# PLAYING WITH FIRE:

## Implications of climate change for disturbances that shape Rocky Mountain forest landscapes

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# Approach to Climate Change in Forests



How might a changing climate affect the disturbances that shape forests?

- "Most imminent and extensive"
- Landscape scale
- Applicable to many regions
- Eye on the past to predict the future

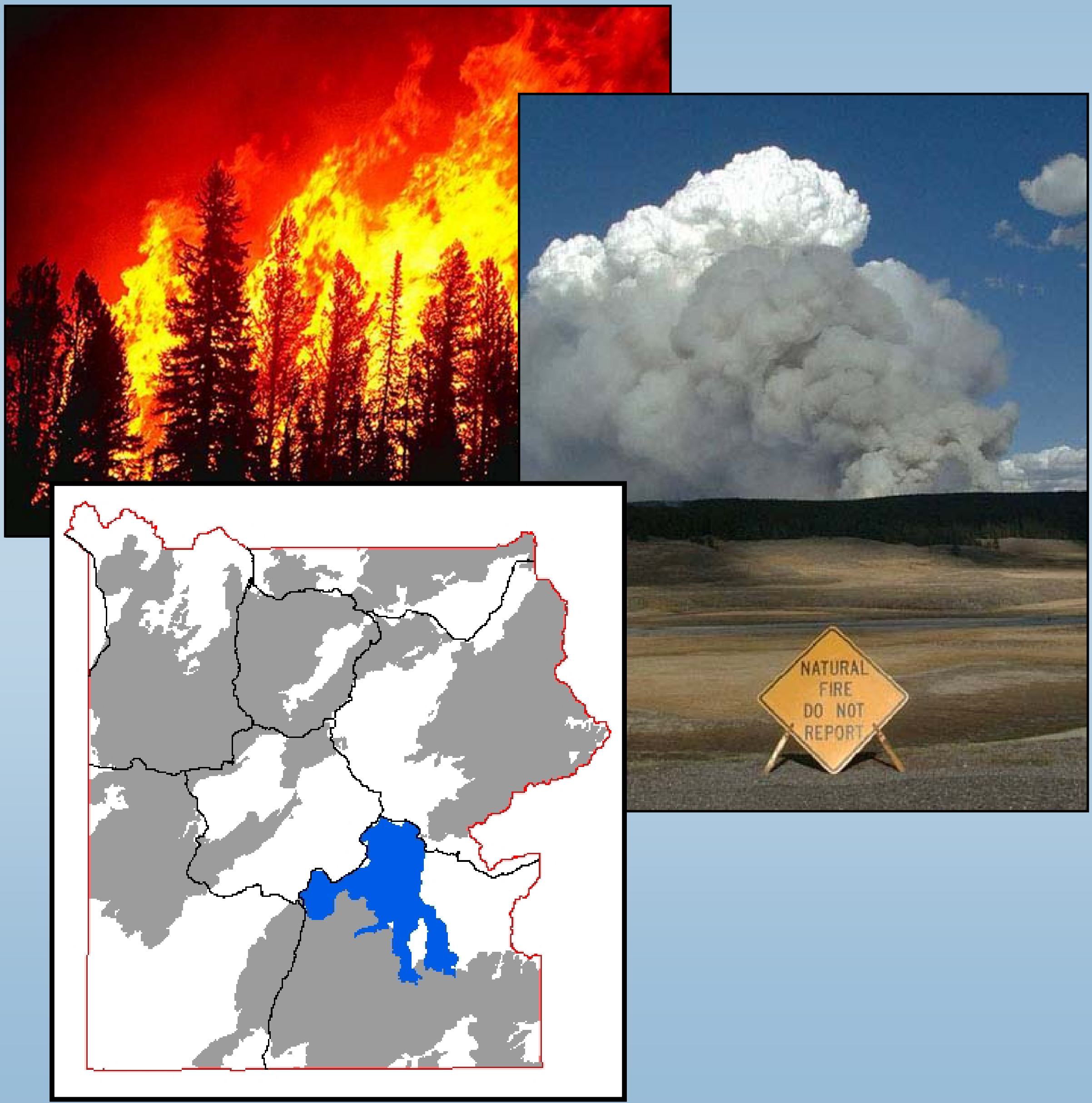
# Outline

## Wildfires and lodgepole pine forests in Yellowstone National Park

- Background: The 1988 Yellowstone fires
- Stand dynamics and convergence in forest structure: potential effects of climate change
- Landscape-level carbon cycling

