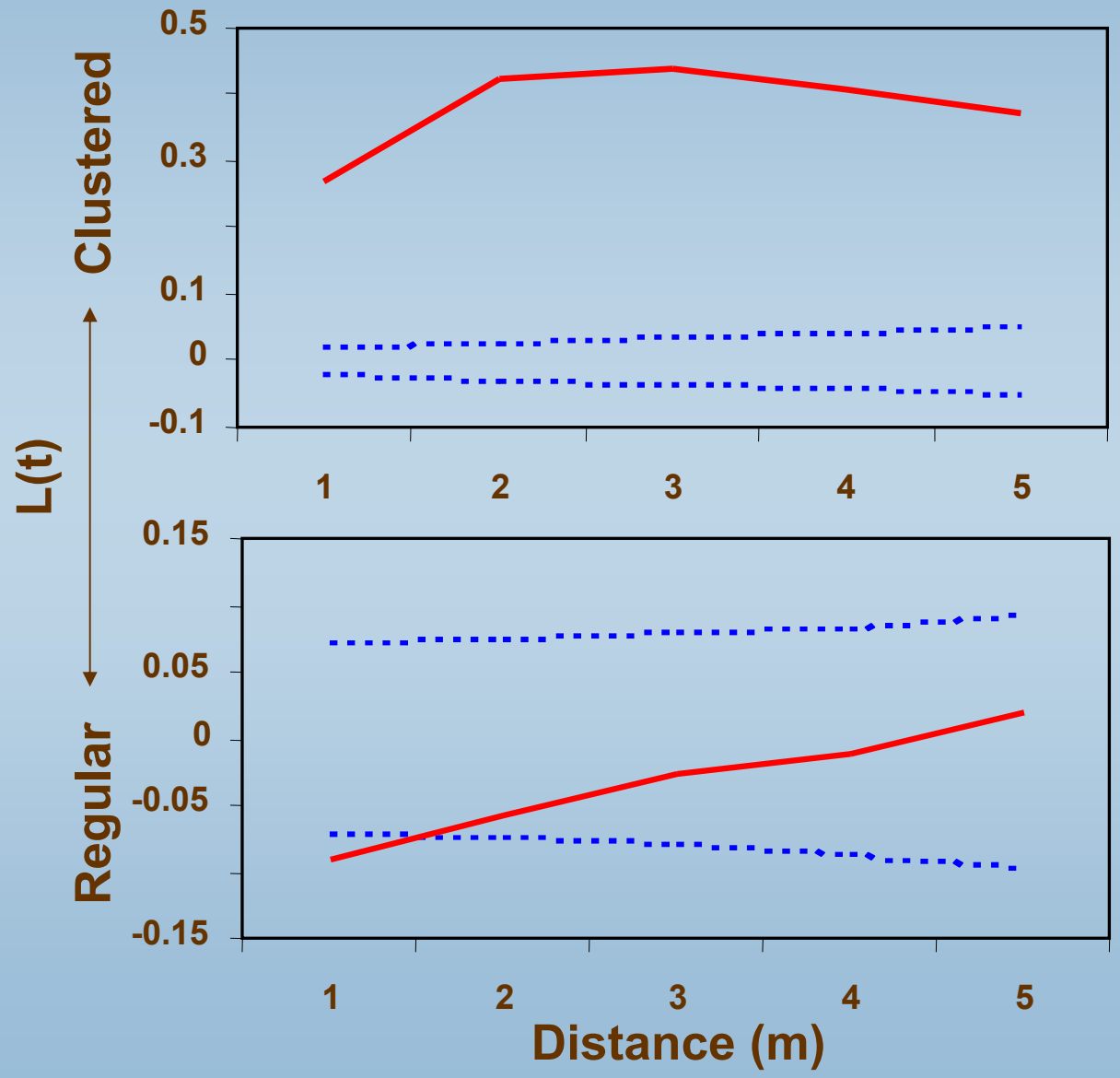
Initially sparse stand

- Bimodal or wide distributions
- Dead trees much less common

Initially dense stand: Spatial patterns

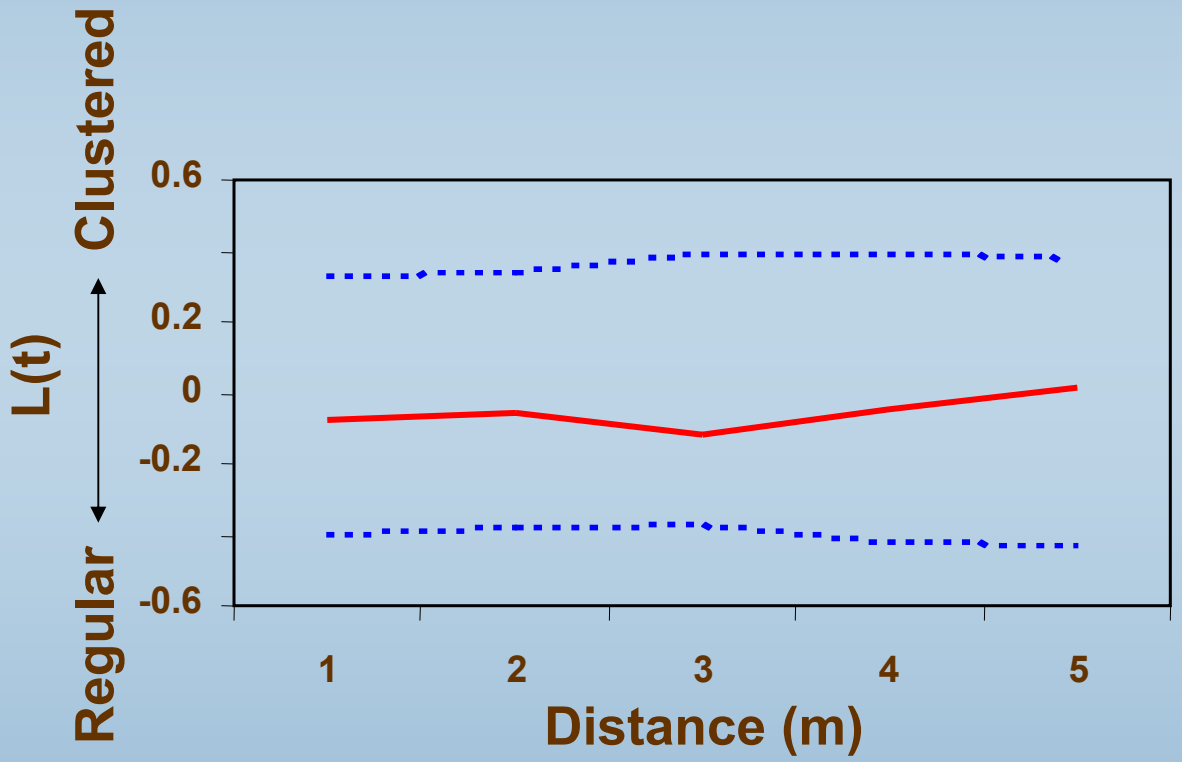
Pre-mortality (live + dead): stems clumped at all scales.

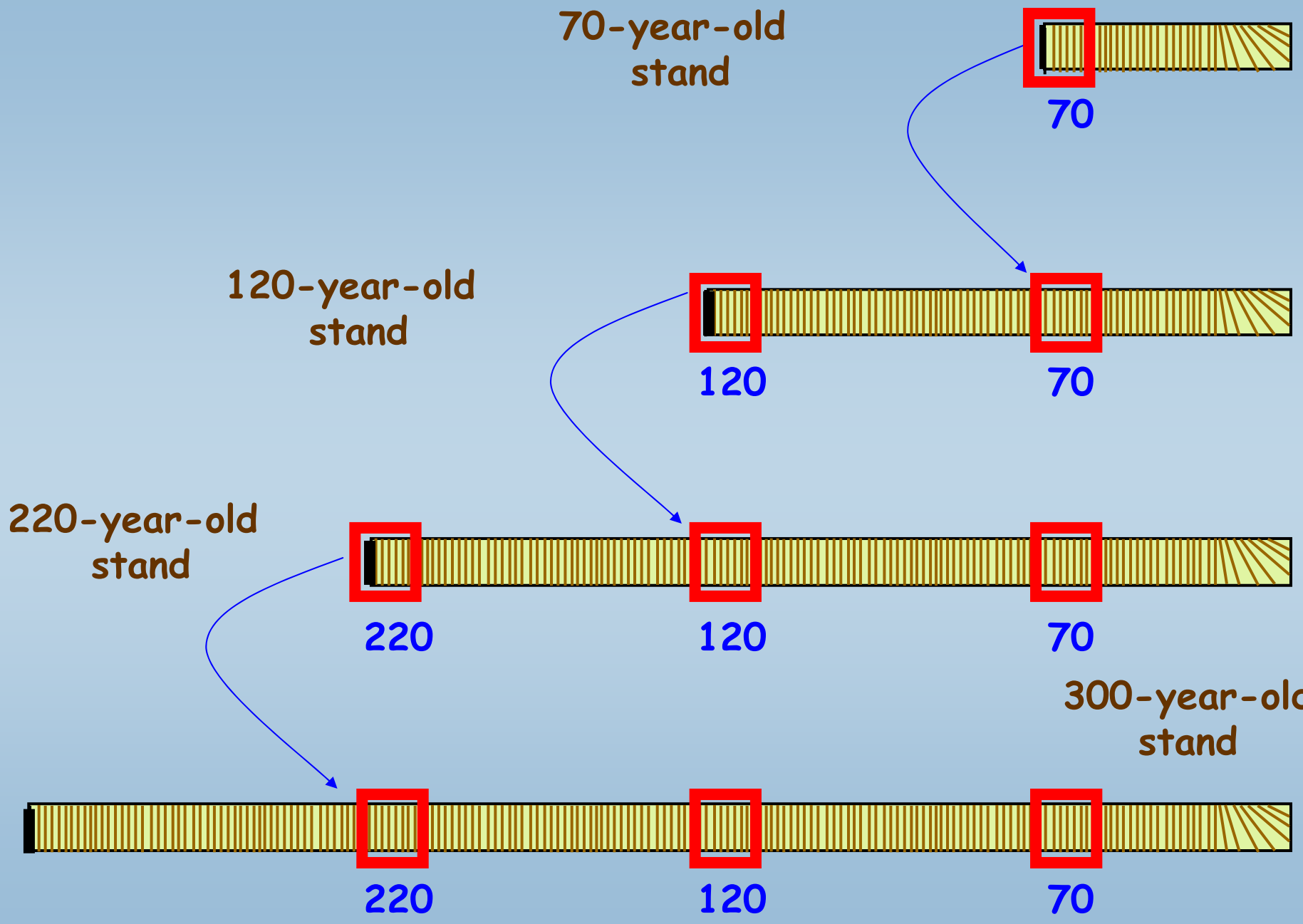
Post-mortality: stems random at most scales



