# Managing forests for carbon storage and resilience to climate change

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# Carbon Markets:
# Carbon Credits Through Forest Management

Kyoto agreement:

- Reforestation or afforestation (plantations established prior to 1990) in developing countries
- In developed countries, 5% of emissions can be offset through forest management.

Emerging cap and trade systems:

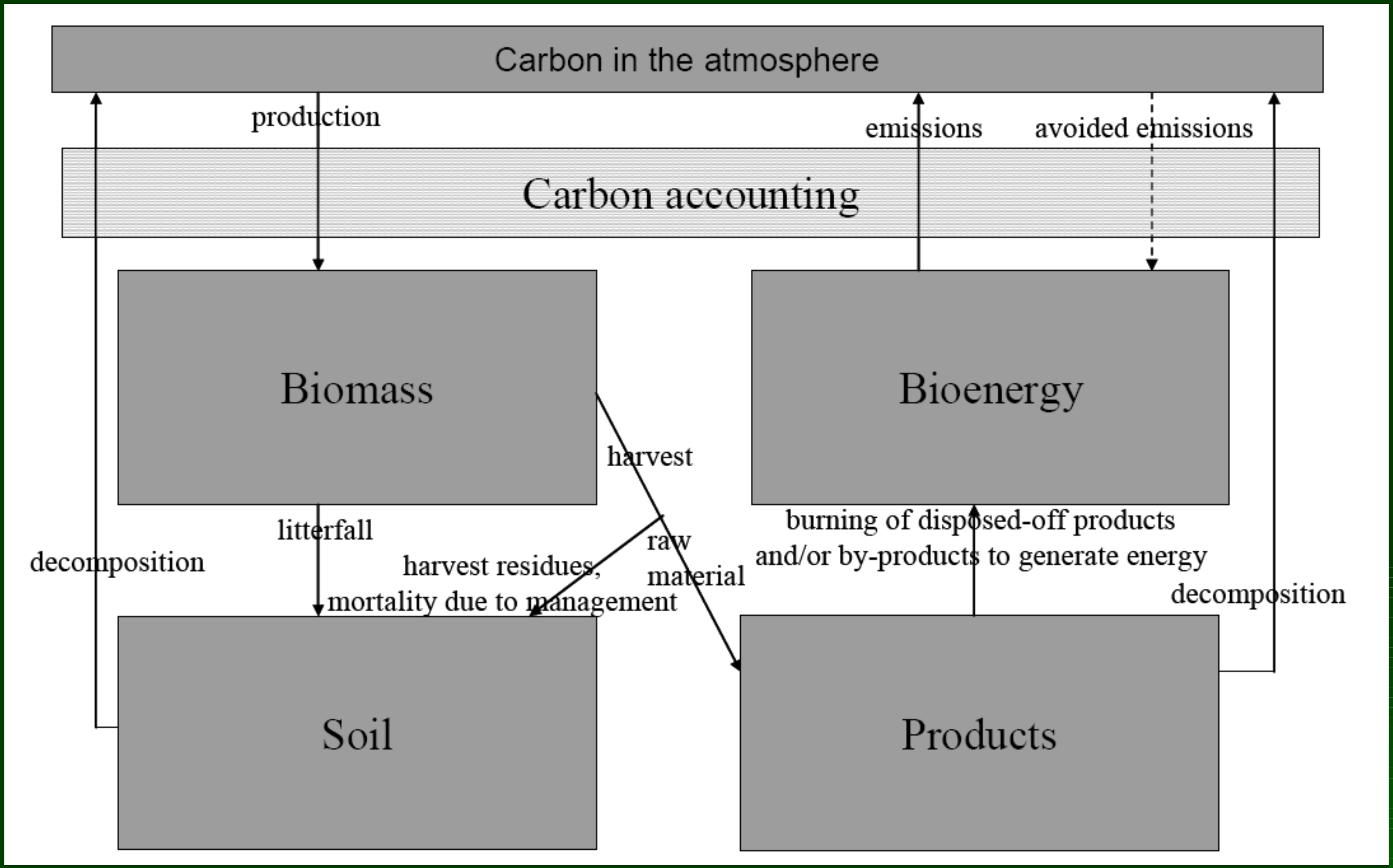
- Possibility for credits from carbon storage "additionality" achieved through a change in management.
- Requires a registry system to establish carbon baselines

# Carbon Revenue

- Estimates of potential carbon credit values range from \$4 to \$60 (or even \$110) per ton of C.
- European market currently trading for \$8 to \$20 per metric ton.
- Future value could increase substantially as international carbon markets develop.

# Chicago Climate Exchange

- "Voluntary 'Cap and Trade' greenhouse gas emission reduction and trading system."
- One Mg Carbon trading for about $5
- Membership from the forest products industry includes:
  - Abitibi-Consolidated
  - Aracruz Celulose S.A.
  - Cenibra Nipo Brasiliera S.A.
  - International Paper
  - Klabin S.A.
  - MeadWestvaco Corp.
  - Stora Enso North America
  - Suzano Papel E Celulose SA
  - Temple-Inland Inc




Modified from: Schelhaas, M.J. et al. 2004. *CO2FIX V 3.1 – A modelling framework for quantifying carbon sequestration in forest ecosystems*.