## Future Directions

# The Yellowstone landscape




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

# Variation in burn severity

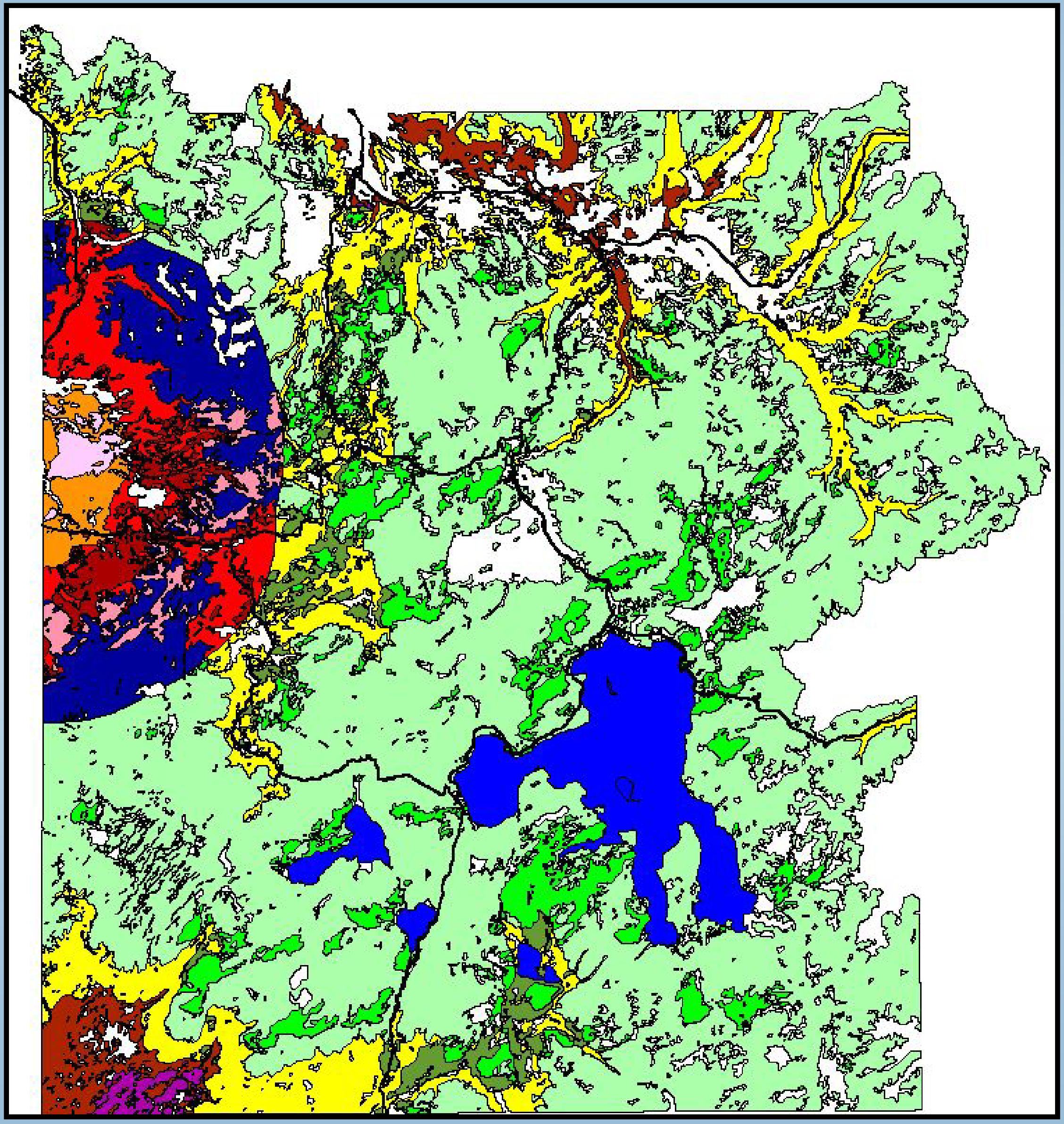
Yellowstone Burn Mosaic, 10/88

Light/Severe Surface Fire

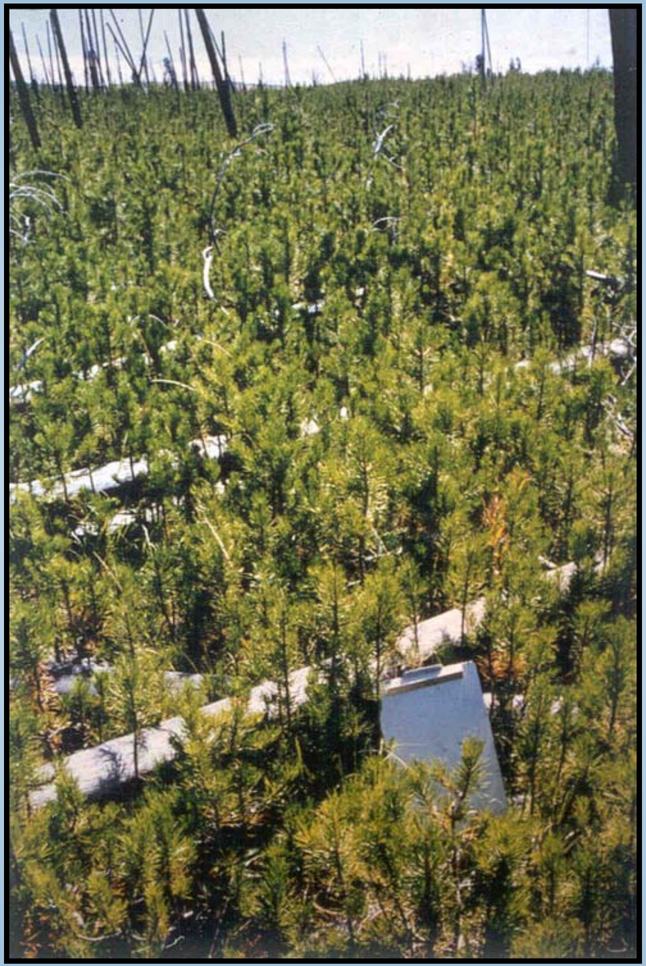
Severe Surface/Crown Fire

# Serotiny in lodgepole pine

# Variation in lodgepole pine serotiny



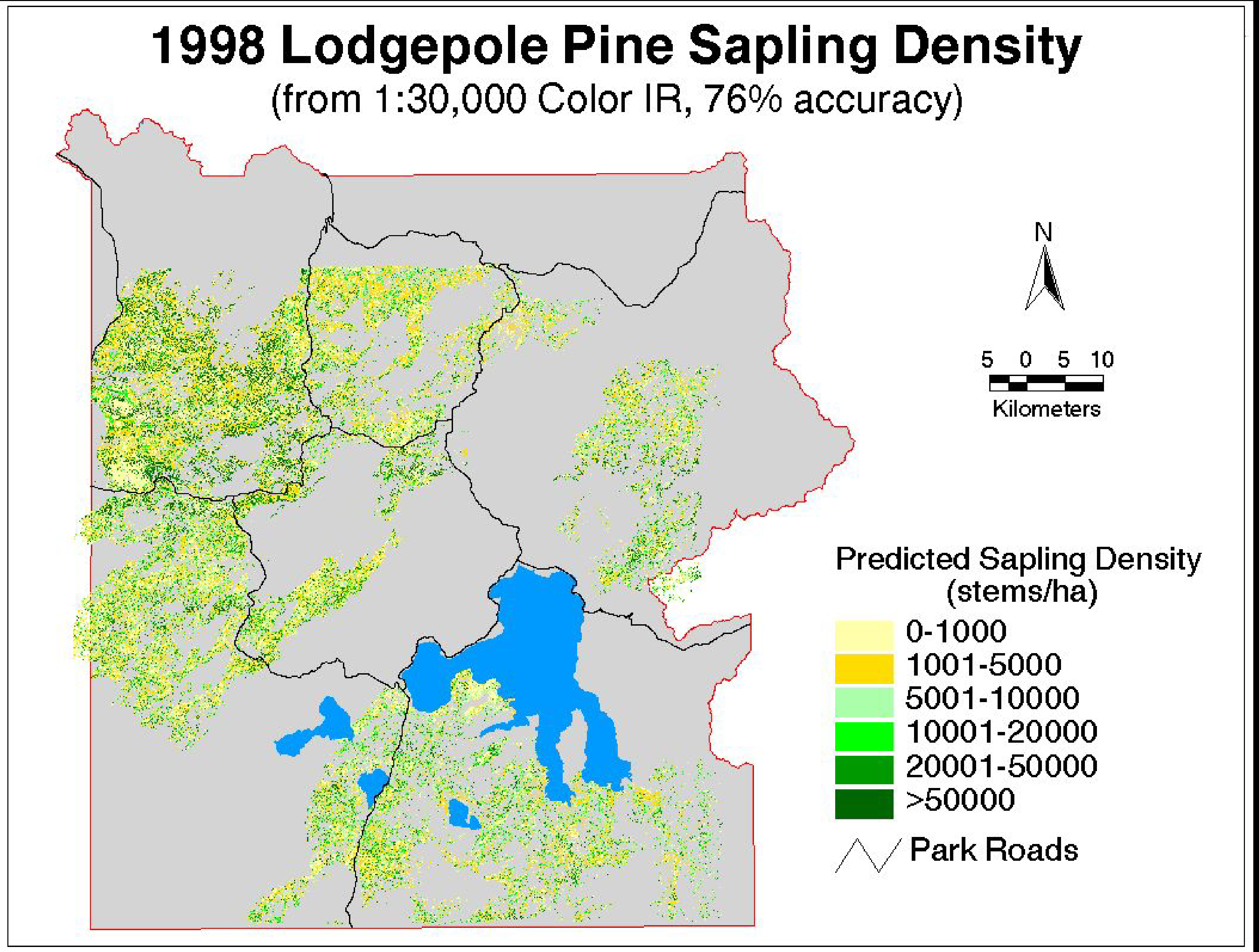

# Variation in regeneration density



>50,000 stems/ha

1,000 stems/ha

0 stems/ha


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

# Variation in Stand Density

Stands shown are in the 50-100 year age class

3,000 stems/ha

11,000 stems/ha

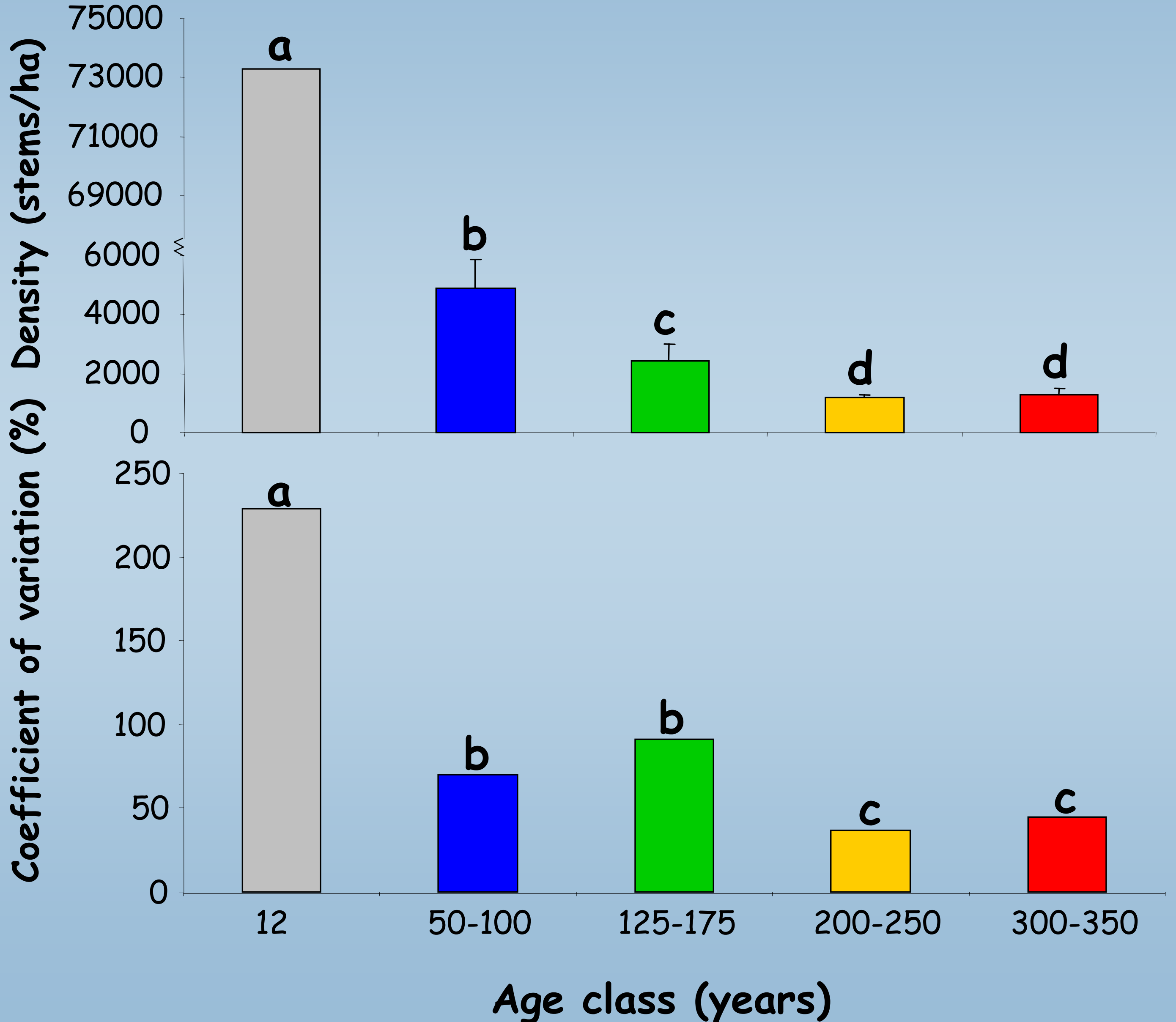
1,100 stems/ha

# Do initially dissimilar stand structures eventually converge?

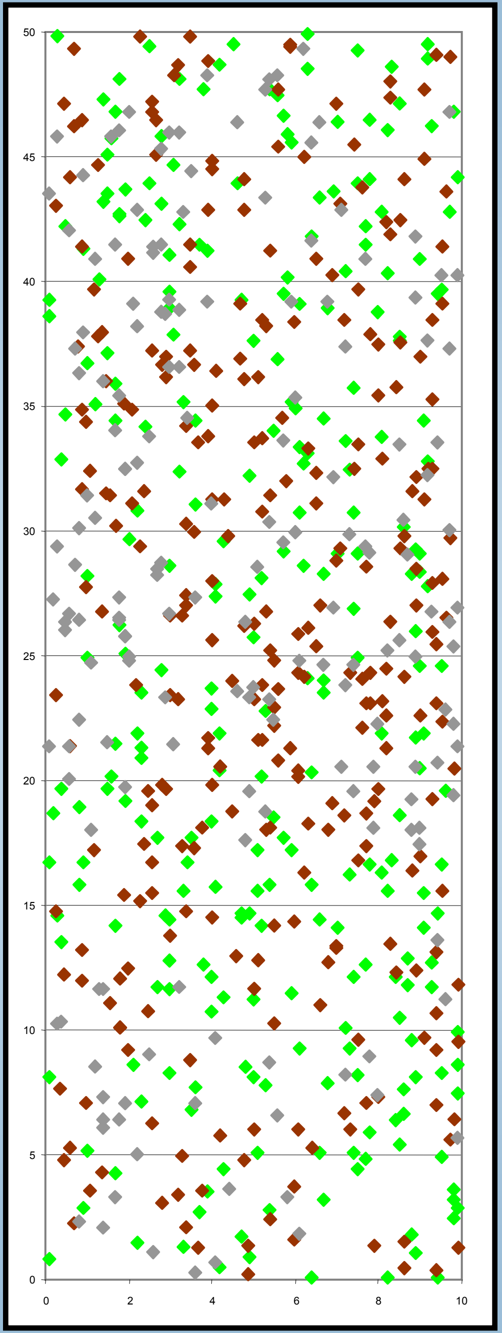
???

???