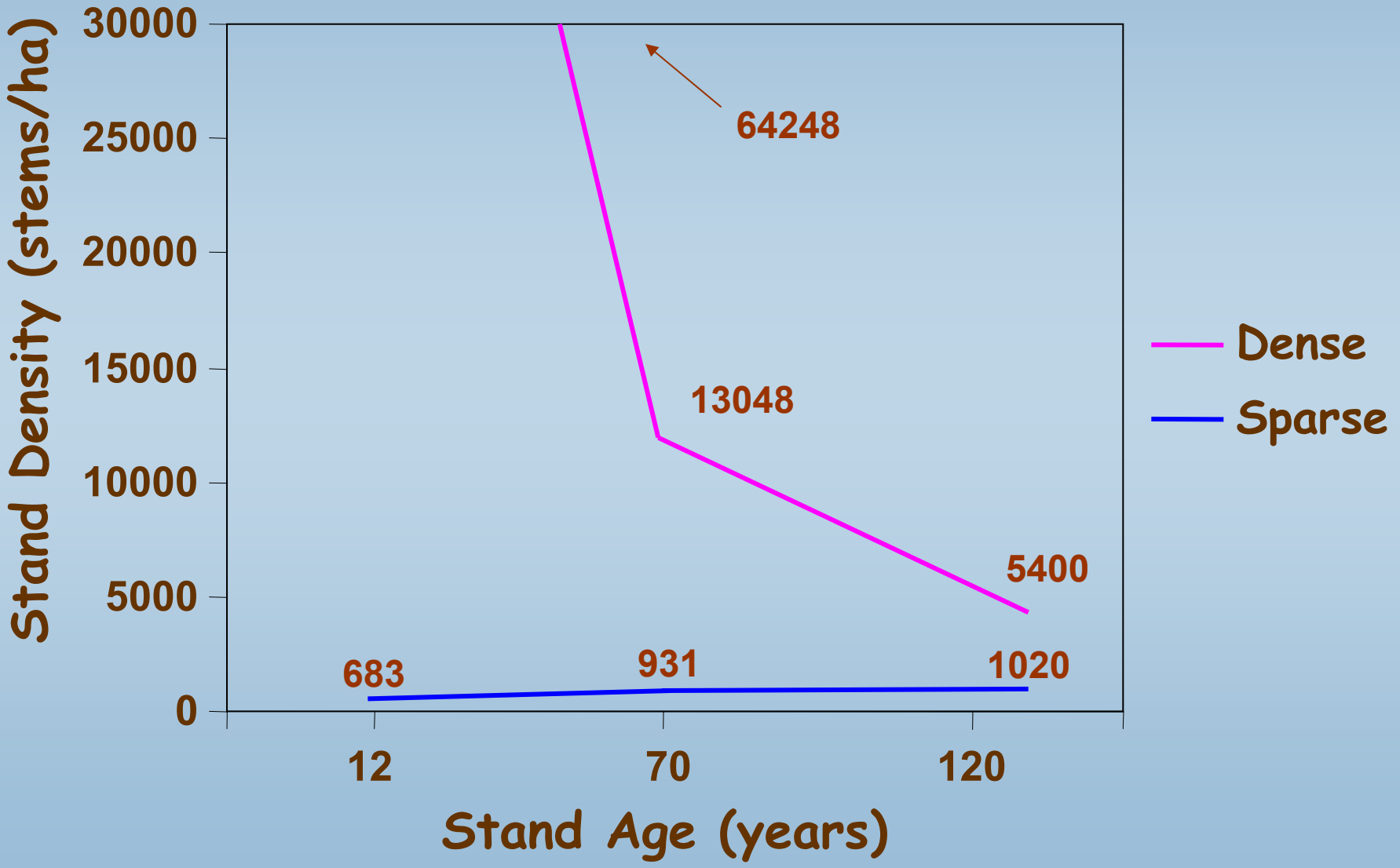
Initially sparse stand: Spatial patterns

Stems random at all scales

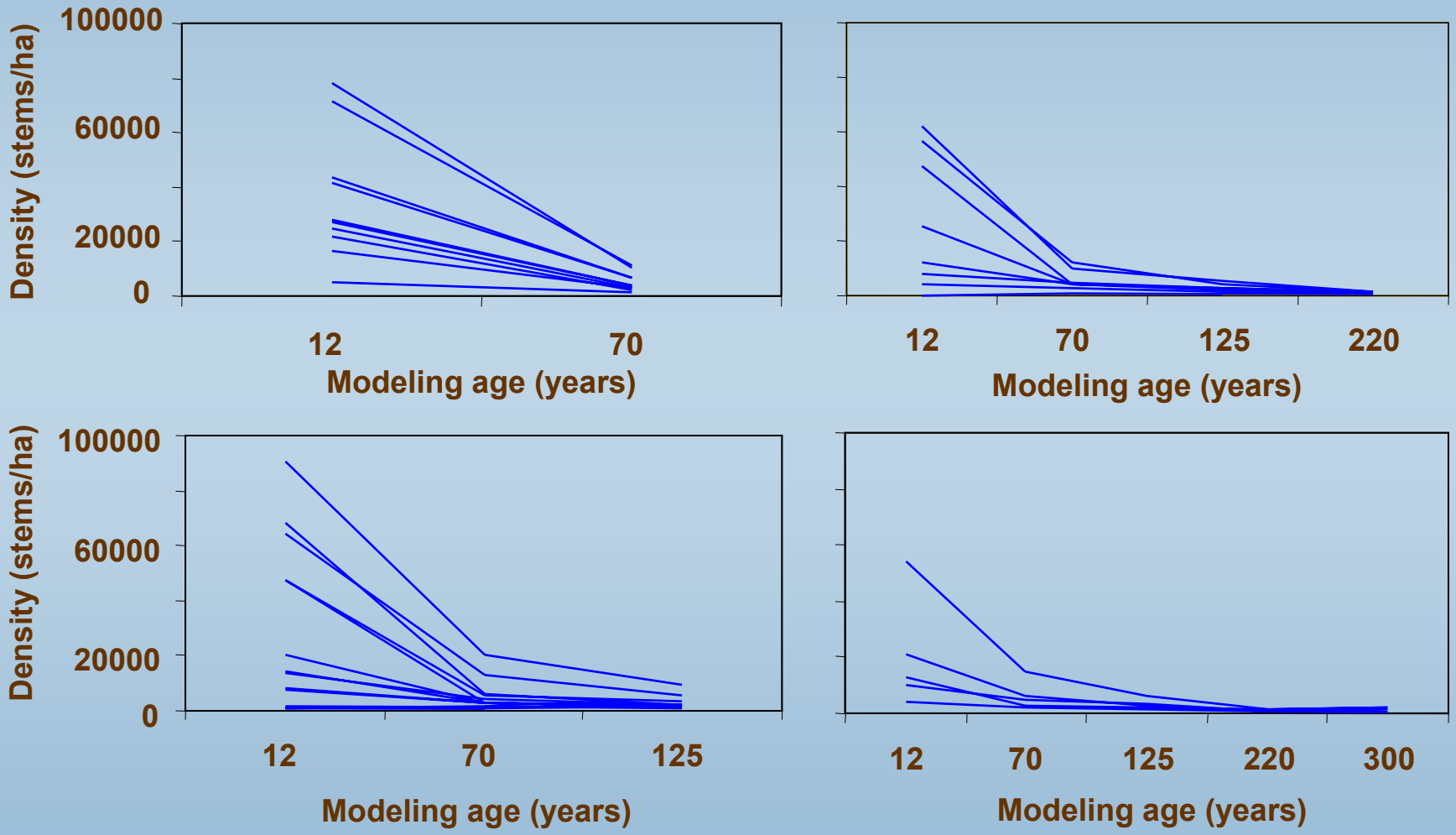



70-year-old stand
70
120-year-old stand
120
70
220-year-old stand
220
120
70
300-year-old stand
220
120
70