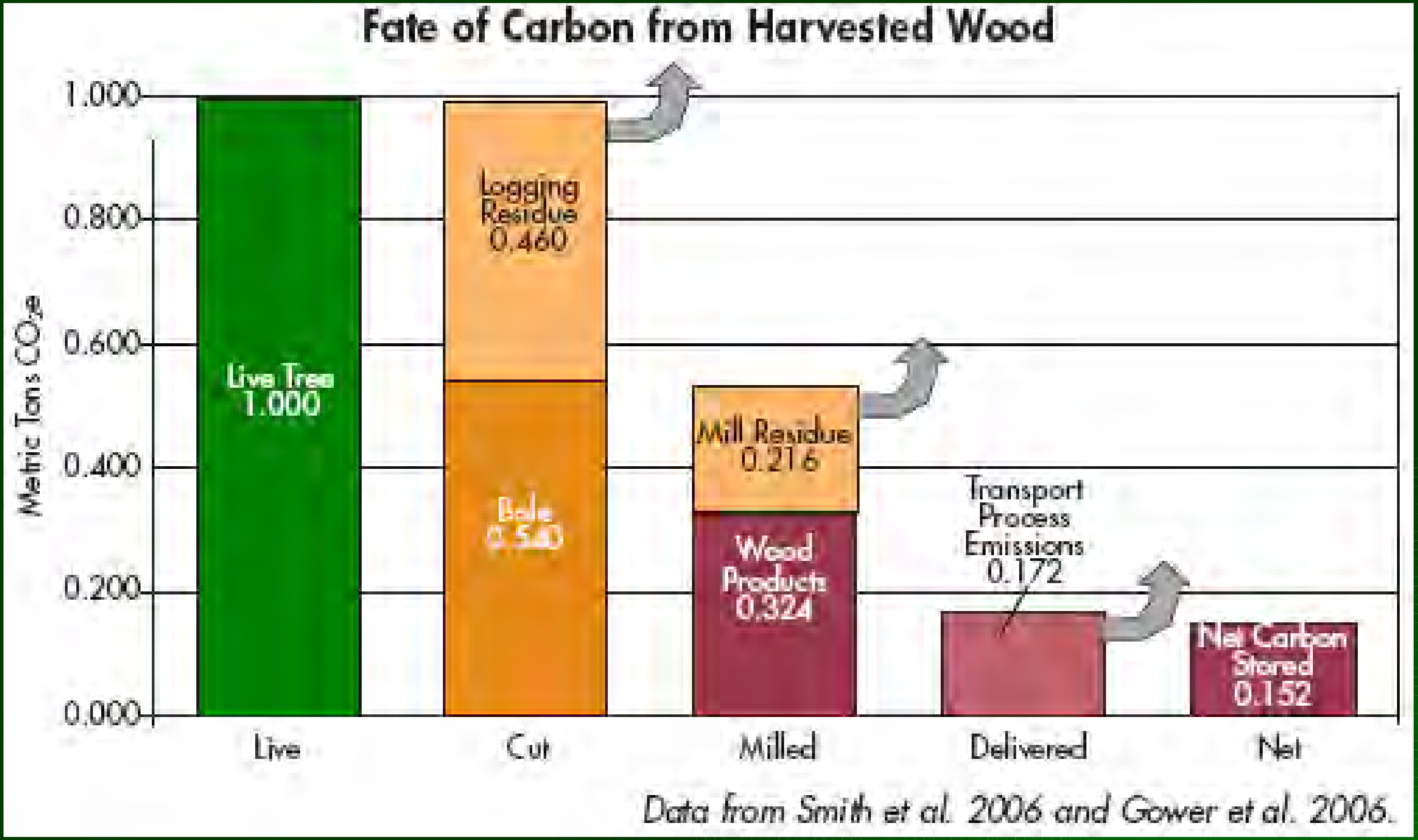
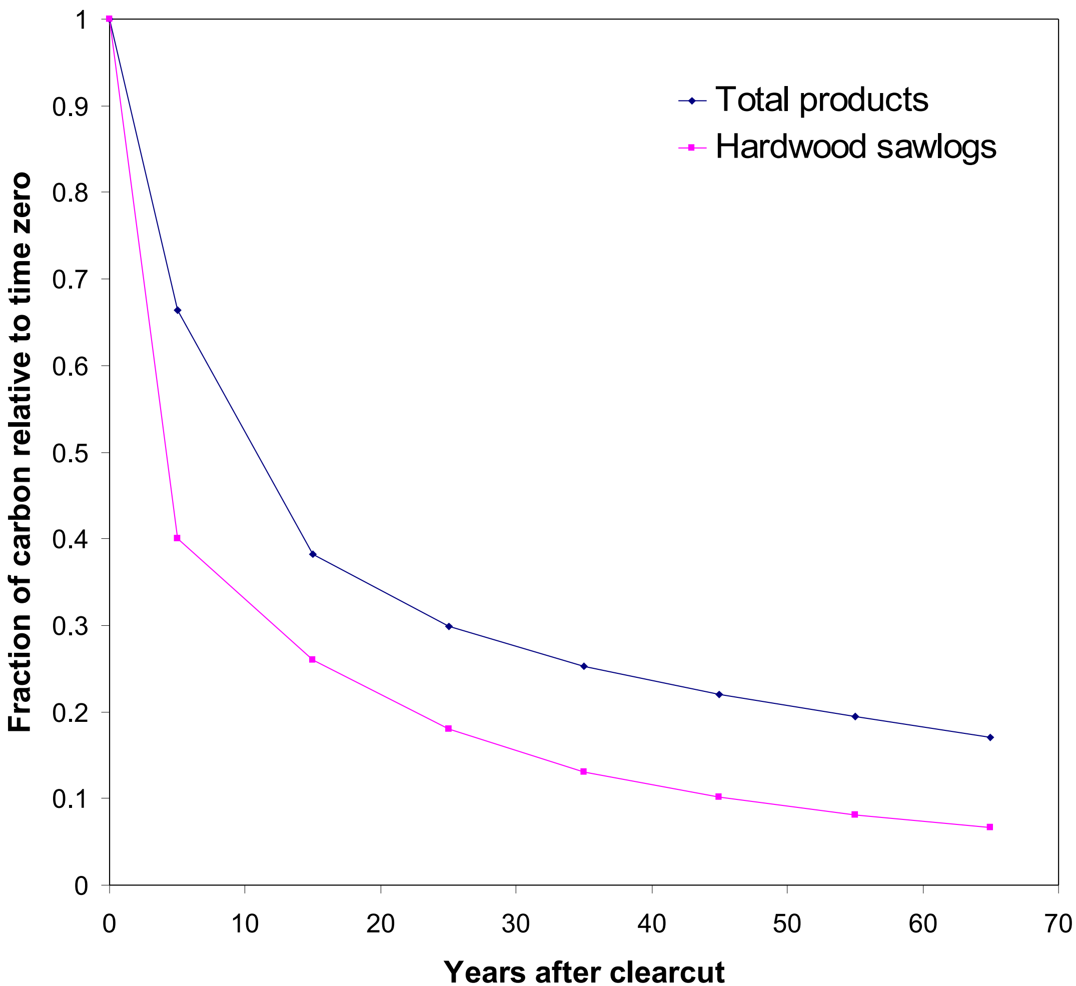



Figure from Ingerson. 2007.