# Variation and change in stand density with age

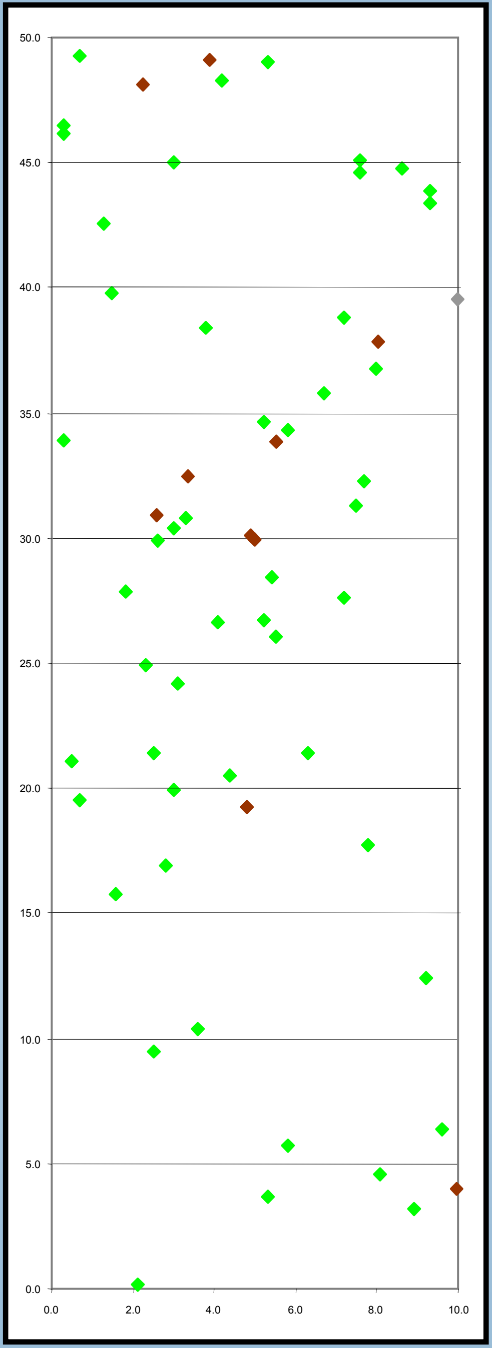


# Stand A: Initially dense

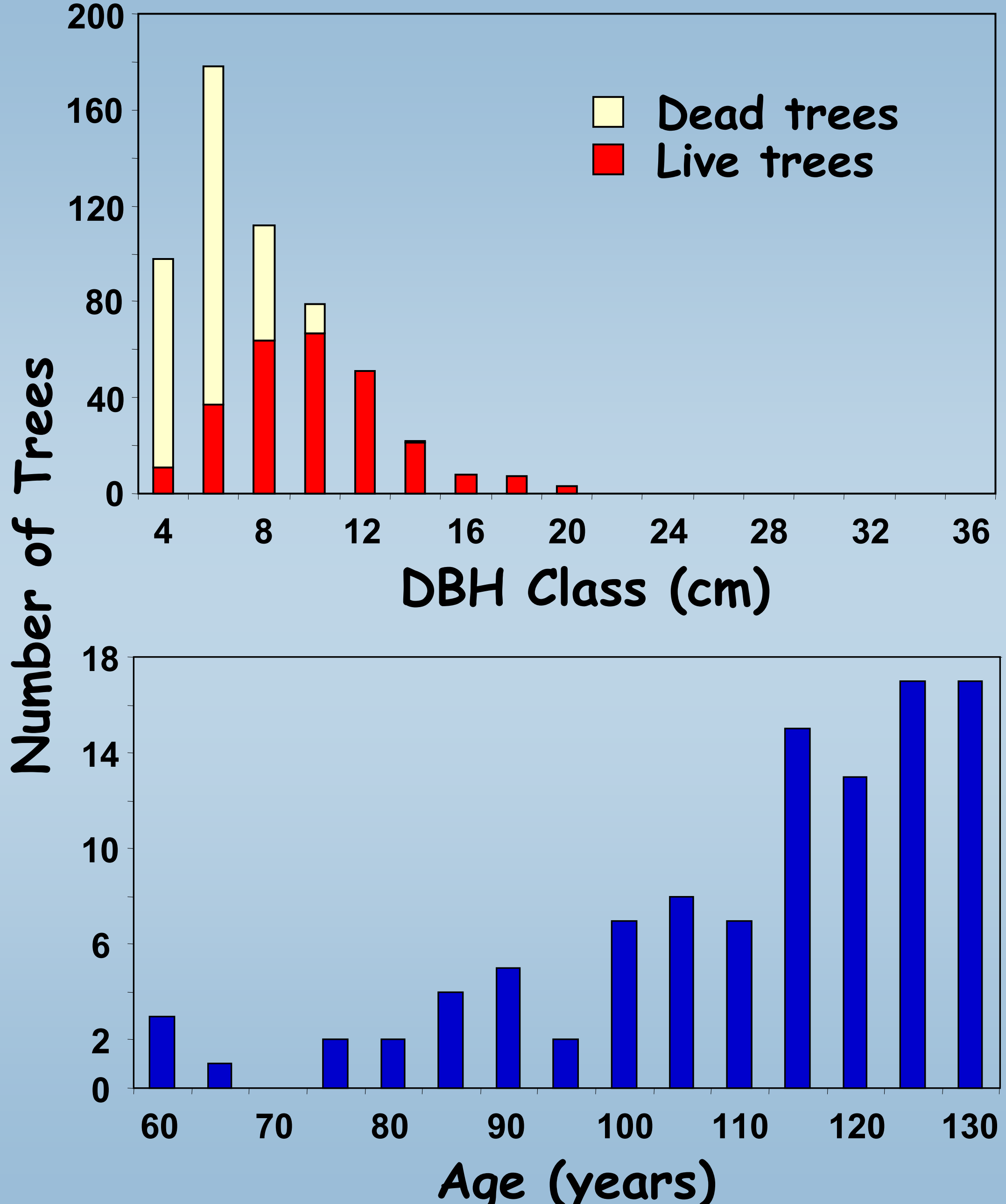



Age: 130 years
Density: 5,400 stems/ha

# Stand B: Initially sparse

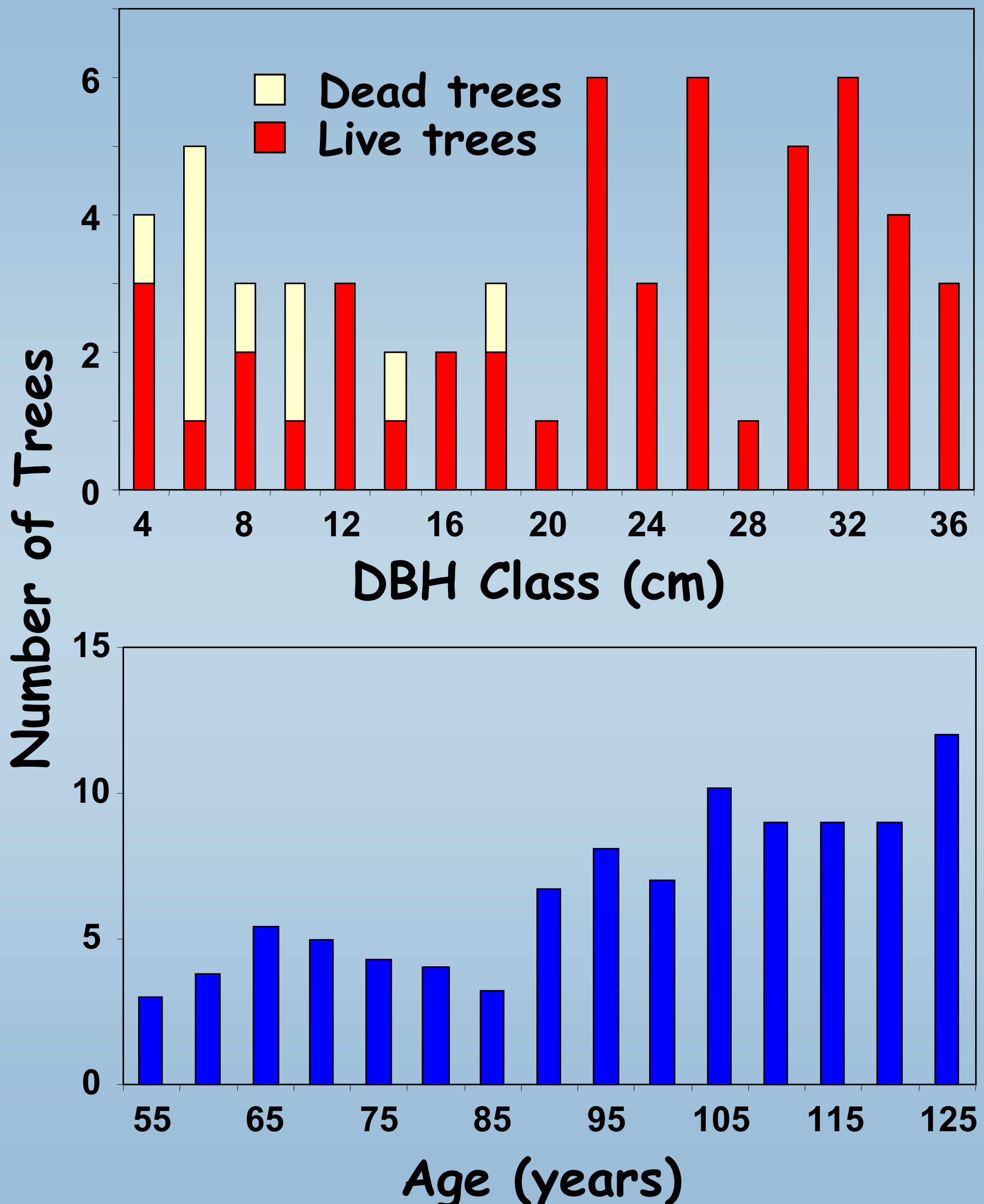



**Age: 130 years**
**Density: 1,020 stems/ha**



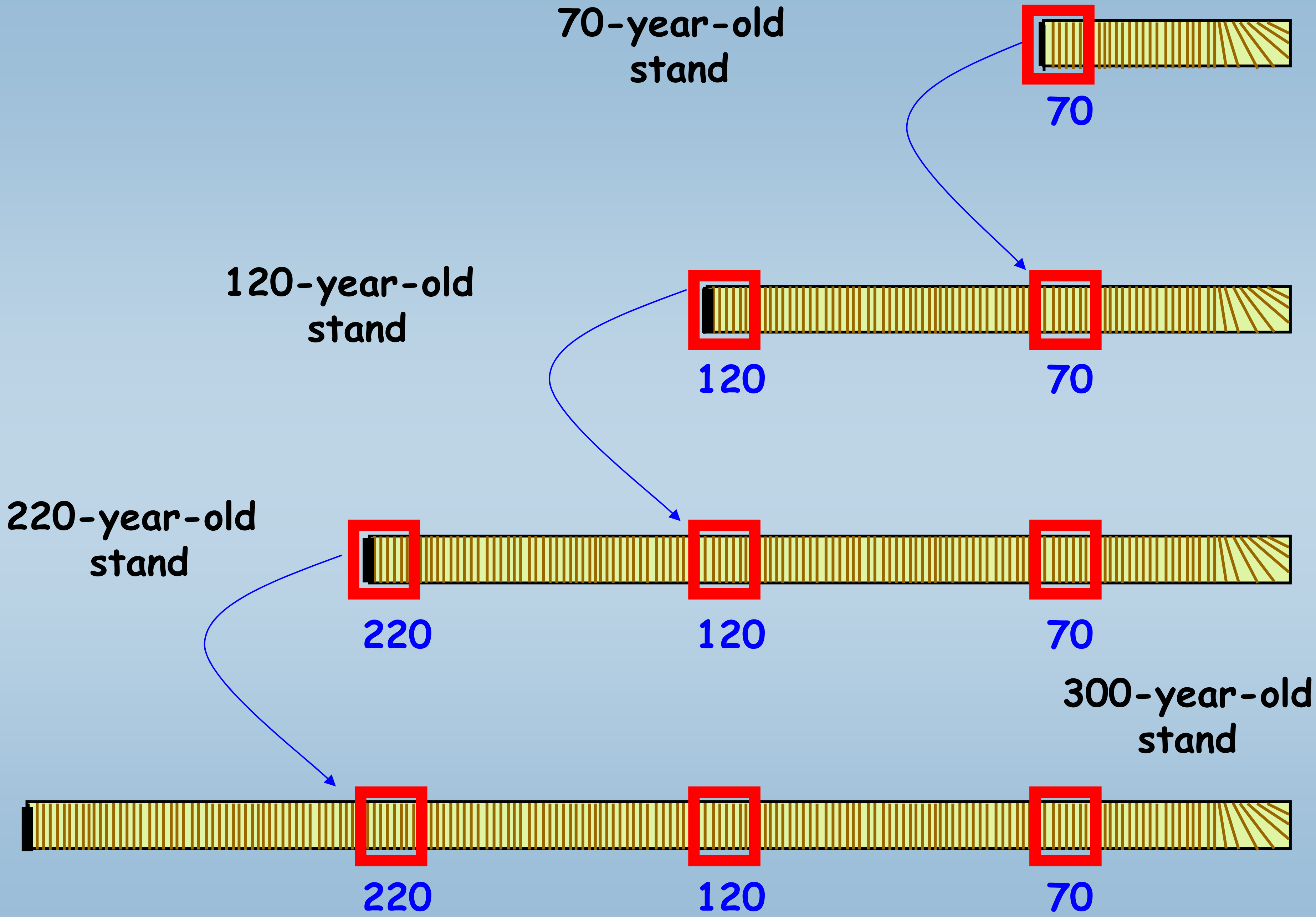