Stand Density Trajectory Reconstruction



Stand Density Trajectory Reconstructions

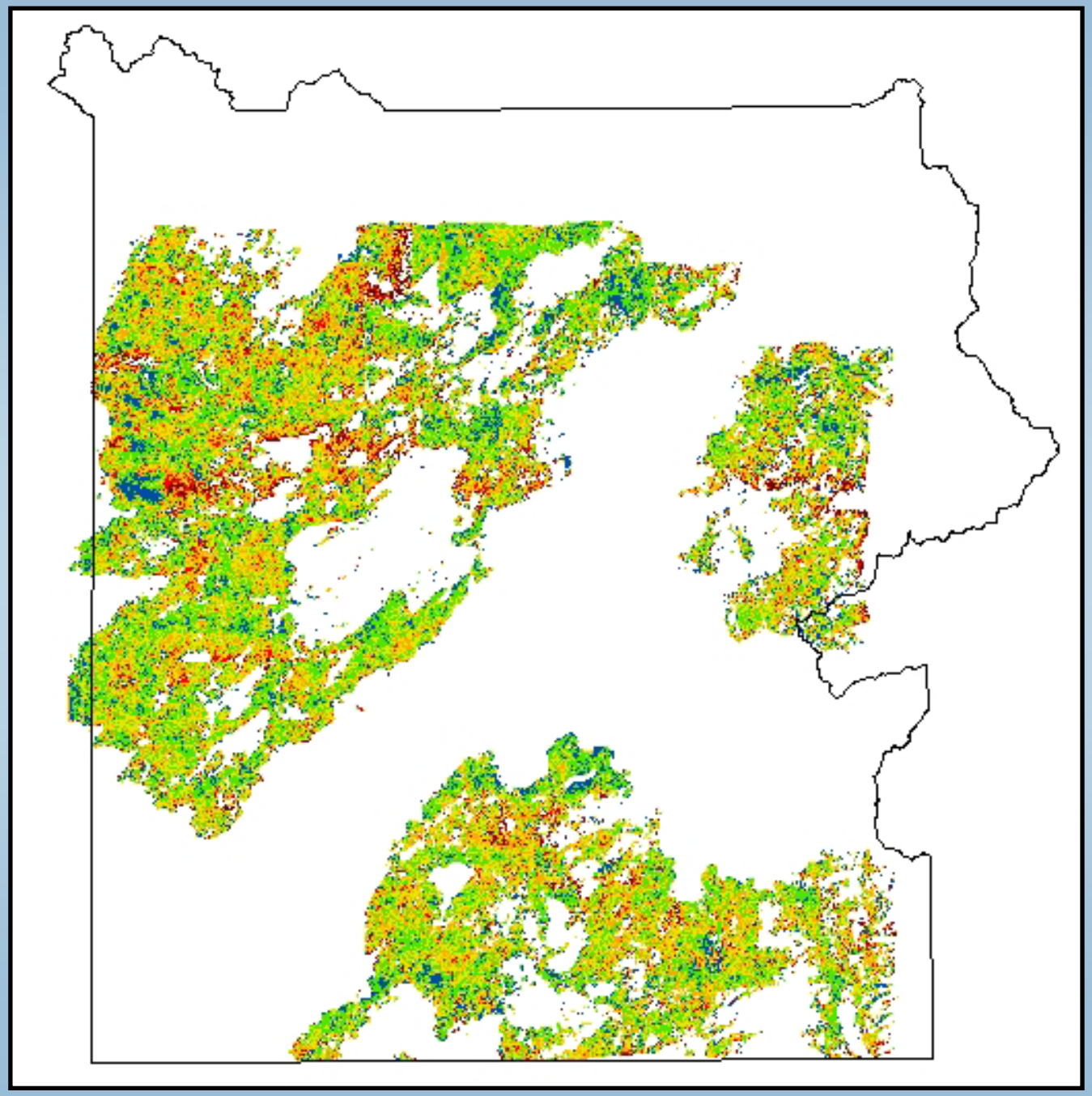


How do stand-level processes affect landscape pattern?

- Rule-based simulation model in Arc based on empirical data.

- Model run on a decadal time step with resolution of 50 meters (0.25 ha).

- Subroutines simulate self-thinning, infilling in young stands, infilling in older stands.

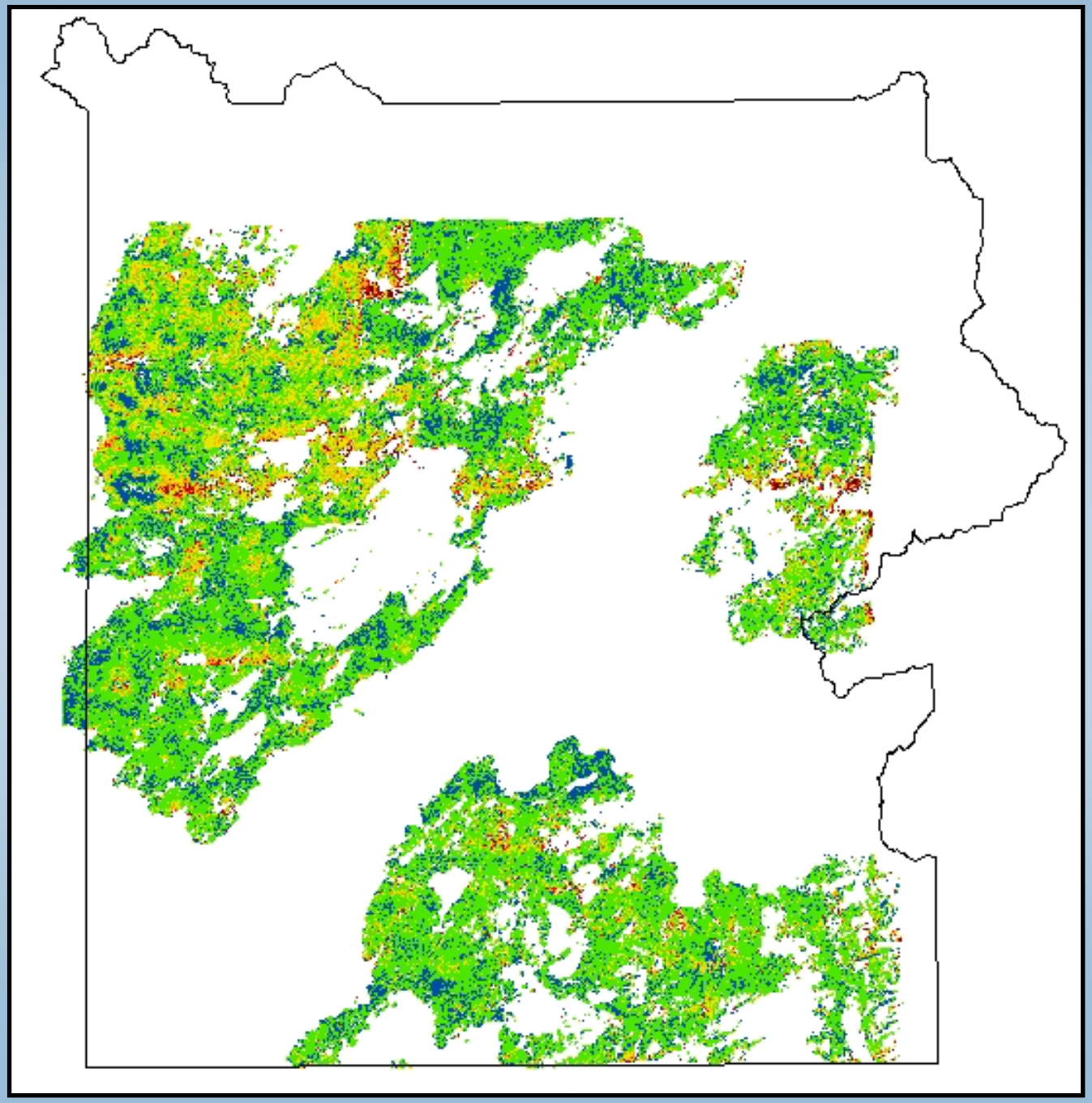


Landscape pattern at 12 years following fire

Relative deviation from median density [(density-median)/ median)]