# Carbon residence time in wood products

*Northern hardwood forests in the U.S. Northeast*




Data from Smith et al. (2006).
USDA Forest Service GTR NE-343

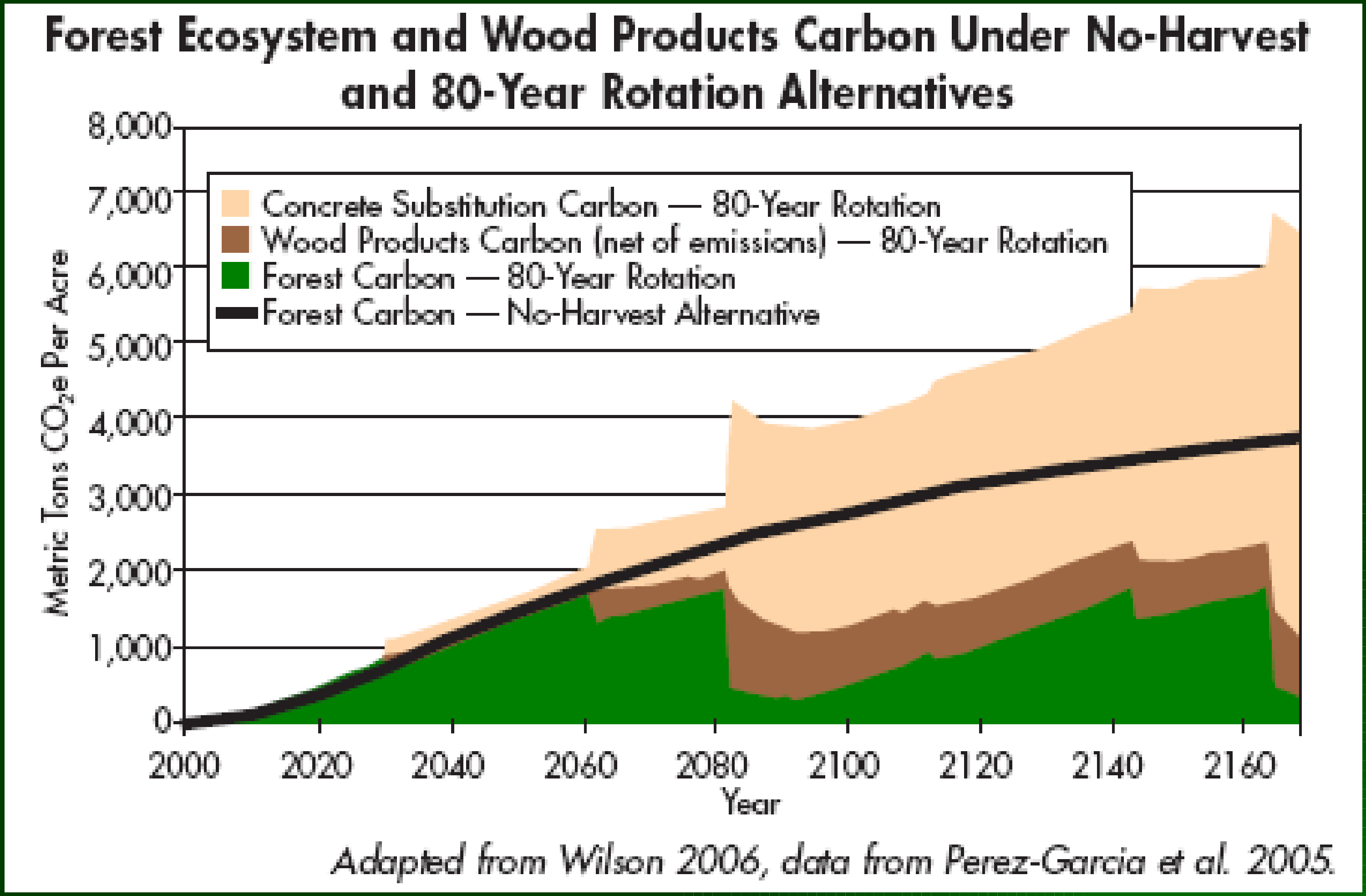
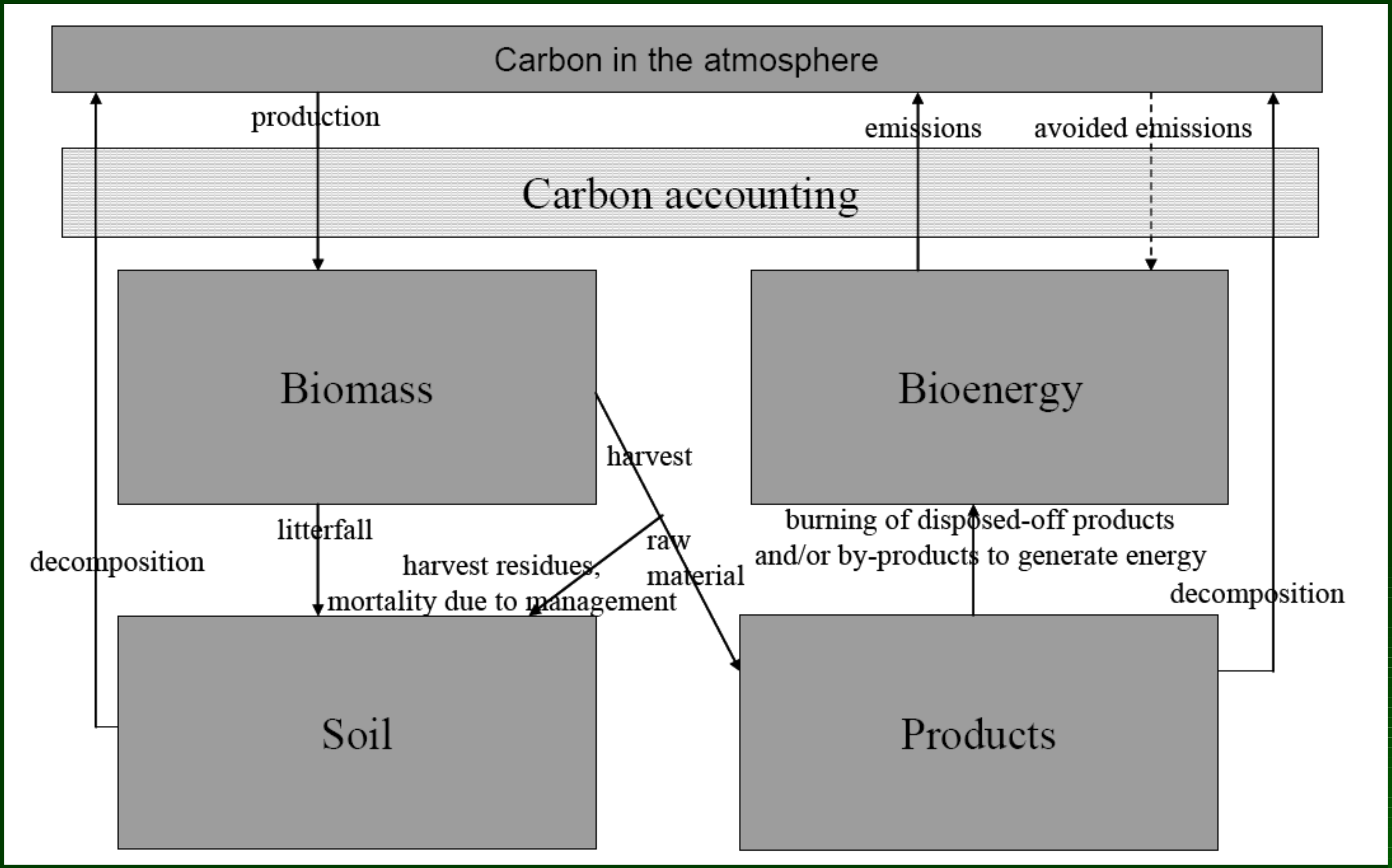