# Initially dense stand

- Unimodal, steep distributions
- Dead trees common and small

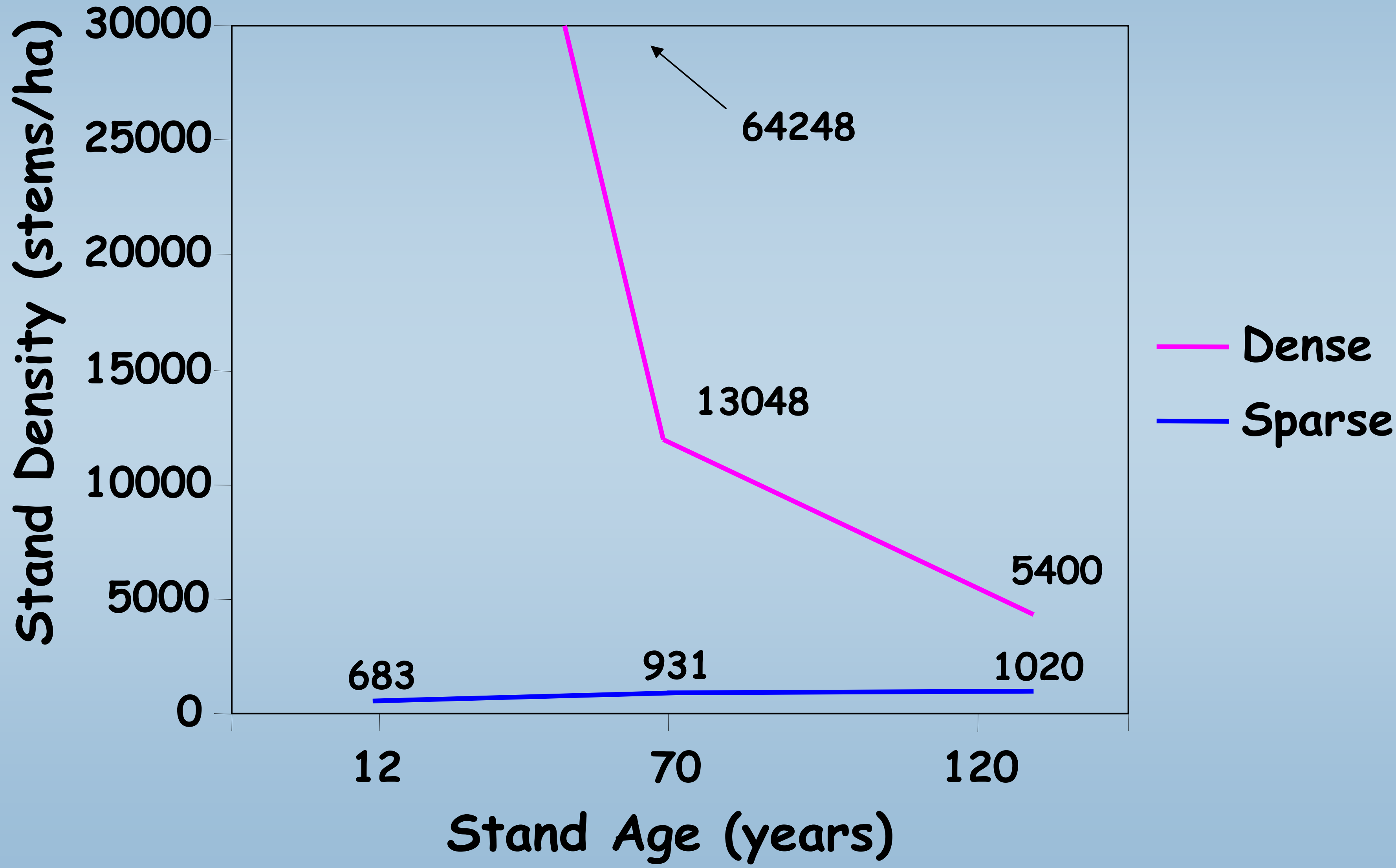



# Initially sparse stand

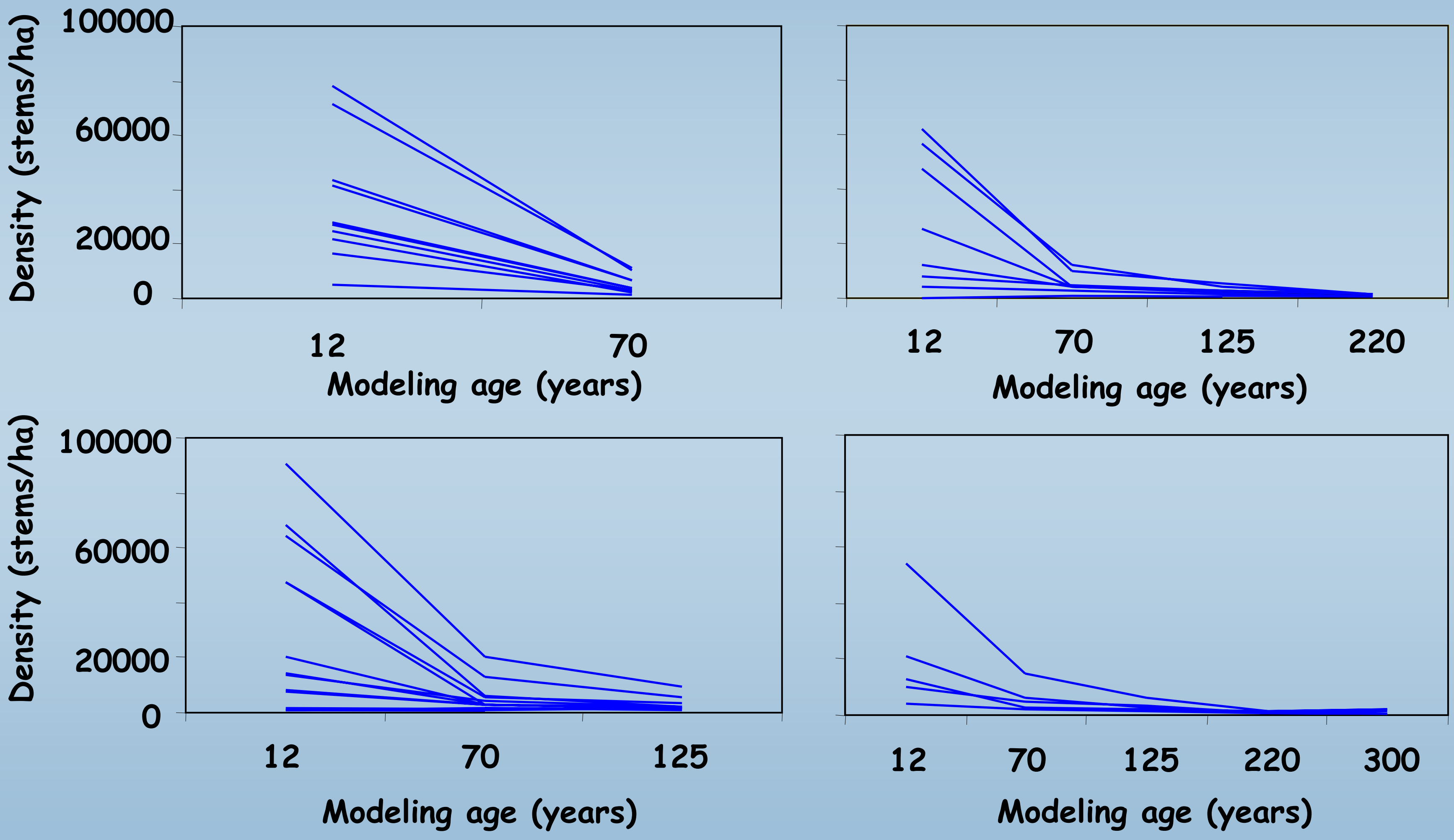
- Bimodal or wide distributions
- Dead trees much less common

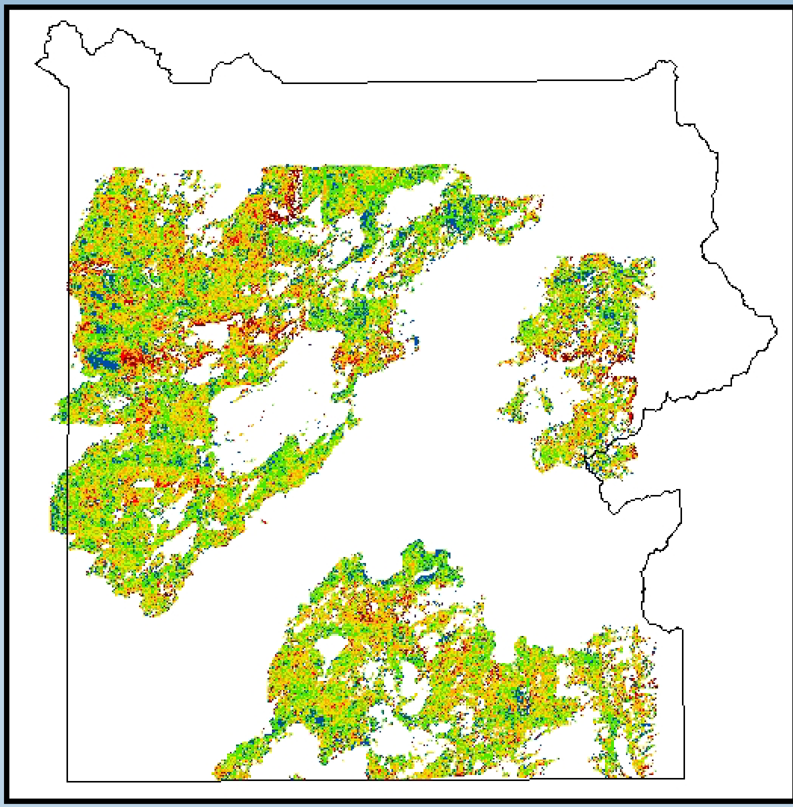

70-year-old stand
70
120-year-old stand
120
70
220-year-old stand
220
120
70
300-year-old stand
220
120
70