- -1 – -0.25
- -0.25 – 0.25
- 0.25 – 1
- 1 - 3
- 3 - 5
- >5

Median density = 2.967 stems/ha

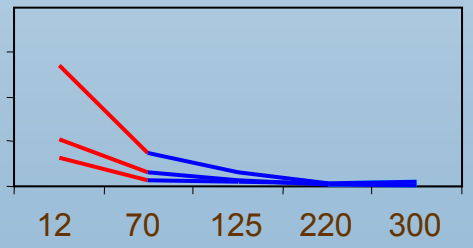


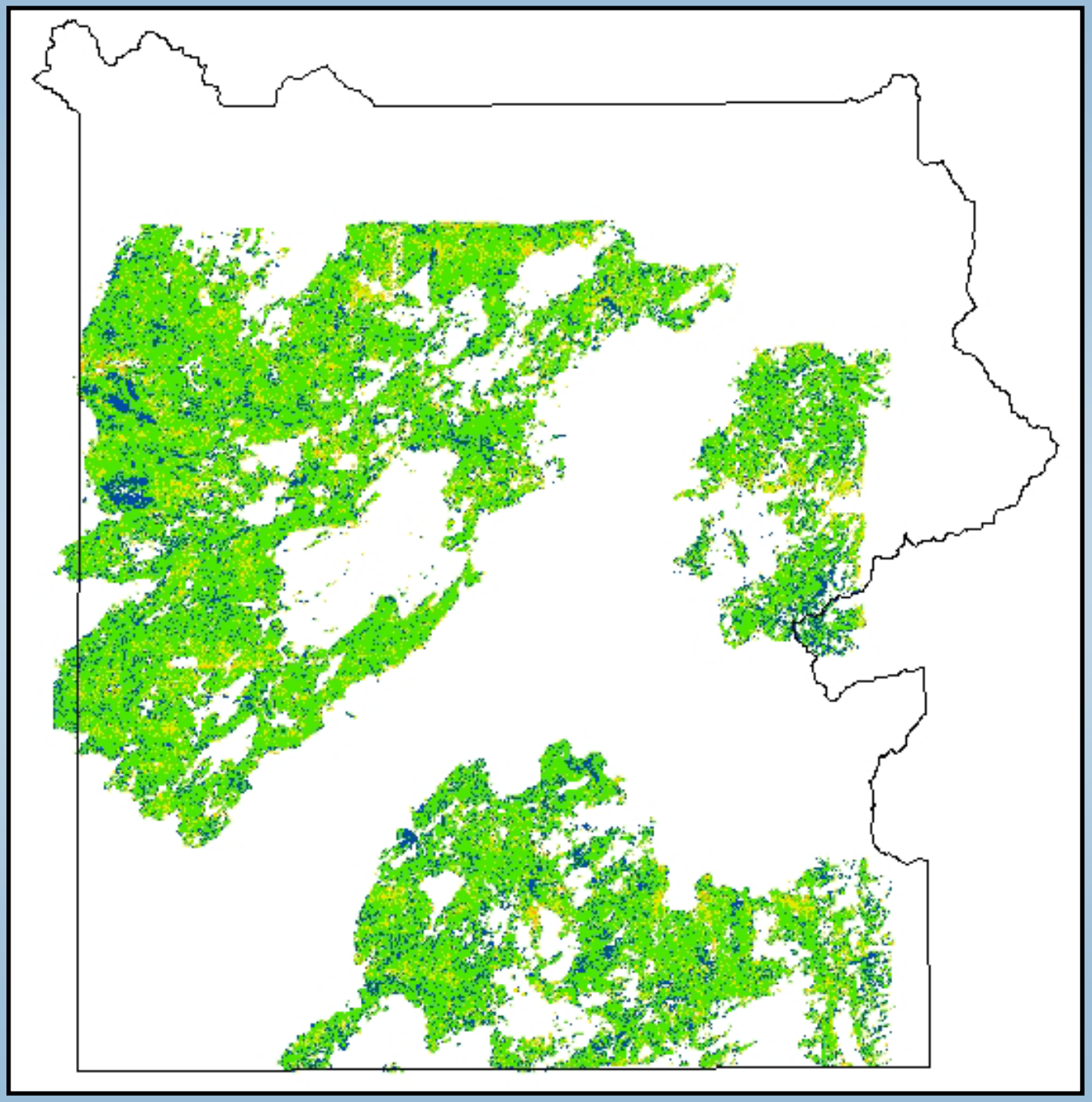
Landscape pattern at 50 years following fire

Relative deviation from median density

- -1 – -0.25
- -0.25 – 0.25
- 0.25 – 1
- 1 – 3
- 3 – 5
- >5

Median density = 1,091 stems/ha



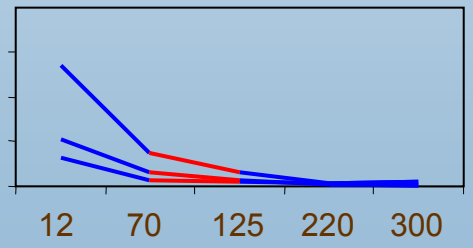


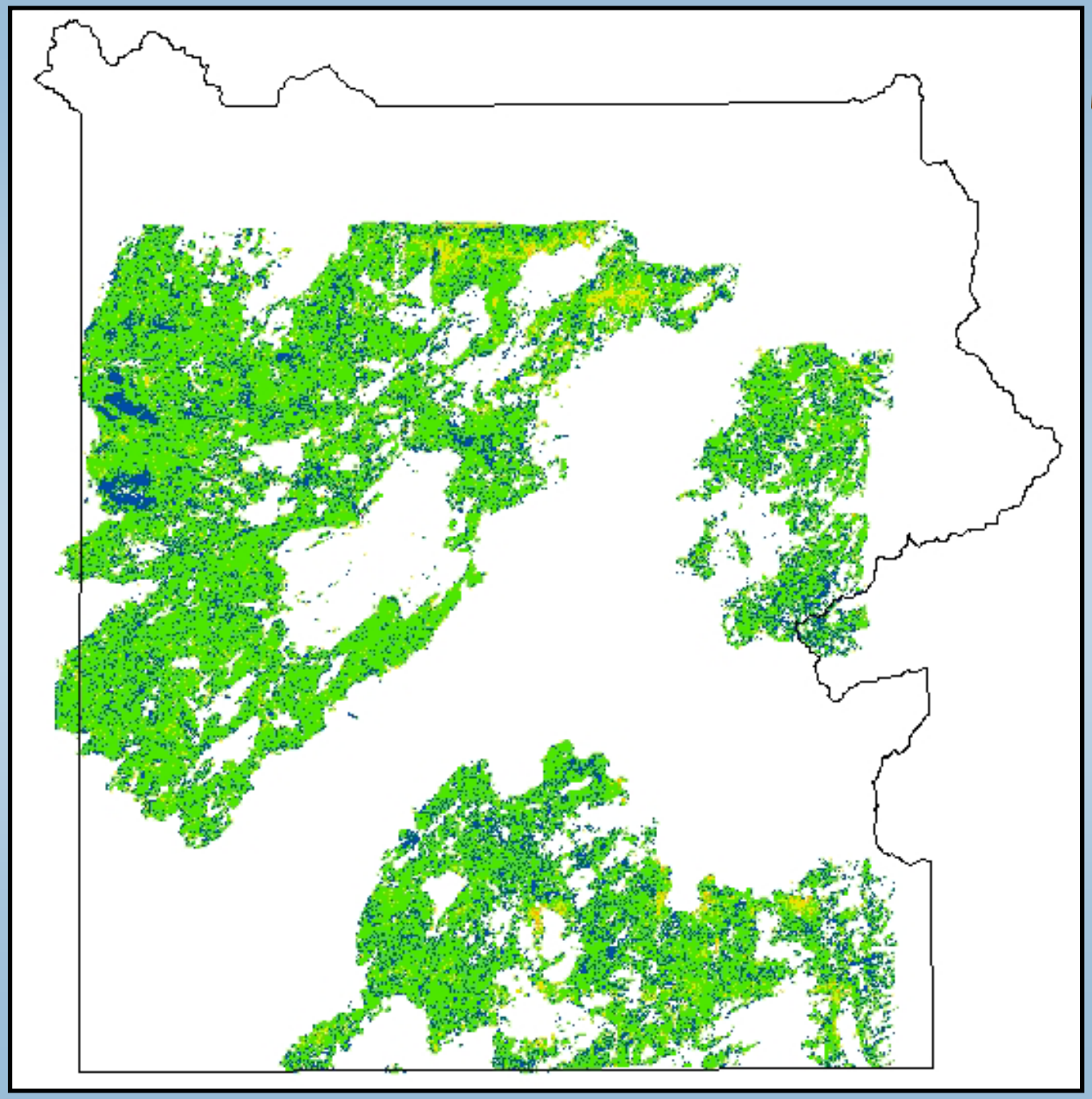
Landscape pattern at 100 years following fire

Relative deviation from median density

- -1 – -0.25
- -0.25 – 0.25
- 0.25 – 1
- 1 – 3
- 3 – 5
- >5

Median density = 866 stems/ha



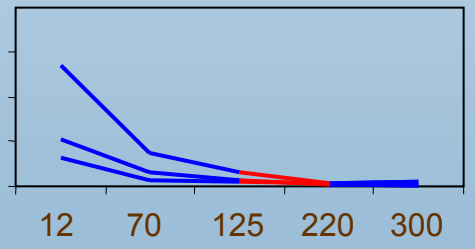


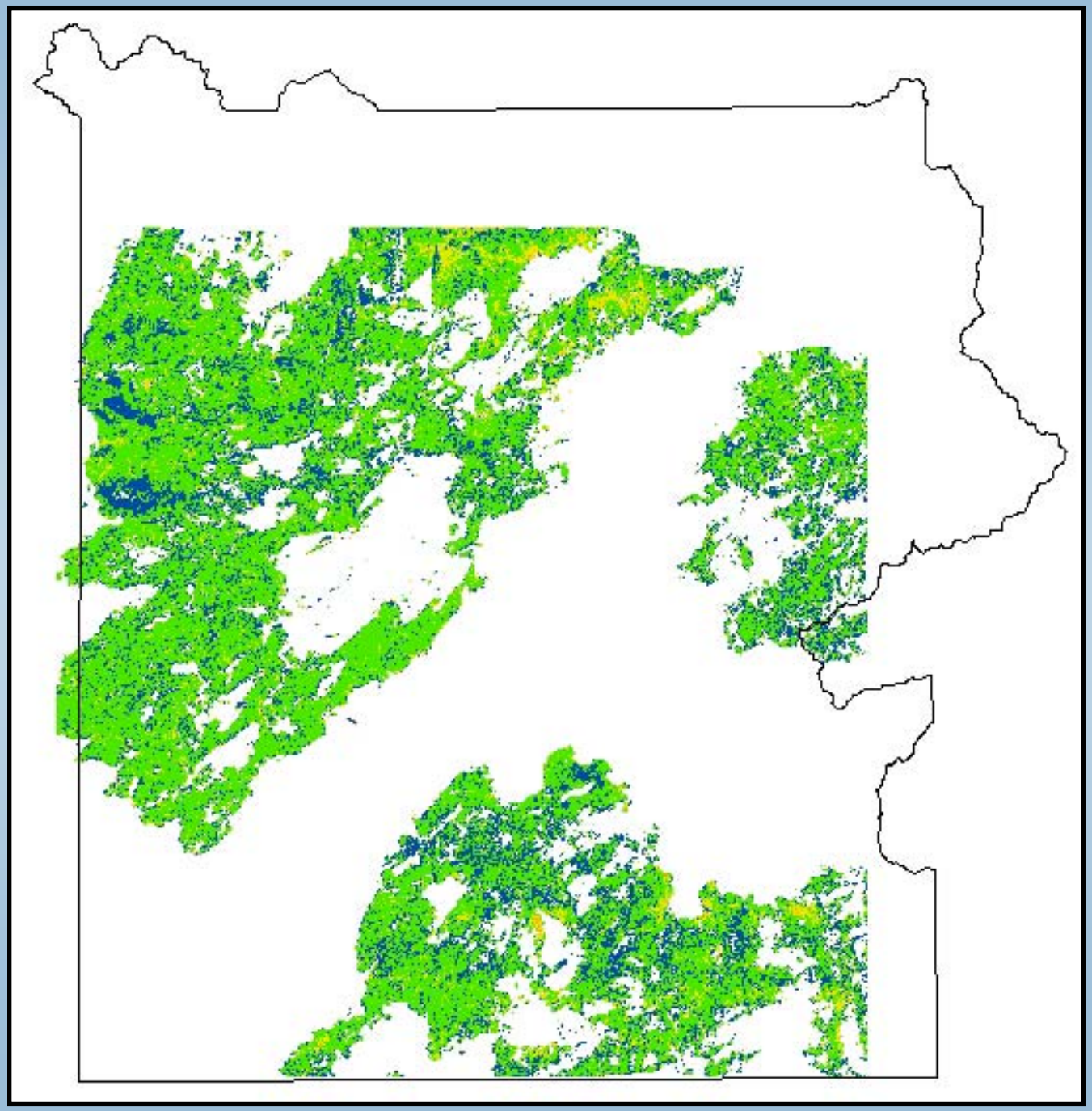
Landscape pattern at 200 years following fire