Figure from Ingerson. 2007.




Modified from: Schelhaas, M.J. et al. 2004. *CO2FIX V 3.1 – A modelling framework for quantifying carbon sequestration in forest ecosystems*.

# Forest Biomass Fuel

★ Key: how will this be generated?

- Added harvest margin during regeneration harvest. e.g. whole-tree harvesting or increased removal of cull
- Stand improvement or thinning to harvest cull.
- Issues and concerns

# Coarse Woody Debris in Northern Hardwood Forests

- Habitat
- Nitrogen Fixation
- Soil organic matter
- Mycorrhizal fungi
- Nurse logs
- Erosion reduction
- Riparian functions

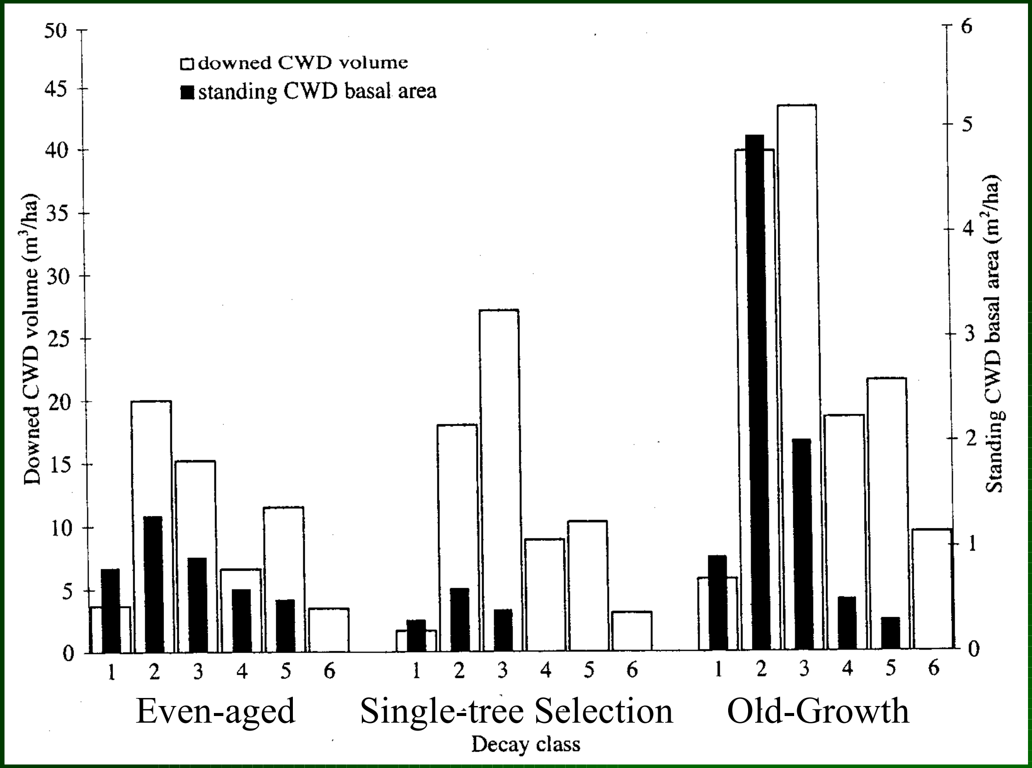
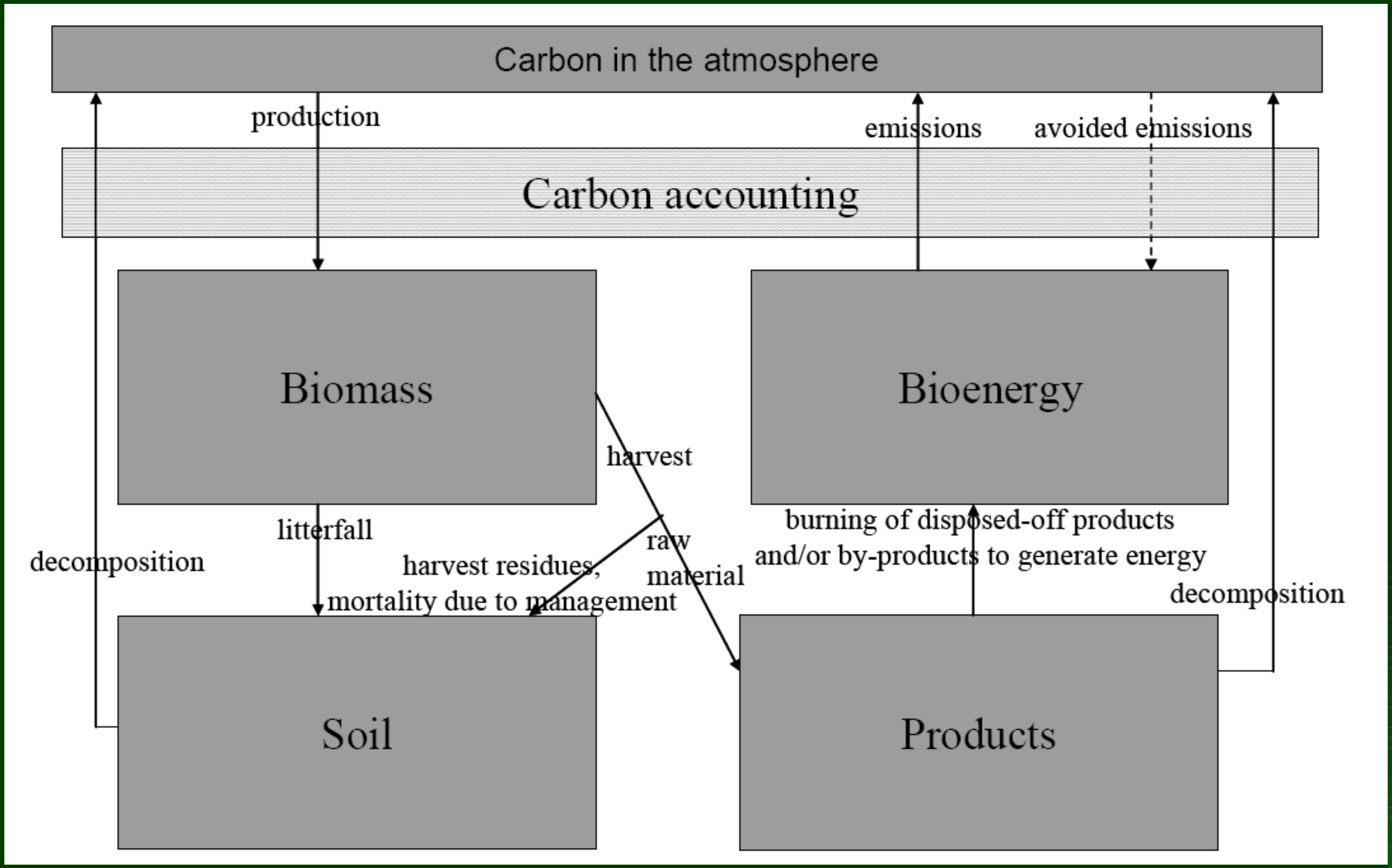
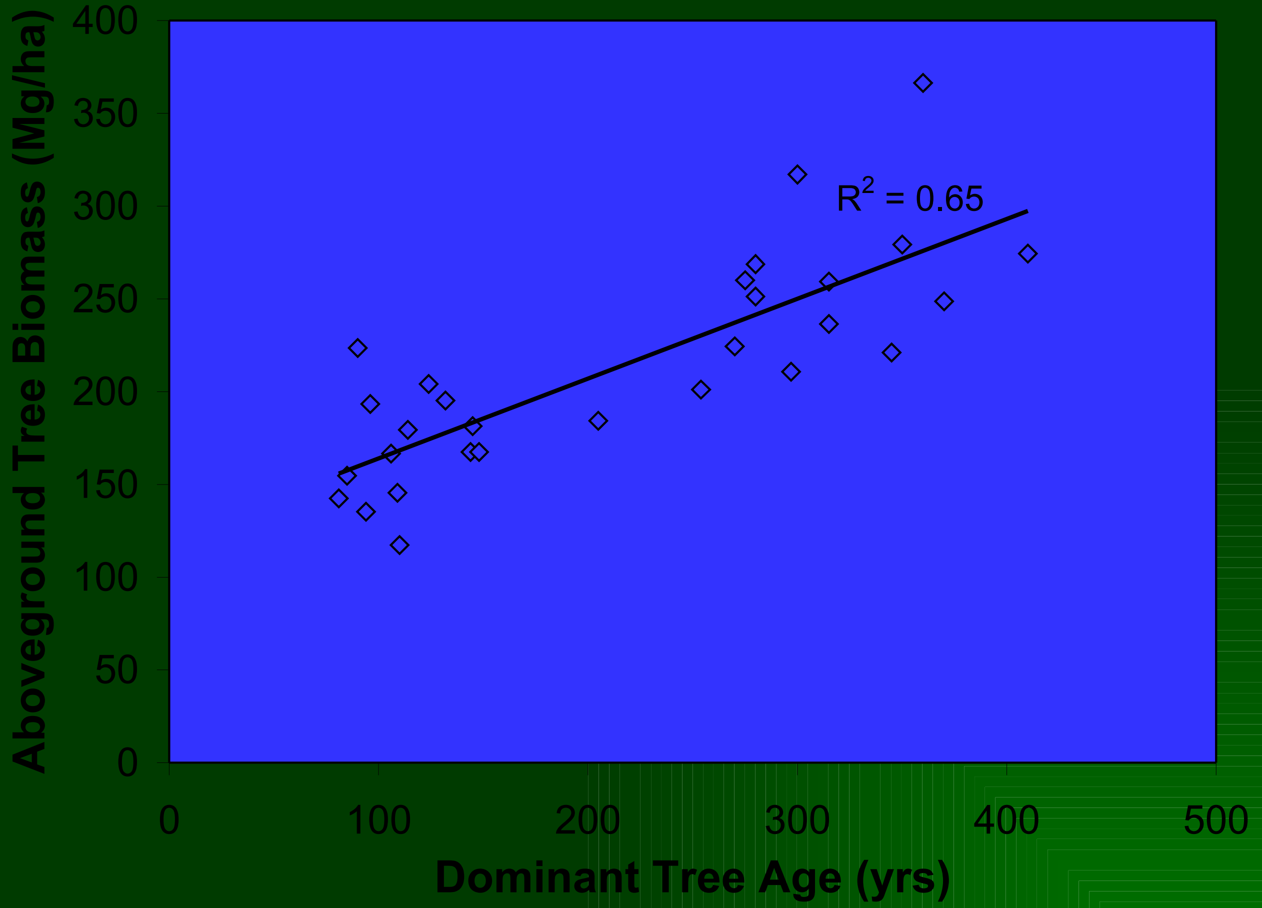