# Stand Density Trajectory Reconstruction

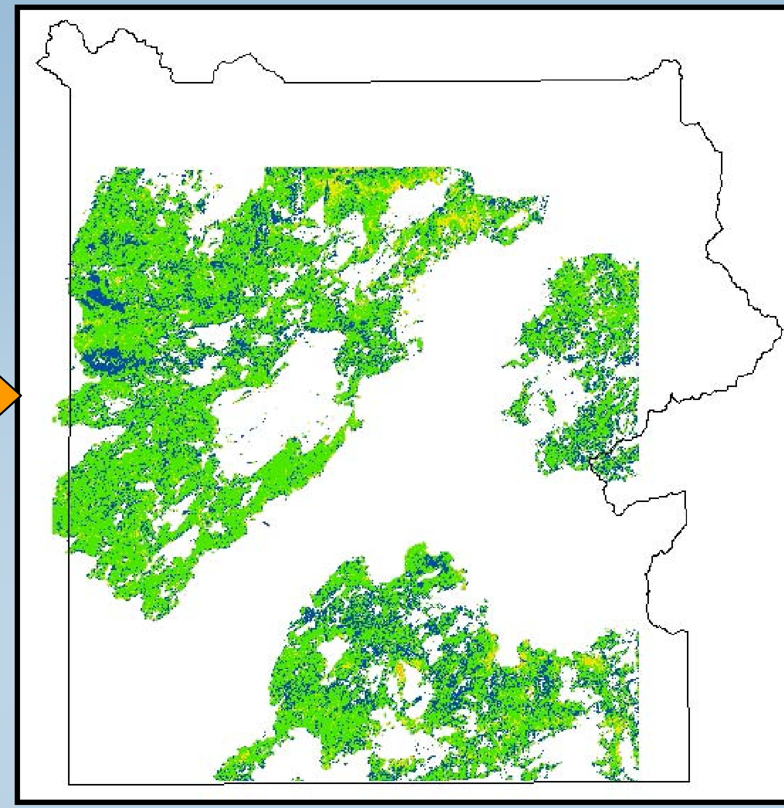


# Stand Density Trajectory Reconstructions





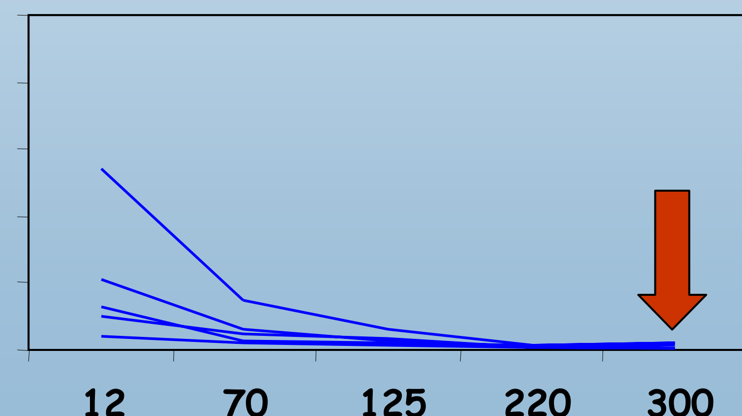
10 years after fire



300 years after fire

**Relative deviation from median density**

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



# How might a changing climate affect forest structure on landscapes?

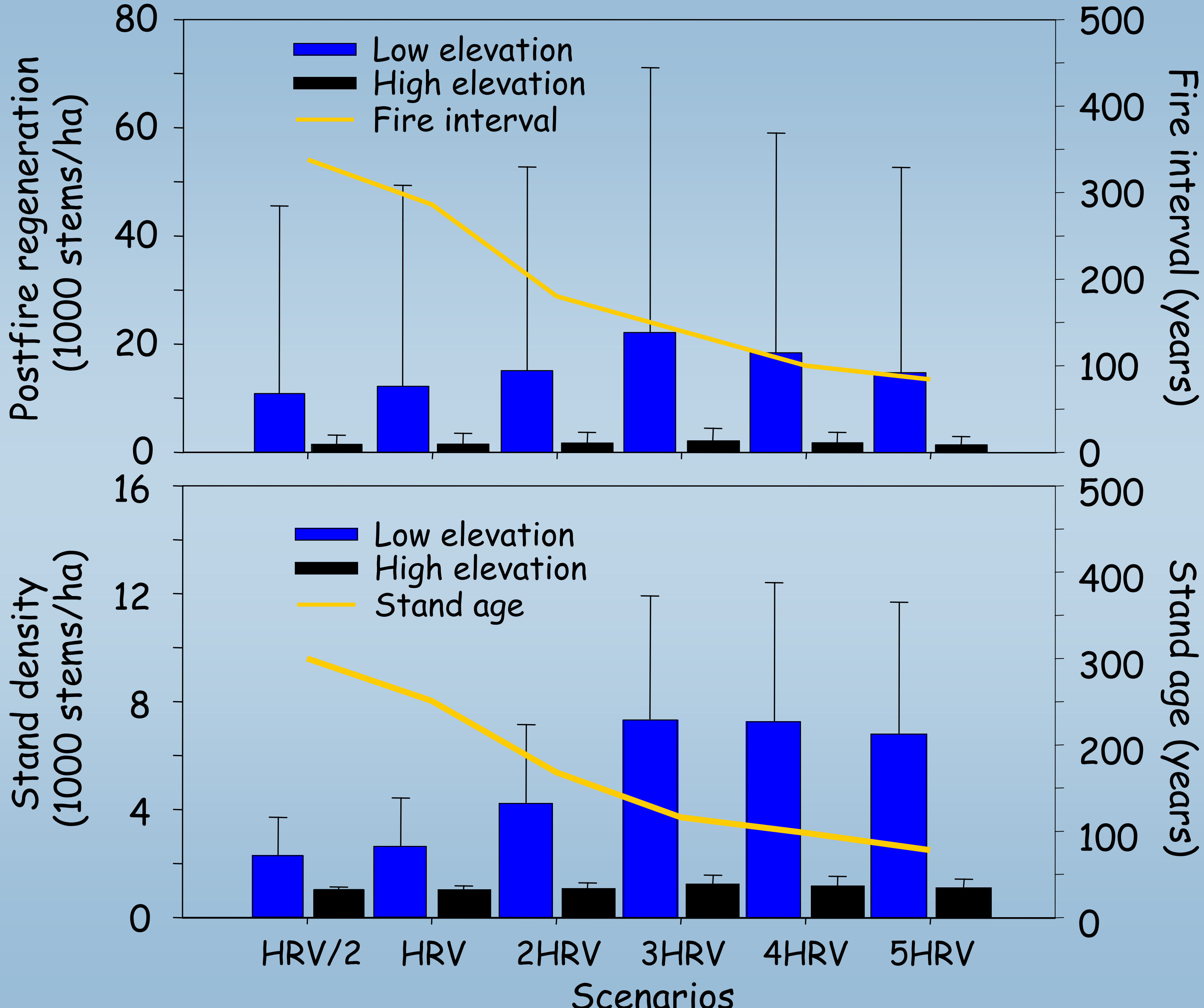
- Probabilistic, cell-based model in SELES based on empirical data (YNPFIRE; Schoennagel et al.).

- Models the response of stand age and density to alterations in frequency of large fires (>10,000 ha).

- Climate scenarios defined by the probability of large fire occurrence.

# YNPFIRE Climate Scenarios

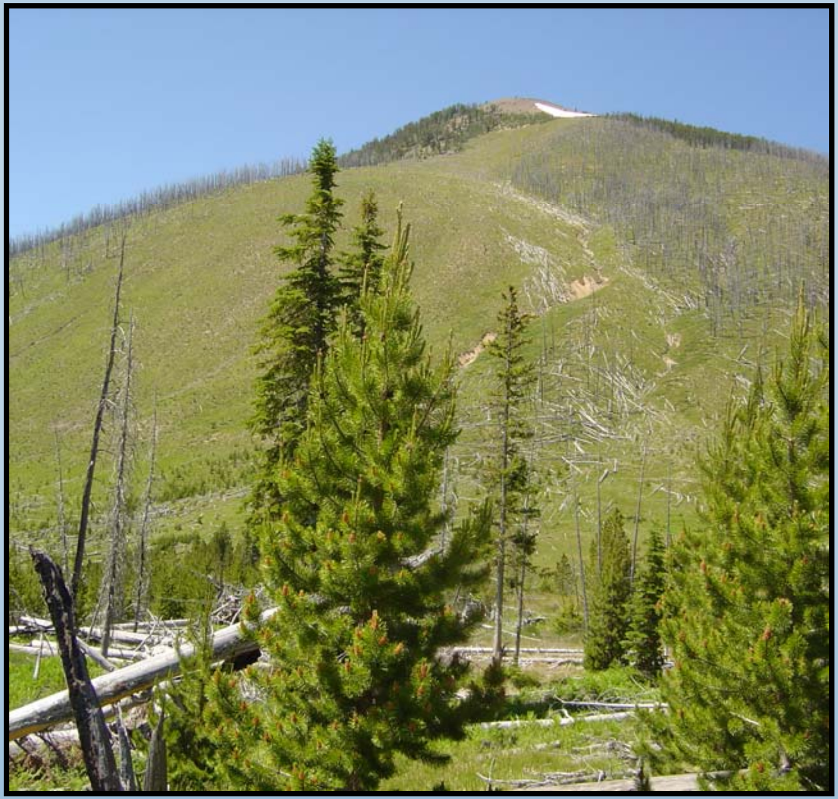
| Scenario | Prob. Extremely Dry Year | # Large Fires per 1,000 years |
|---|---|---|
| Less Extreme (HRV/2) | 0.003 | 3 |
| Nominal (HRV) | 0.006 | 6 |
| More Extreme (2HRV) | 0.012 | 12 |
| More Extreme (3HRV) | 0.018 | 18 |
| More Extreme (4HRV) | 0.024 | 24 |
| More Extreme (5HRV) | 0.030 | 30 |



80
60
40
20
0
Postfire regeneration (1000 stems/ha)
500
400
300
200
100
0
Fire interval (years)
Low elevation
High elevation
Fire interval
16
12
8
4
0
Stand density (1000 stems/ha)
500
400
300
200
100
0
Stand age (years)
Low elevation
High elevation
Stand age
HRV/2
HRV
2HRV
3HRV
4HRV
5HRV
Scenarios

# Implications for the geographic distribution of lodgepole pine forests

- Serotiny would increase with increasing fire frequency
- Post-fire regeneration would increase with fire frequency
- Upper timberline would rise, but lower timberline would be maintained
- Alpine species may be extirpated



# Structure Conclusions

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

- Under the current climate, variation in stand structure across the landscape decreases with time and converges near 200 years.