Relative deviation from median density

- -1 – -0.25
- -0.25 – 0.25
- 0.25 – 1
- 1 – 3
- 3 – 5
- >5

Median density = 619 stems/ha



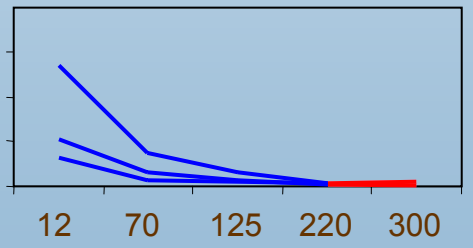


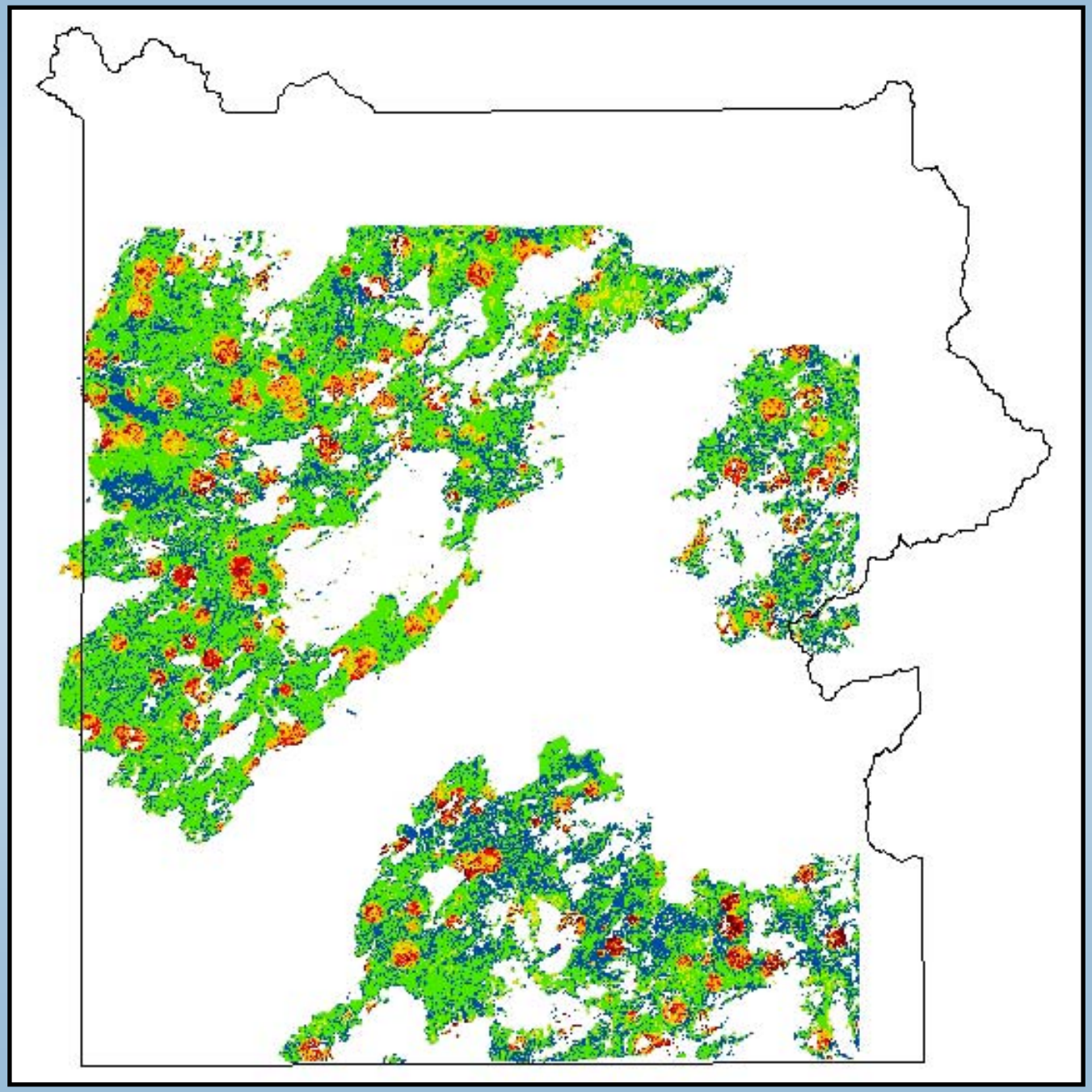
Landscape pattern at 300 years following fire

Relative deviation from median density

- -1 – -0.25
- -0.25 – 0.25
- 0.25 – 1
- 1 – 3
- 3 – 5
- >5

Median density = 627 stems/ha





Landscape pattern at 300 years following fire (with small fires)

Relative deviation from median density

- -1 – -0.25
- -0.25 – 0.25
- 0.25 – 1
- 1 – 3
- 3 – 5
- >5

Median density = 700 stems/ha

Structure Conclusions

- Structural variability is likely related to initial variation in postfire density.

- Variation in stand structure across the landscape decreases with time and converges near 200 years.

- Large, infrequent disturbances leave an imprint on the landscape that may endure for two centuries.

What are the implications of dissimilar stand structures for landscape carbon storage?

- How do large fires affect landscape carbon storage?

- How sensitive is carbon storage of a landscape to changes in climate and/or disturbance regimes?

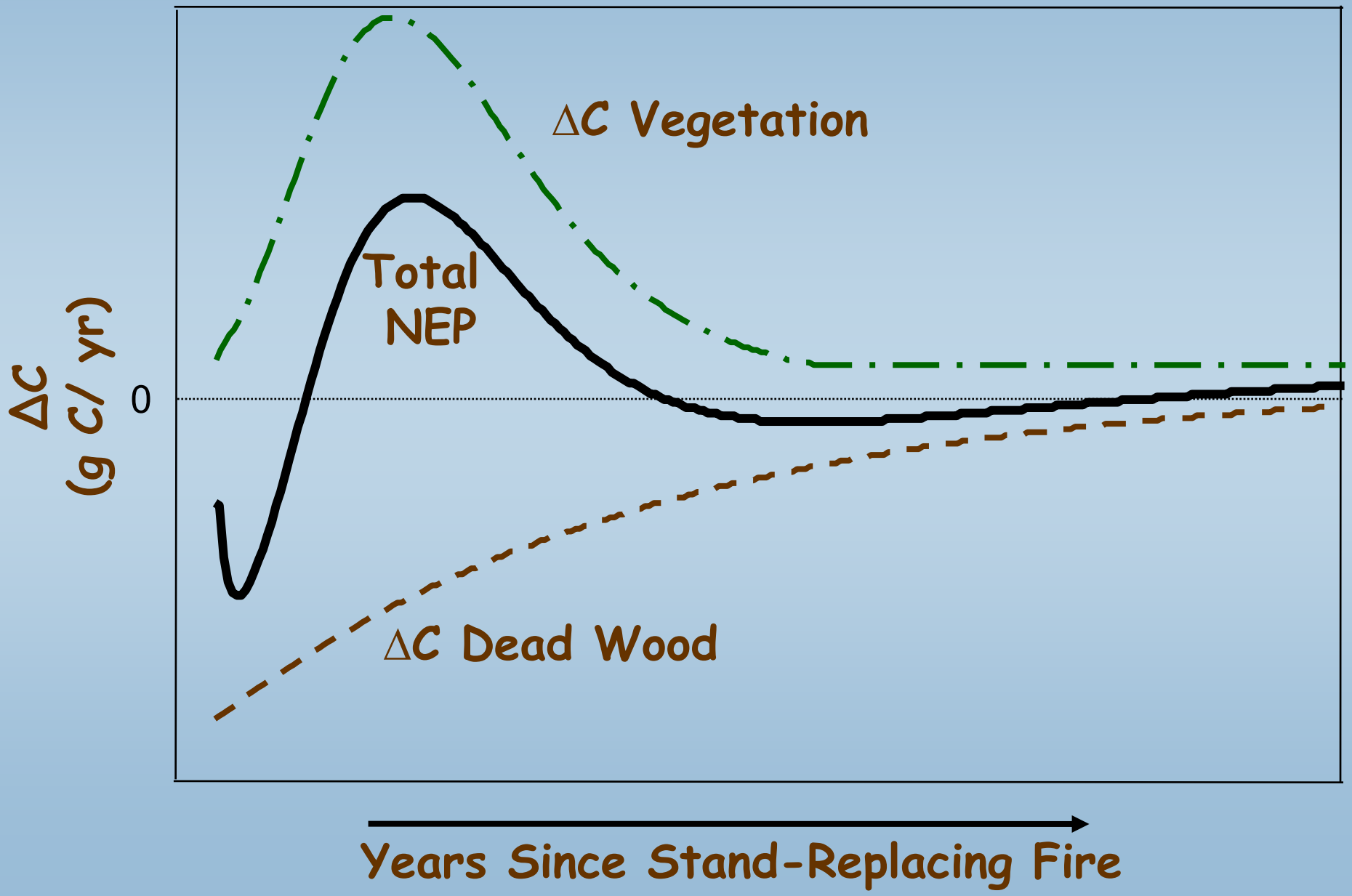
Landscape carbon storage is affected by:

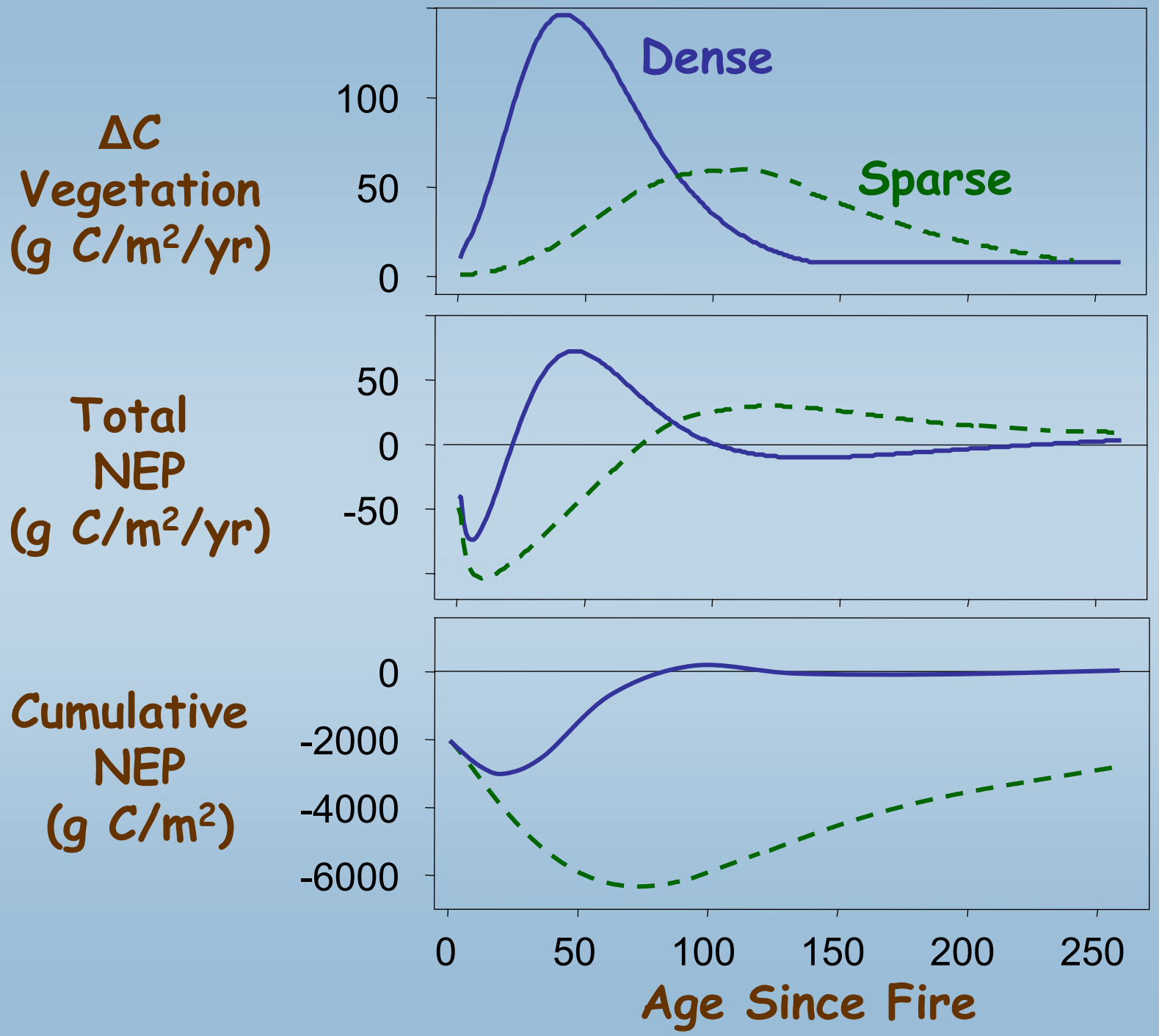
- **Balance** between carbon accumulating in vegetation/forest floor and carbon lost through decomposition of dead wood.

- Changes in the **stand density distribution** across the landscape following fires.

- Changes in the **stand age distribution** across the landscape following fires.

NEP = C gained (NPP) – C lost (decomposition)




ΔC
Vegetation
(g C/m²/yr)
Dense
Sparse
100
50
0
Total
NEP
(g C/m²/yr)
50
0
-50
Cumulative
NEP
(g C/m²)
0
-2000
-4000
-6000
0
50
100
150
200
250
Age Since Fire

Do stand structures "replace themselves"?

Sparse pre-fire

Sparse post-fire

Little change = in C stored over fire cycle

Dense pre-fire

Dense post-fire

Little change = in C stored over fire cycle

Do stand structures "replace themselves"?