Figure from McGee et al. (1999)

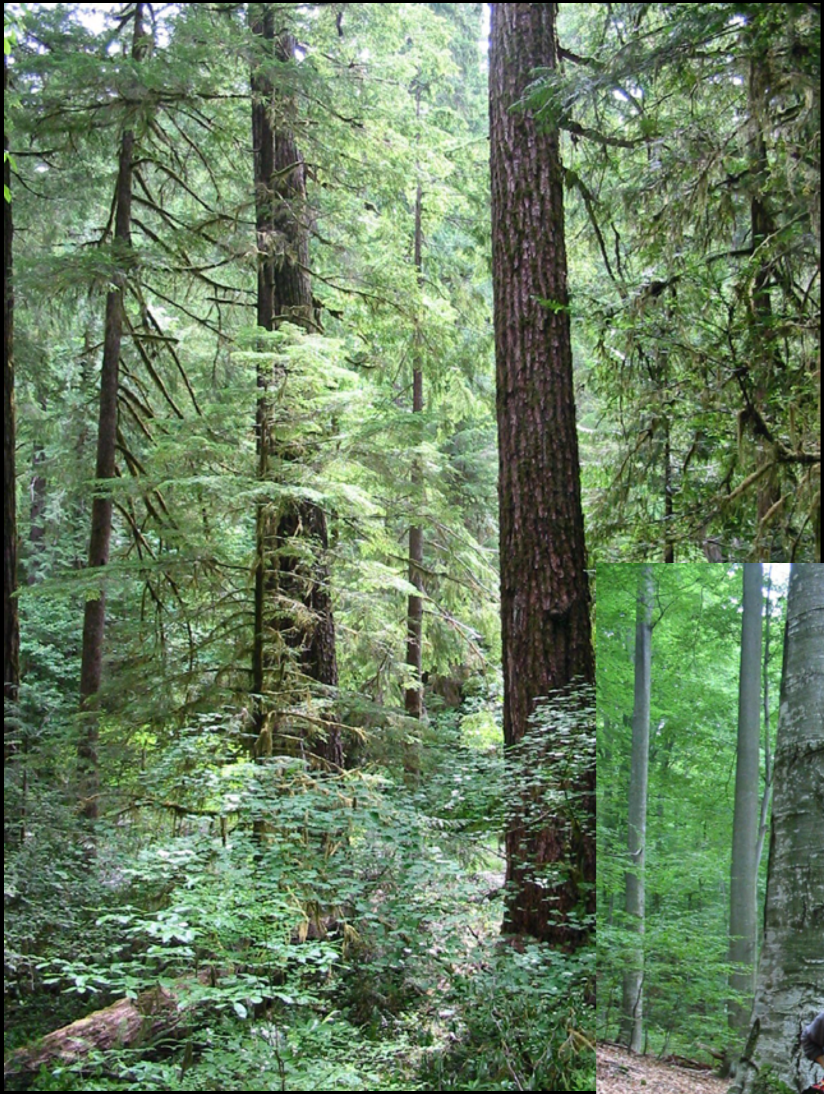



Modified from: Schelhaas, M.J. et al. 2004. *CO2FIX V 3.1 – A modelling framework for quantifying carbon sequestration in forest ecosystems*.