- Climate scenarios that reduce the fire interval are likely to increase stand density and heterogeneity on the landscape.

# What are the implications of changing climate for landscape carbon storage?

- How do large fires affect landscape carbon storage?

- How sensitive is carbon storage of a landscape to changes in disturbance regimes?

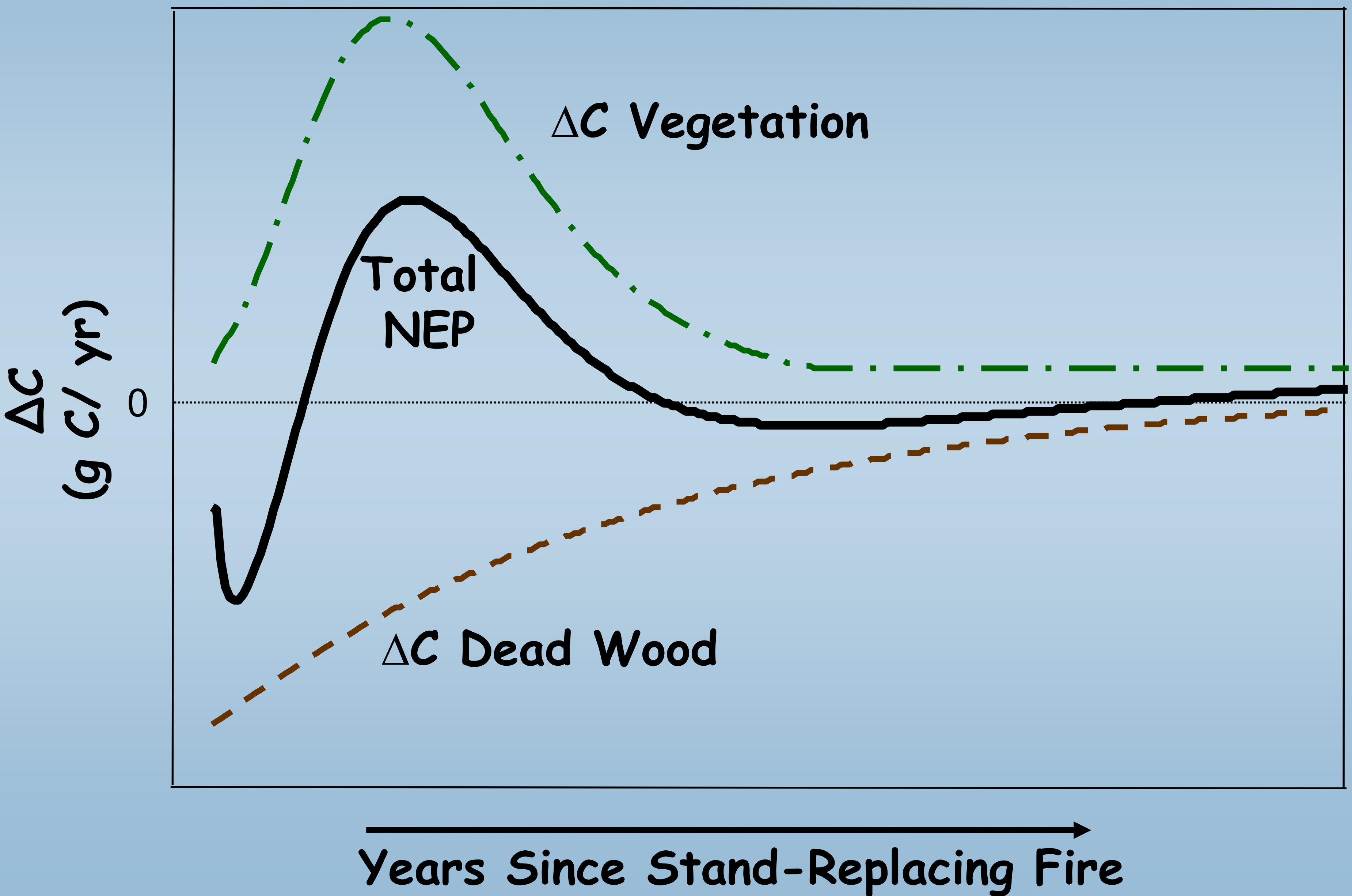
# Landscape carbon storage is affected by:

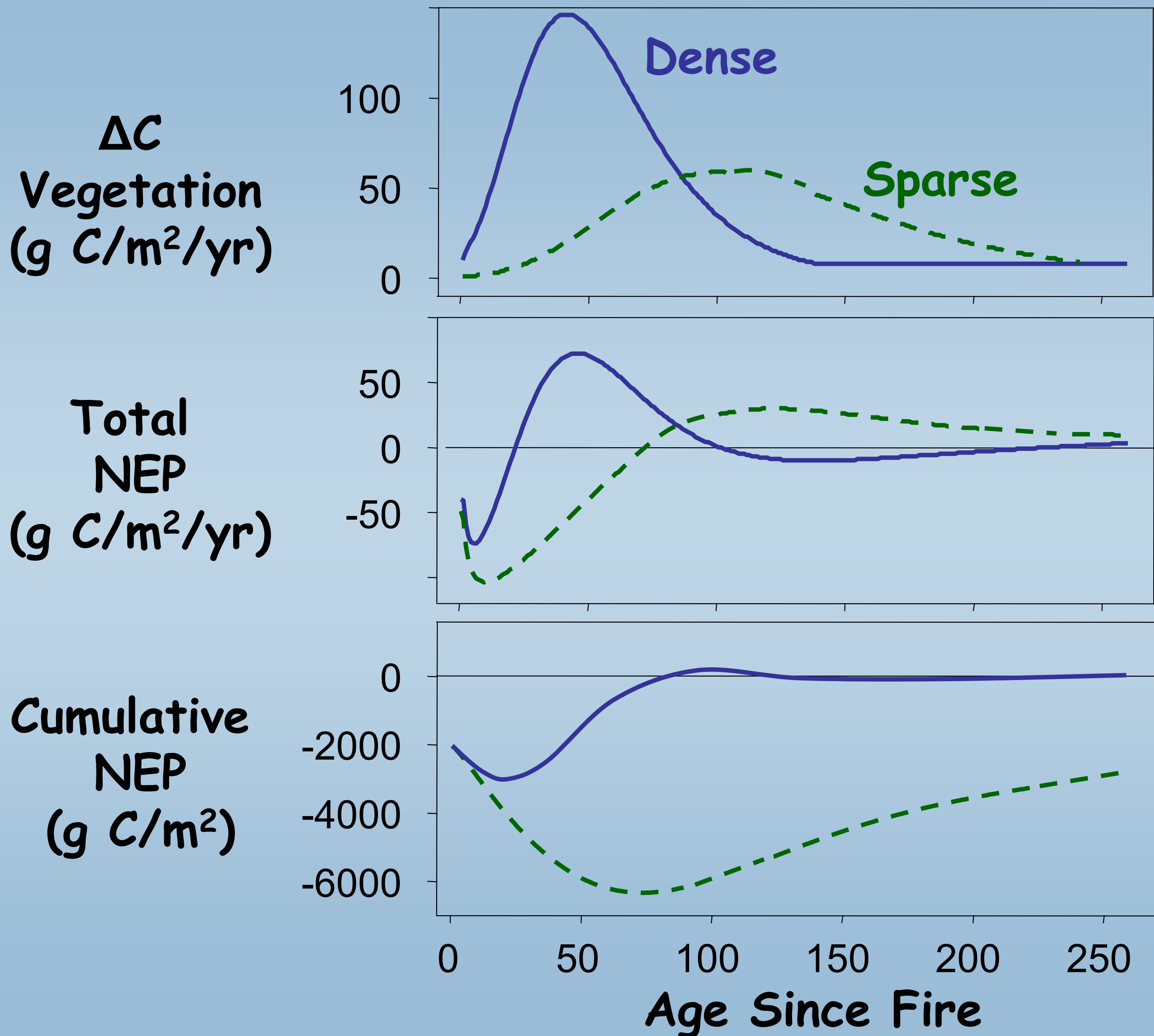
- Balance between carbon accumulating in vegetation/forest floor and carbon lost through decomposition of dead wood.

- 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)



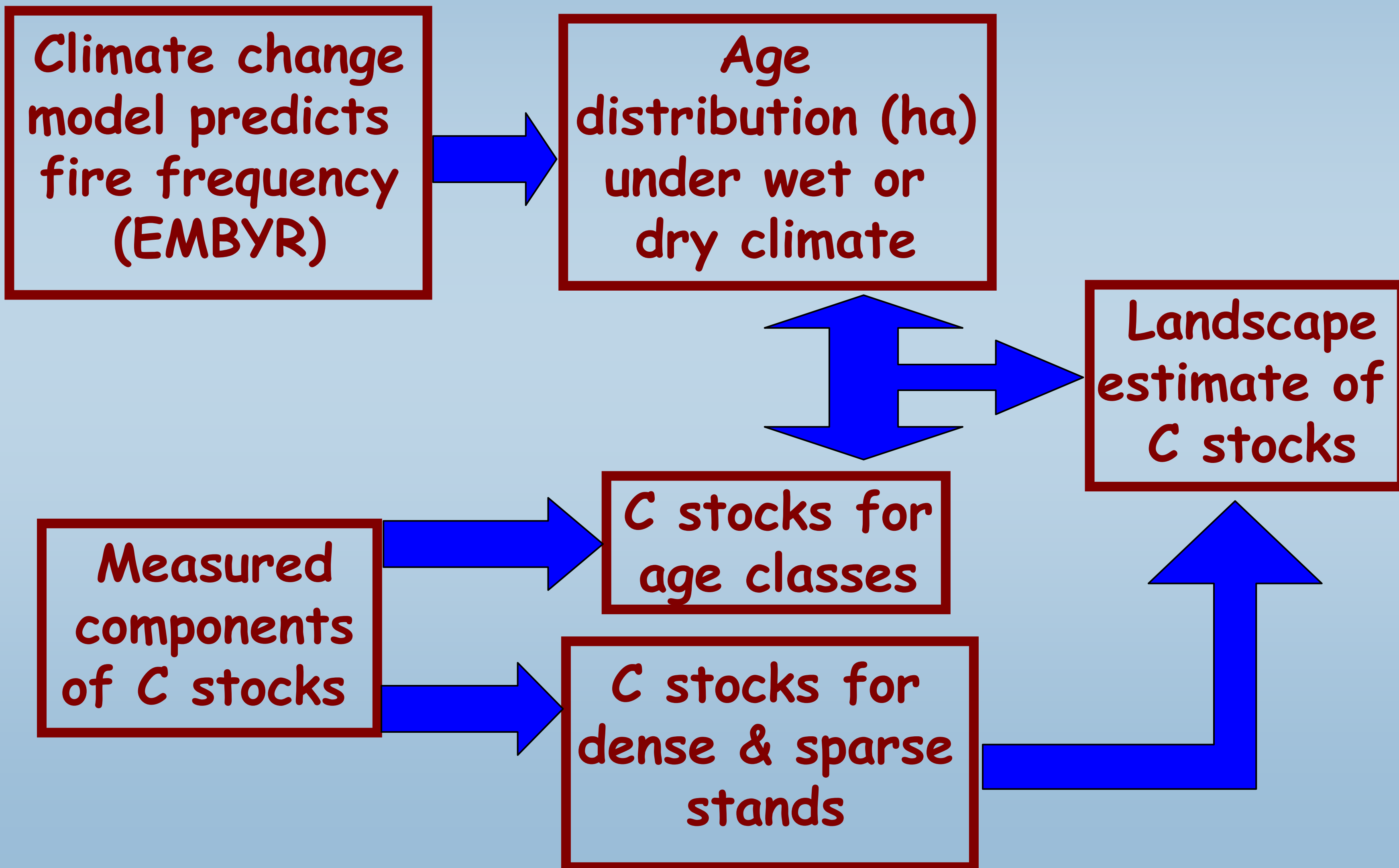


ΔC
Vegetation
(g C/m²/yr)
Dense
Sparse
100
50
0
Total
NEP
(g C/m²/yr)
50
0
-50
Cumulative
NEP
(g C/m²)
0
-2000
-4000
-6000
0
50
100
150
200
250
Age Since Fire