Sparse pre-fire

Sparse post-fire

= C lost over fire cycle

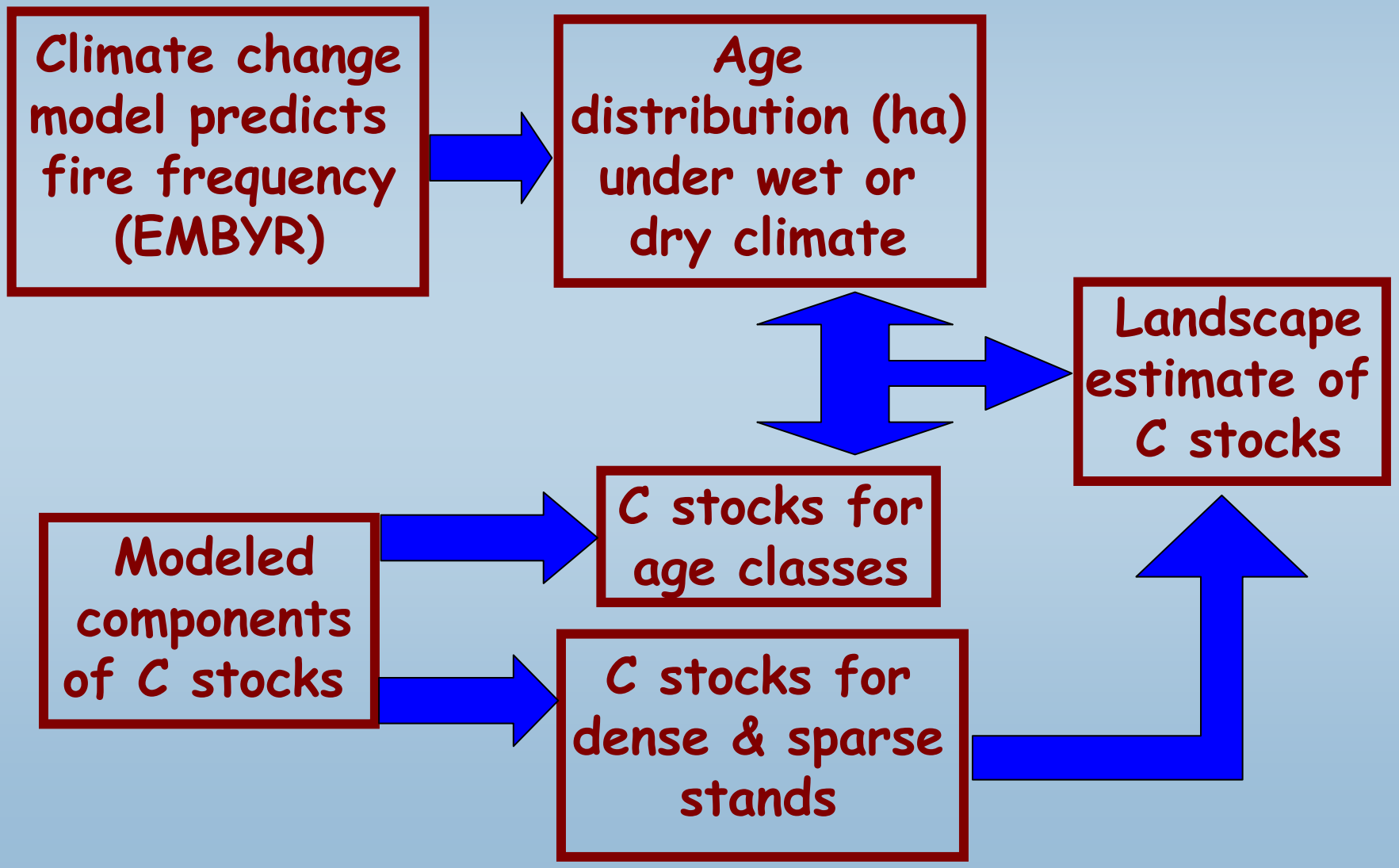
Dense pre-fire

Dense post-fire

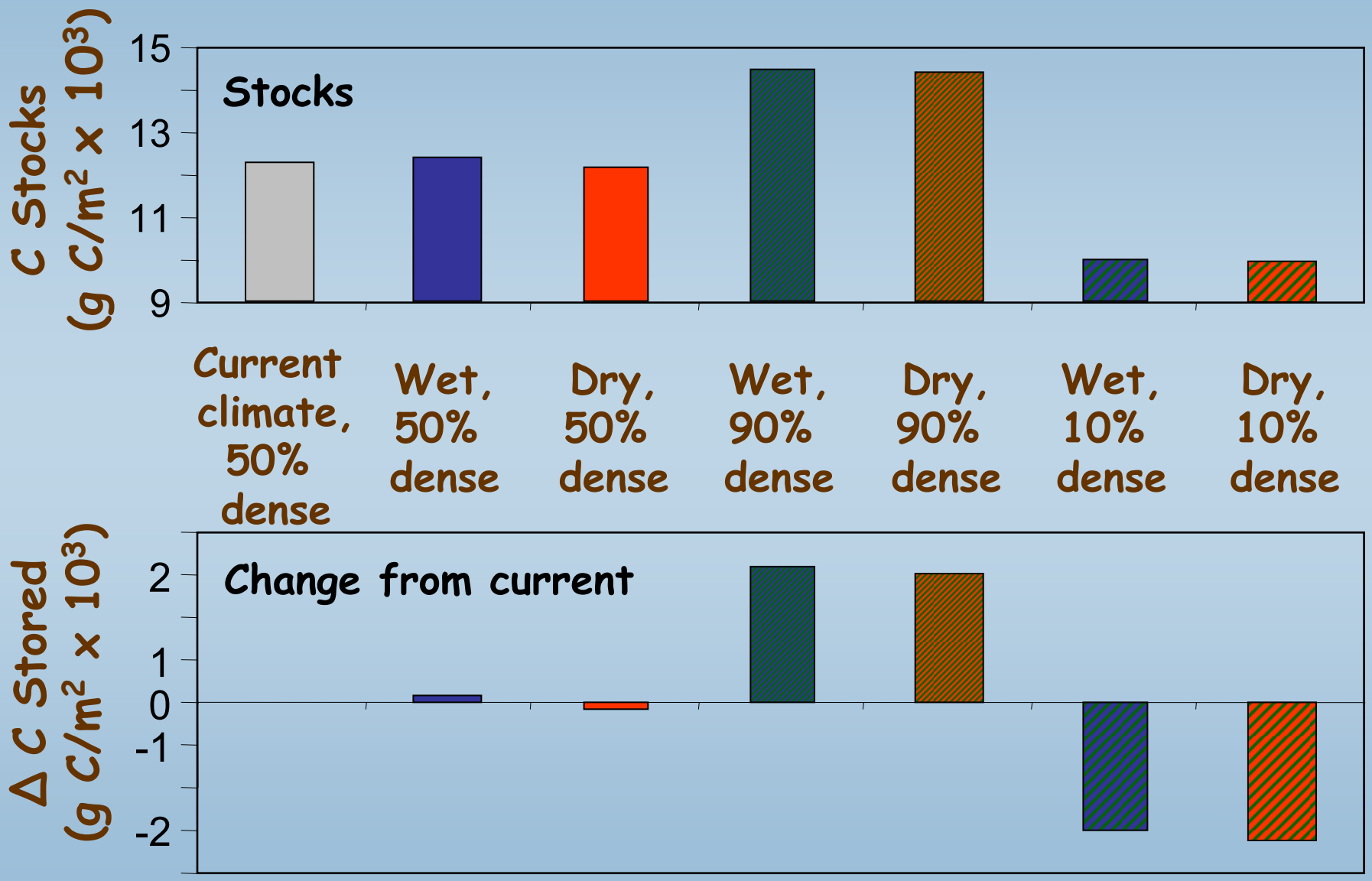
= C gained over fire cycle

Stand age distributions affect landscape NEP

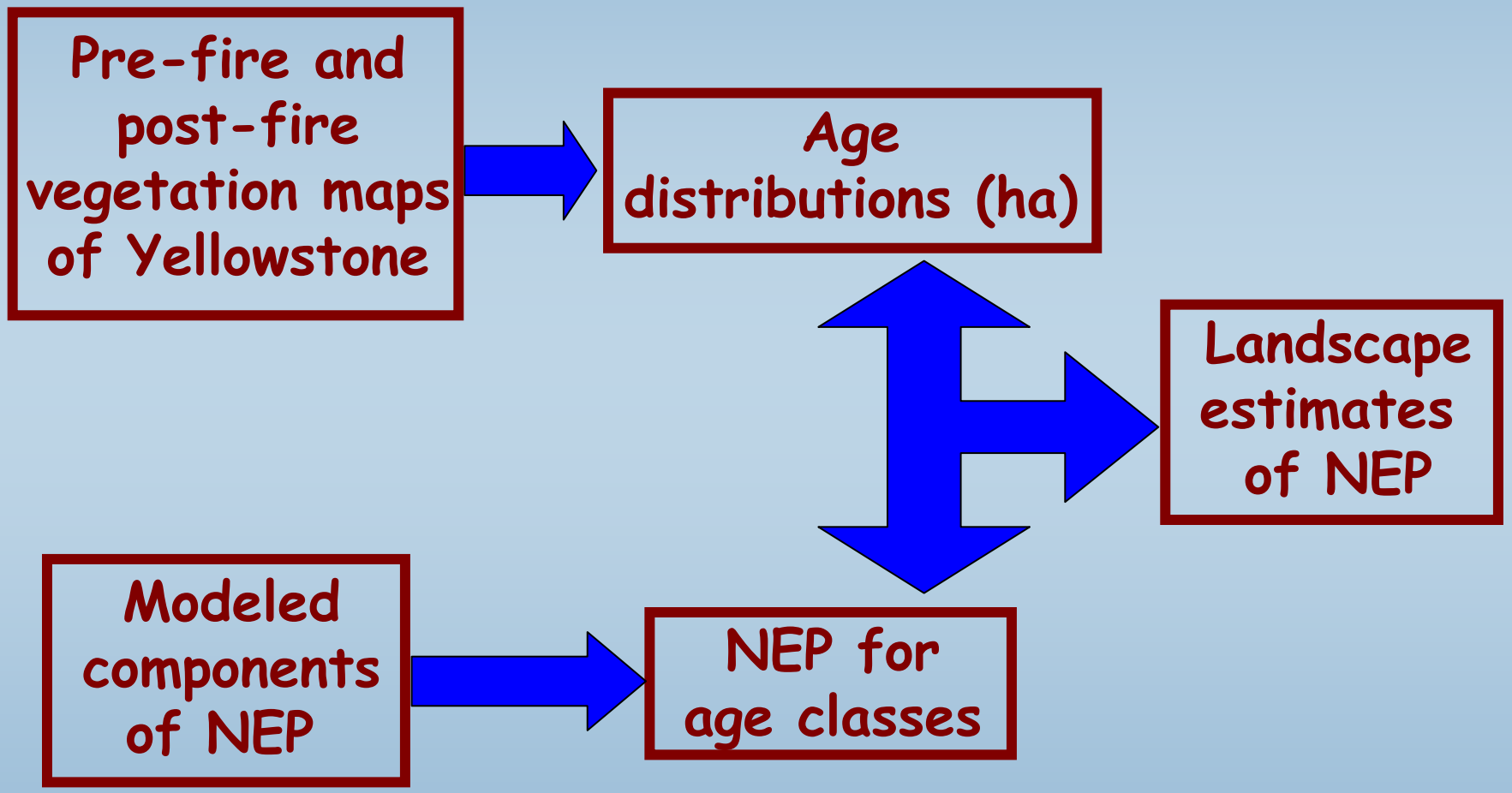
Modeling stand age and density effects on landscape C storage