# Carbon storage in old and structurally complex forests

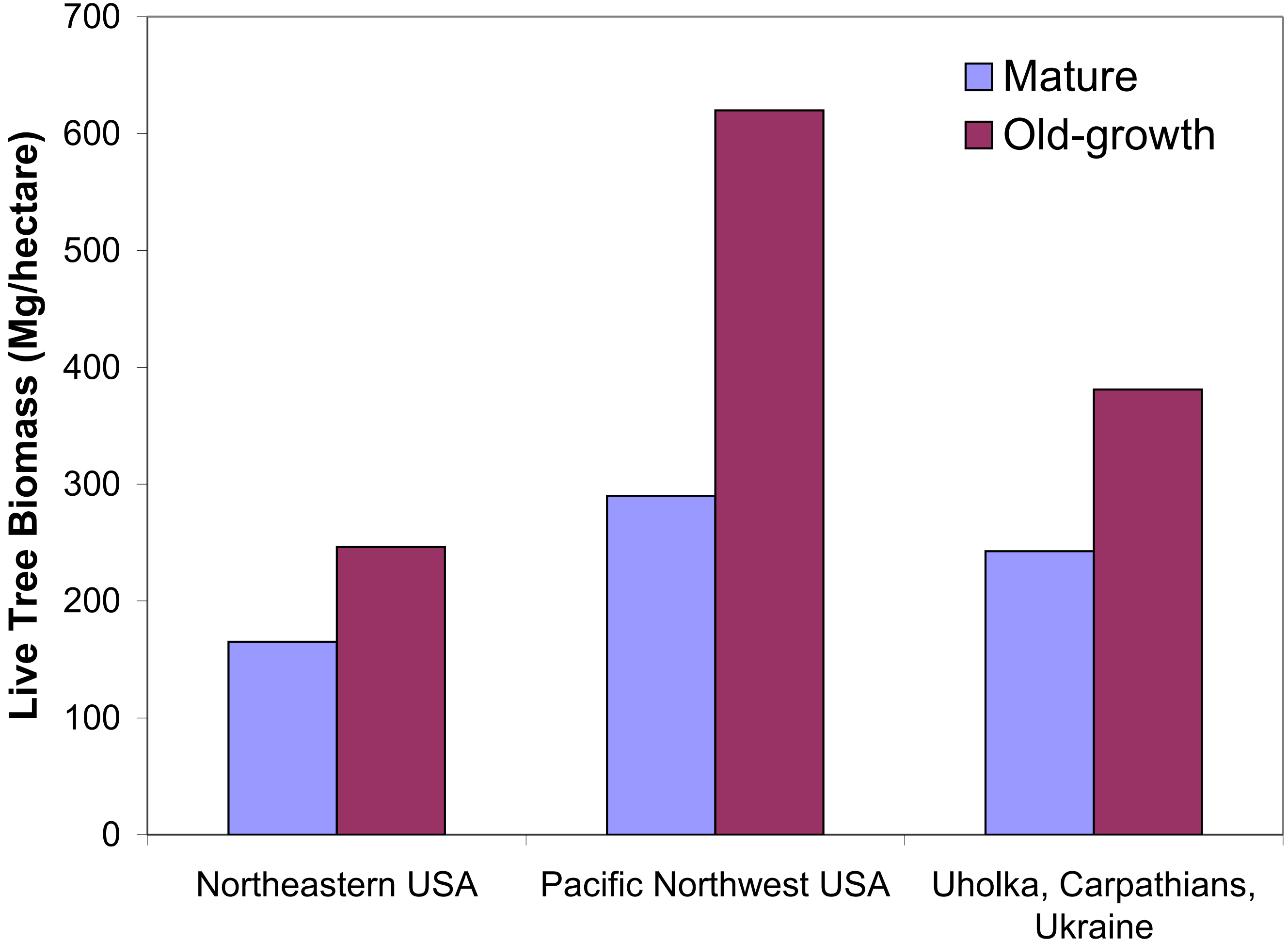



Keeton et al. 2007. Ecological Applications



Biomass in Mature vs. Old-growth Forests:

*Old Forests Store Large Amounts of Carbon!*

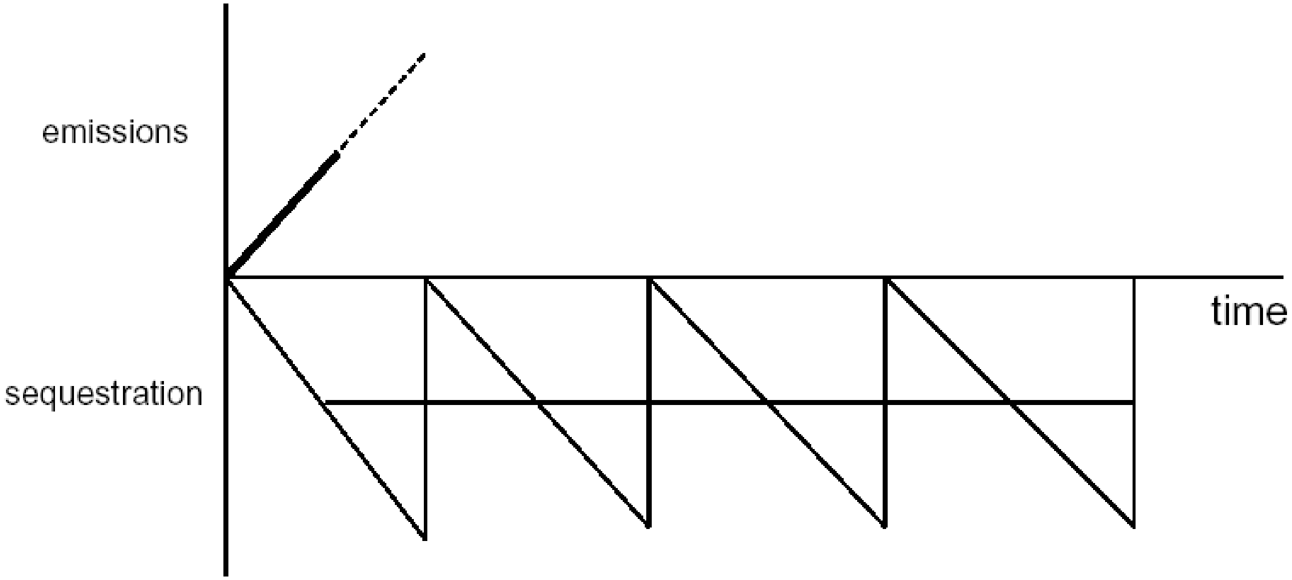



Data Sources:

Ukraine: M. Tchernyavskyy and W. Keeton
U.S. Pacific Northwest: J. Franklin
U.S. Northeast: W. Keeton

# Biomass in Stand

## Carbon accounting: Average storage method




Project only receives the average amount of credits in the long run.
Replacement is only required if the planting/harvesting cycle is discontinued

# VMC - Vermont Forest Ecosystem Management Demonstration Project

1. Single-Tree Selection

   → BDq modified to enhance post-harvest structural retention

2. Group Selection

   → BDq modified to enhance post-harvest structural retention

   → Mimic opening sizes (0.05 ha) created by fine-scale disturbances (Seymour et al. 2002)