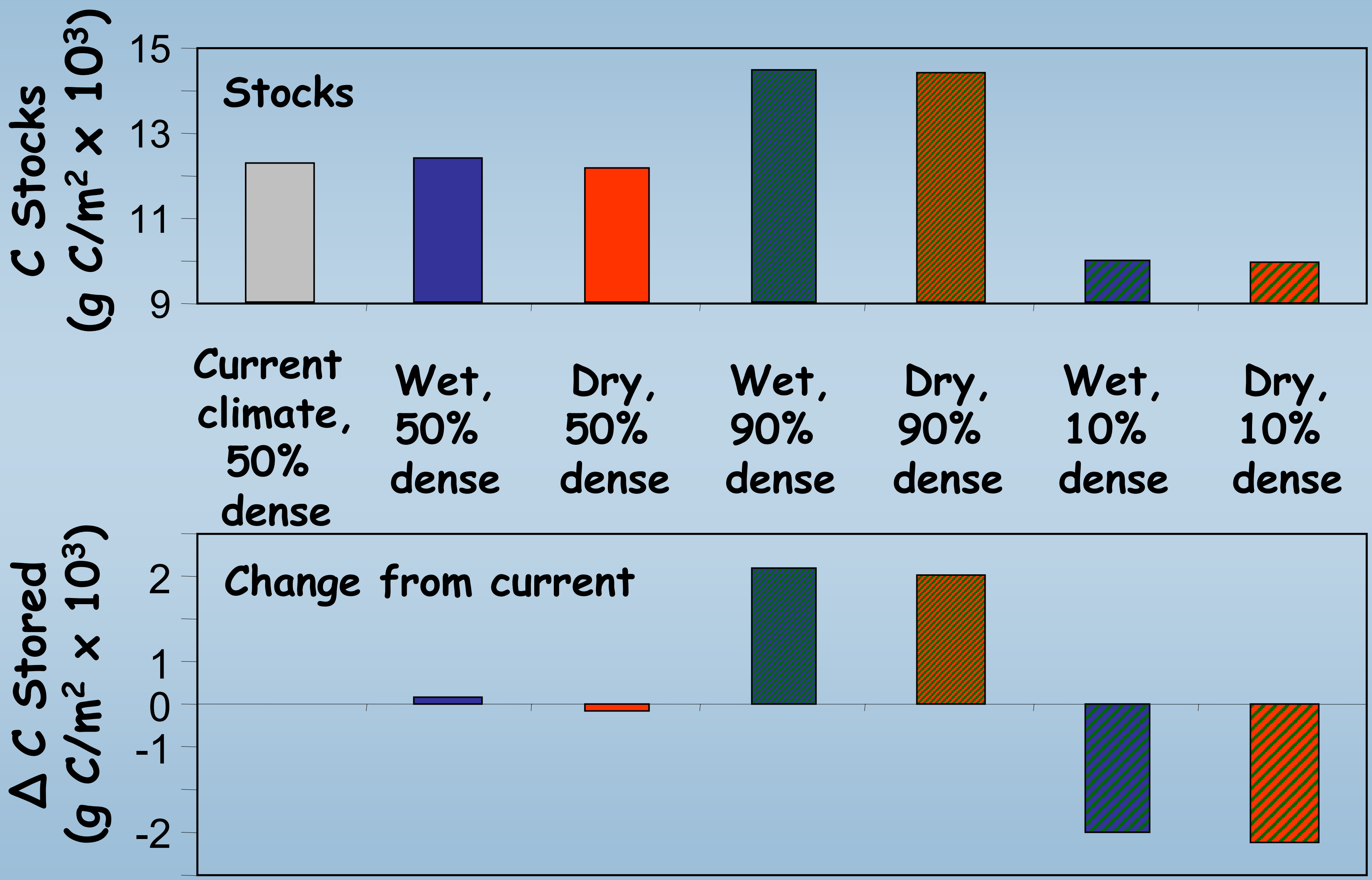
# Stand age distributions affect landscape NEP