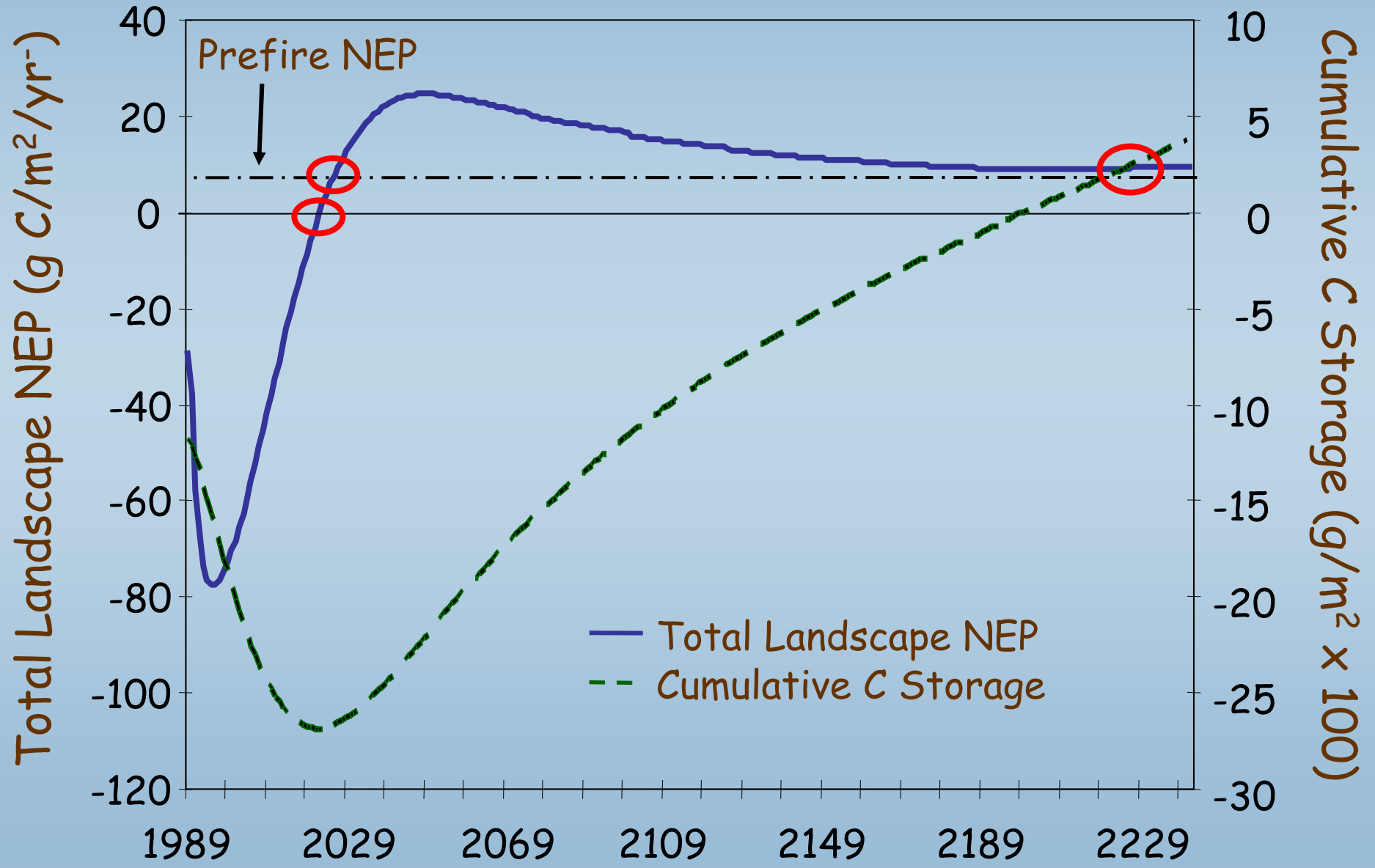
Stand age and density effects on C storage



Modeling future landscape C storage for Yellowstone



Long-term changes in C storage for Yellowstone

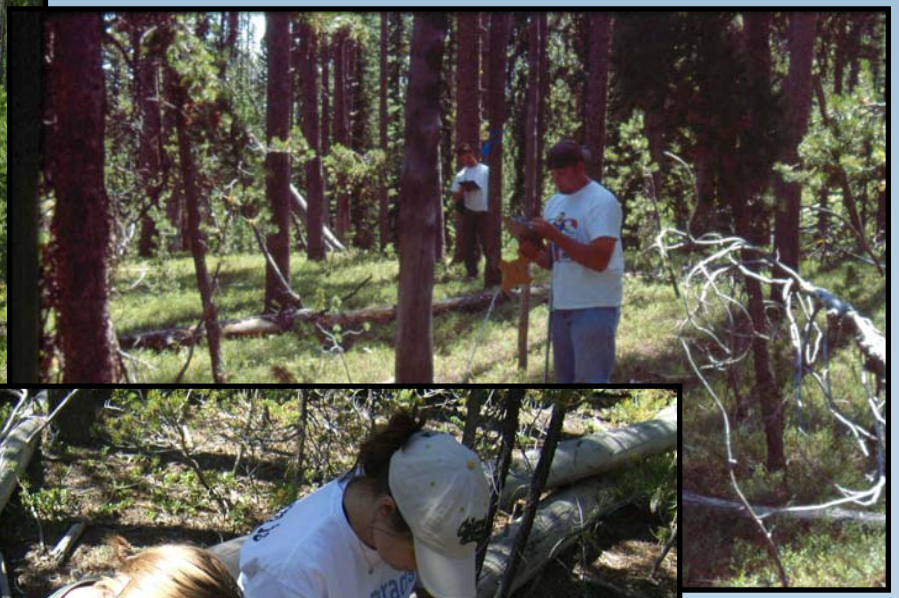


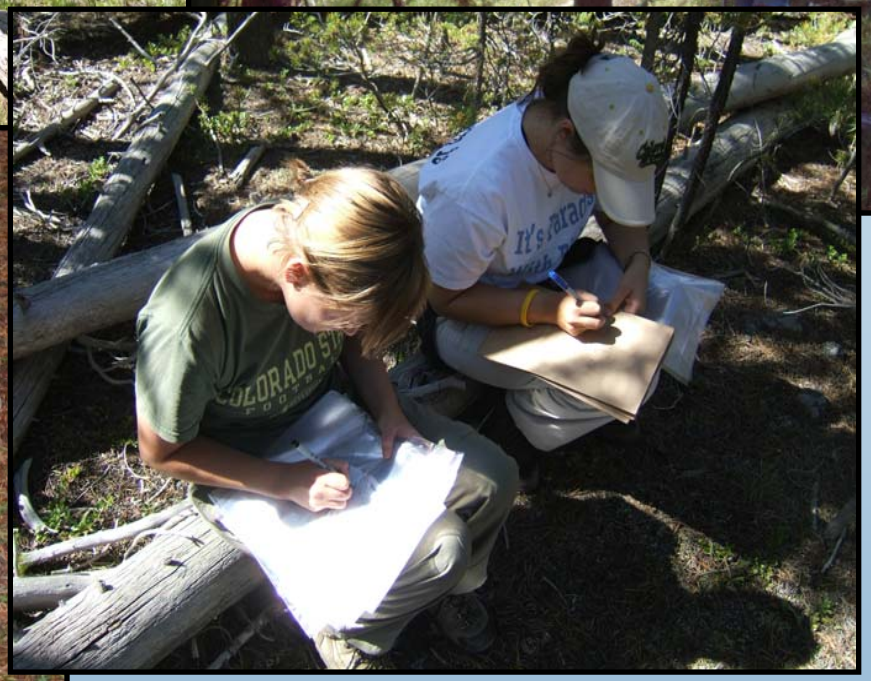
"Function" Conclusions:

- Equilibrium C storage is resistant to changes in disturbance regimes at landscape scales.

- Large changes in the distribution of stand densities on the landscape are necessary to shift its ability to store carbon.

- The post-1988 Yellowstone landscape will recover all carbon lost within the fire cycle (~230 years), but it is currently a large source of C to the atmosphere.





Current Projects:

- Carbon budgets along replicated age and density chronsequences
- Landscape carbon budget of Yellowstone using Century, EMBYR and Landsat
- Changes in productivity with tree age using stable carbon isotopes ($\Delta^{13}C/\Delta^{12}C$)
- Changes and variability in foliar nitrogen with stand age and denisty.

Future research directions

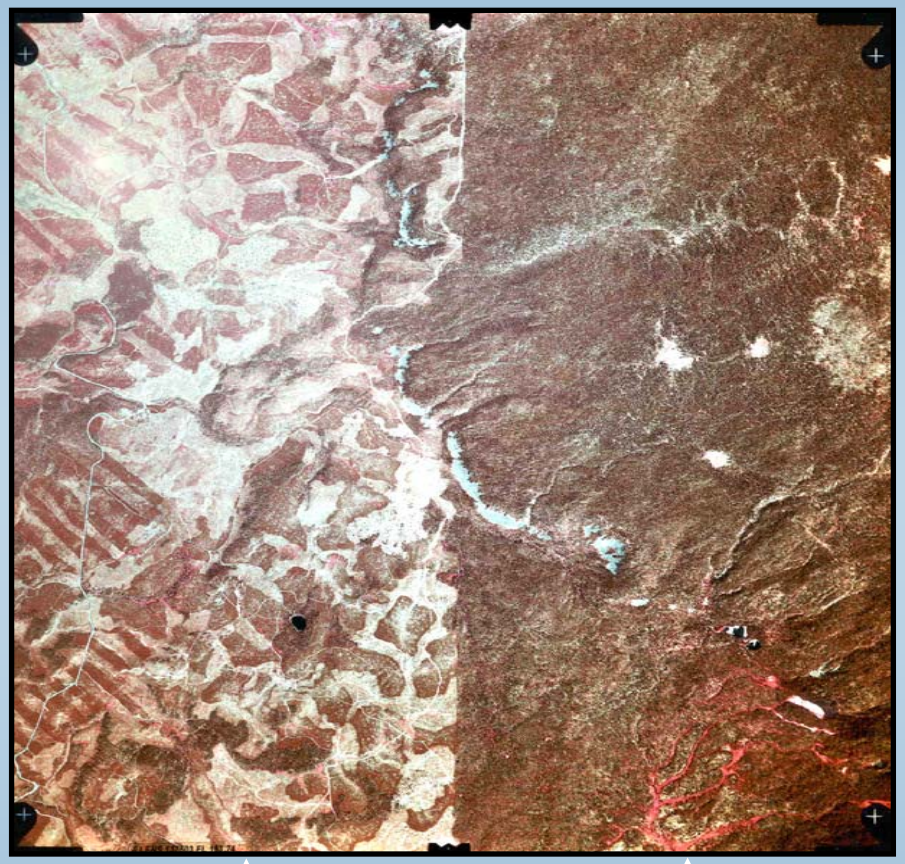
How have disturbance regimes affected human land use, and how is this linked to climate change?

How do exotic disturbances affect forest structure and function compared to native disturbances?

What are the critical links between terrestrial systems (landscapes) and aquatic systems?

Defining Landscape Ecology

1. Broad spatial scales
2. Spatial heterogeneity
3. Pattern and process
4. The human role/impact
5. Collaboration



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