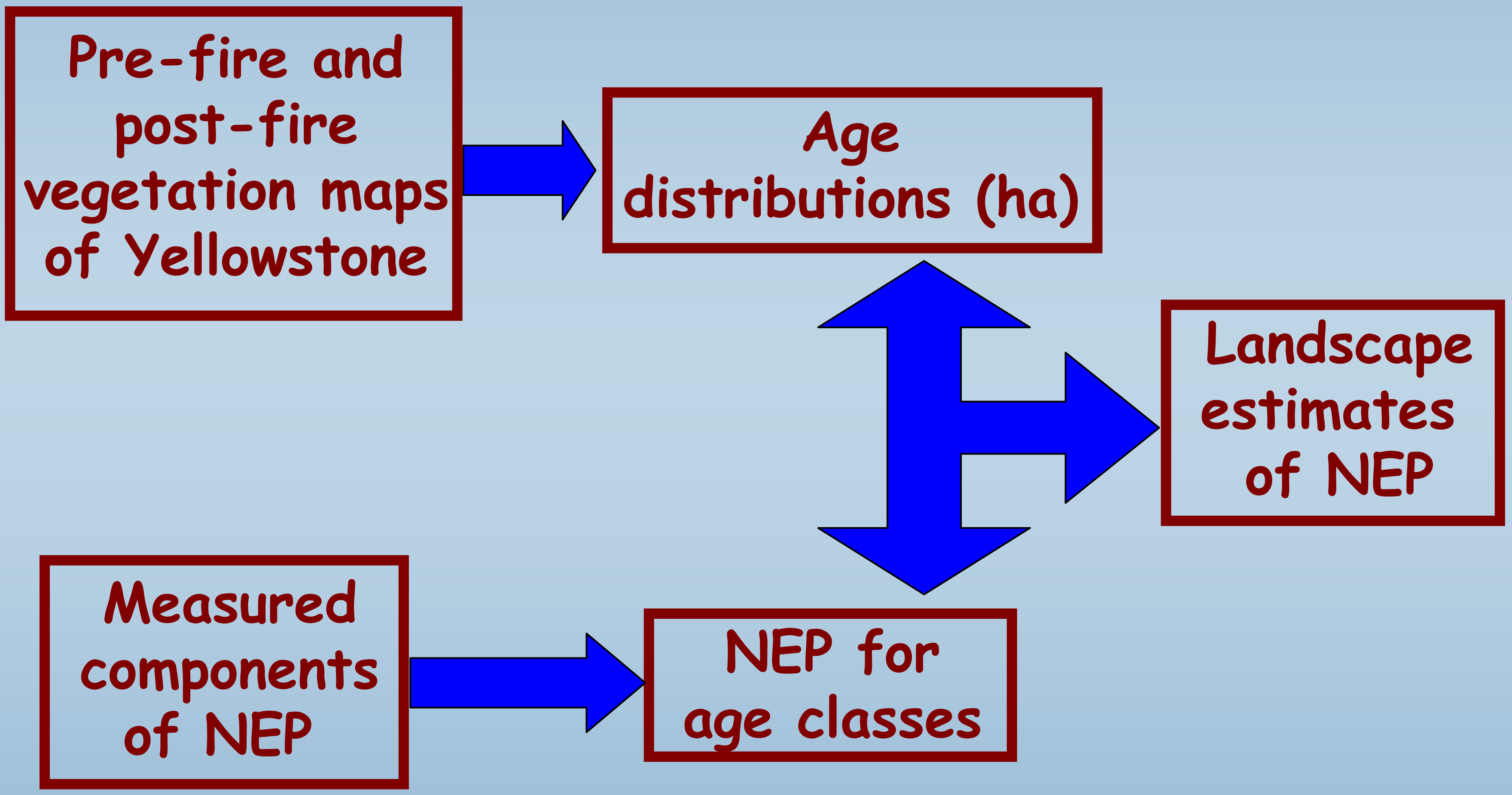

# Stand age and density effects on landscape C storage



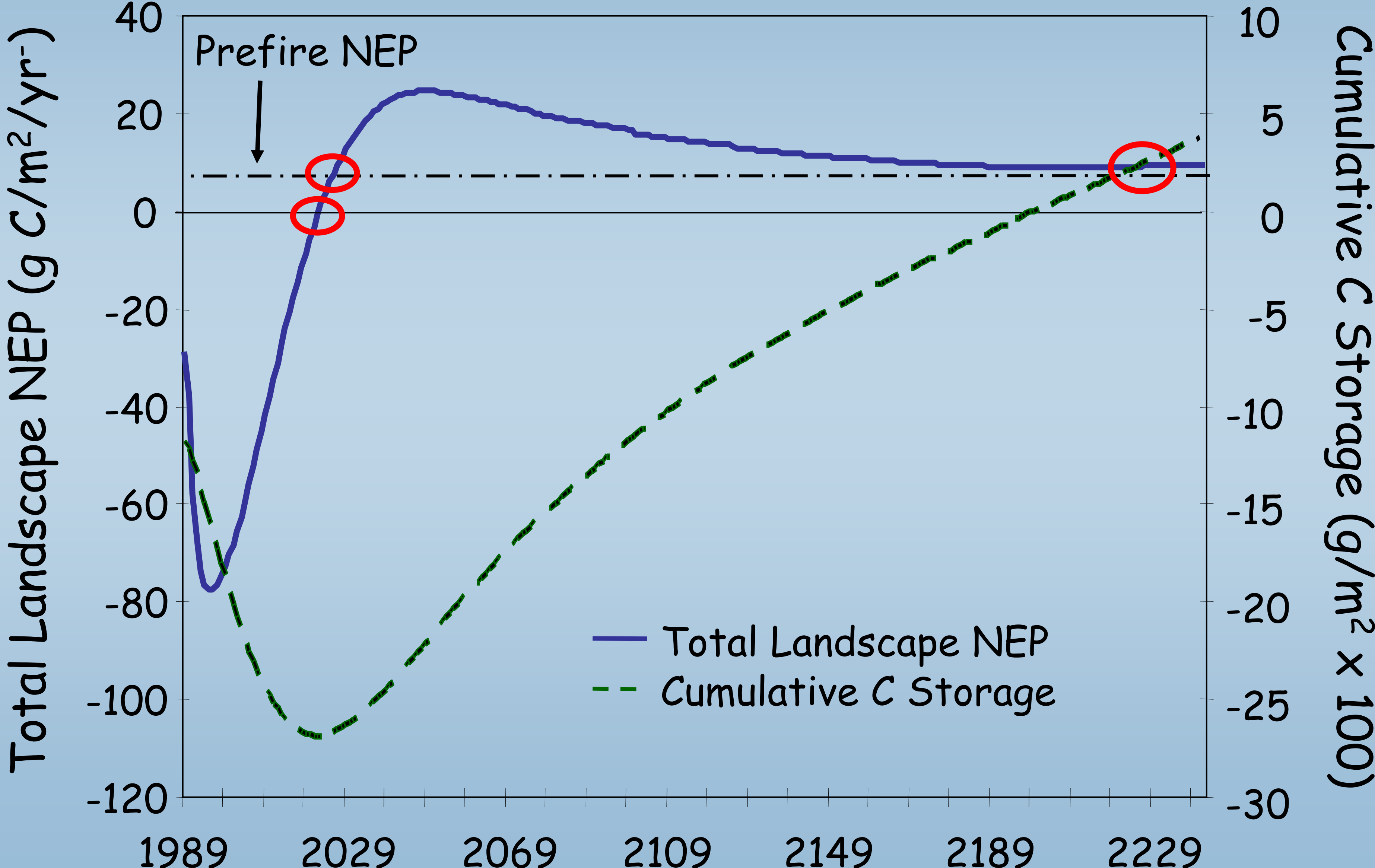
# Stand age and density effects on C storage



# *Predicting future landscape C storage for post-1988 Yellowstone*



# Long-term changes in C storage for Yellowstone



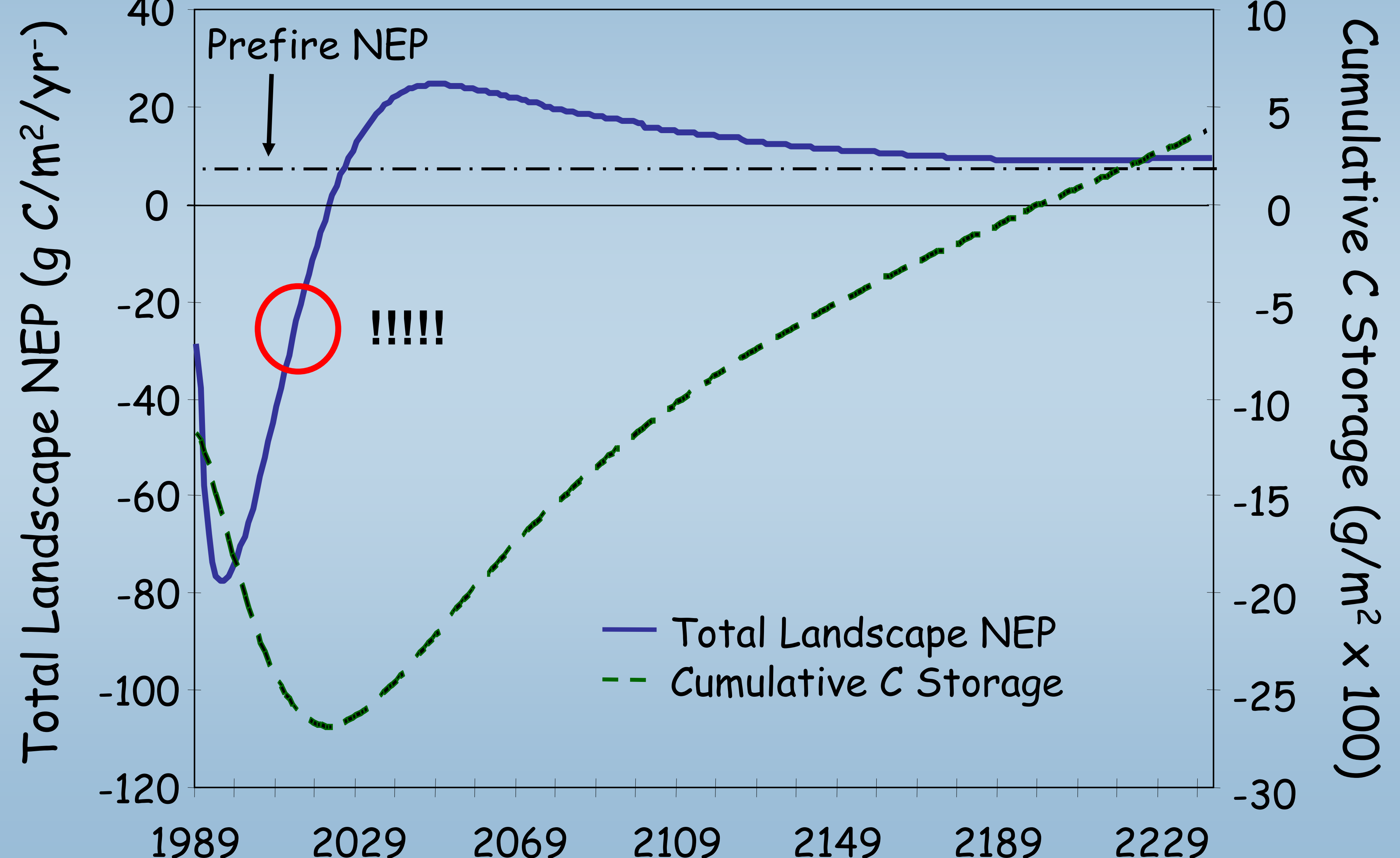
# Carbon Storage Conclusions:

- 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).

# Long-term changes in C storage for Yellowstone



# Future research directions

How do forest disturbances interact, and will climate change affect these interactions?

How do exotic disturbances affect forests compared to native disturbances?

What are the critical links between terrestrial systems and aquatic systems under multiple climate scenarios?

# An Application to SE Michigan: The Emerald Ash Borer

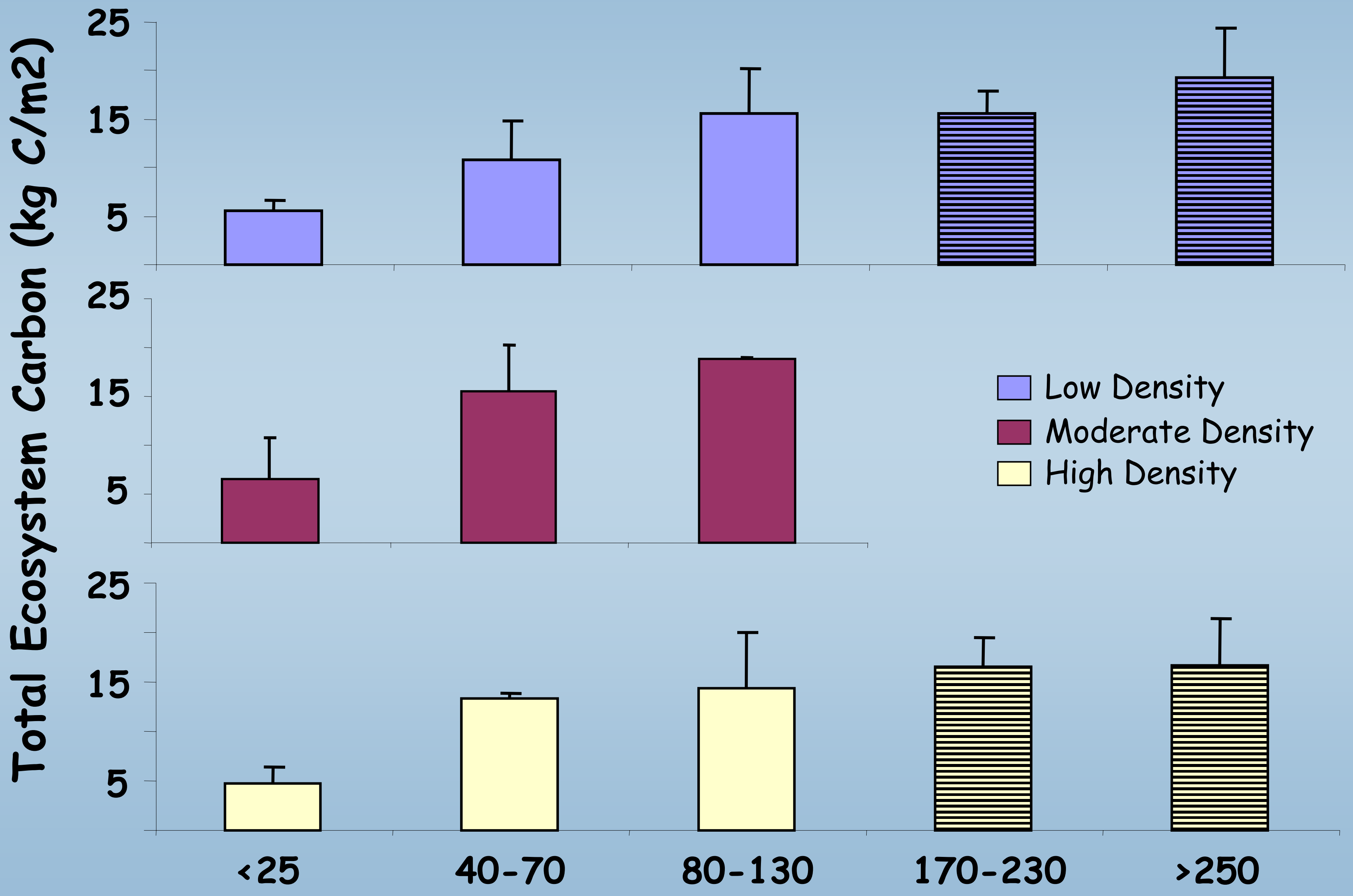
How might climate change affect the ability of ash trees to regenerate?

- Flood regimes in river floodplains (GA) and swamps (BA)
- Ice storms on uplands (WA)

# Current Projects/Proposals:

- Interaction of insect outbreaks, fire, and climate change in Idaho (to NSF)
- Relationship of bedrock geology to forest vegetation and structure in YNP (to NSF)
- Changes in productivity/climate with tree age using stable carbon isotopes ($^{13}C/^{12}C$) in YNP
- Effects of increased fire frequency and plantations on jack pine regeneration in Michigan

# Total Ecosystem Carbon Stocks



# 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

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