3. Structural Complexity Enhancement:

   → Promotes late-successional/old-growth characteristics

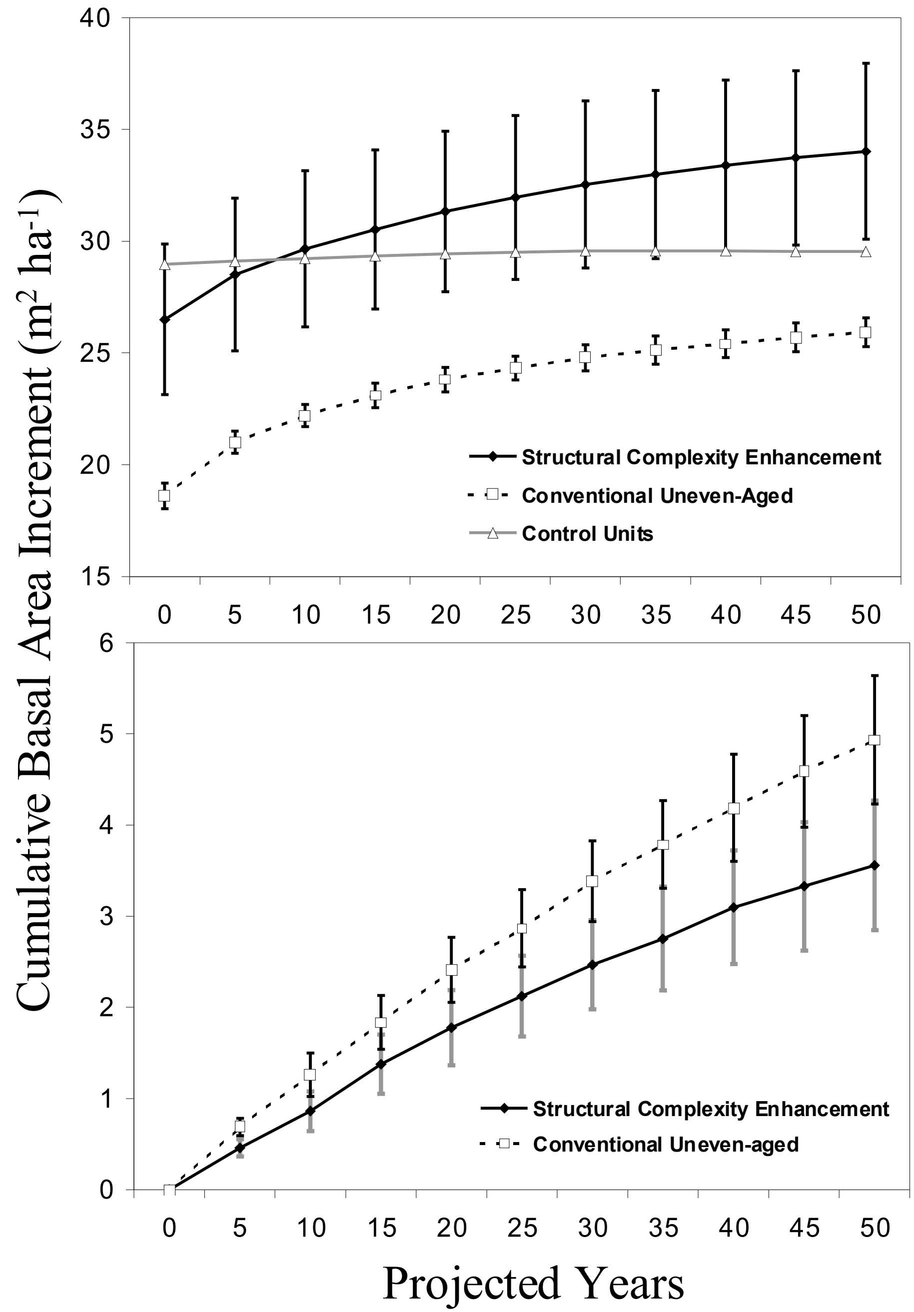

Mt Mansfield State Forest
University of Vermont, Jericho Research Forest


FRANKLIN
KEEP CLEAR

# Cumulative Projected Total Basal Area

# How much have we accelerated growth rates?

Normalized cumulative BAI: “treatment BAI” minus “no treatment BAI” at each time step

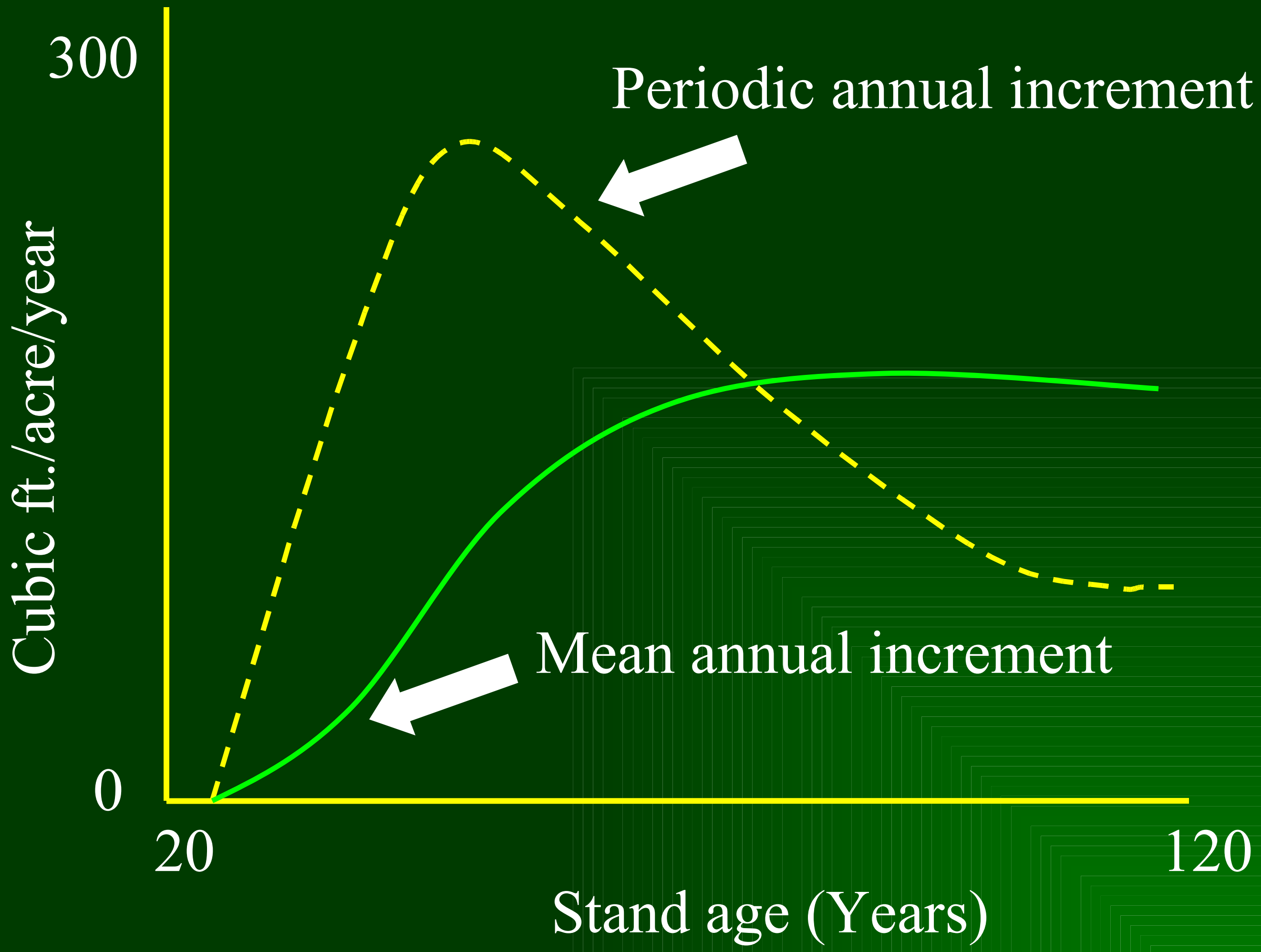



Keeton. 2006. Forest Ecology and Management

# Silvicultural Options:

- Even-Aged/Multi-aged systems


# Extended Rotations

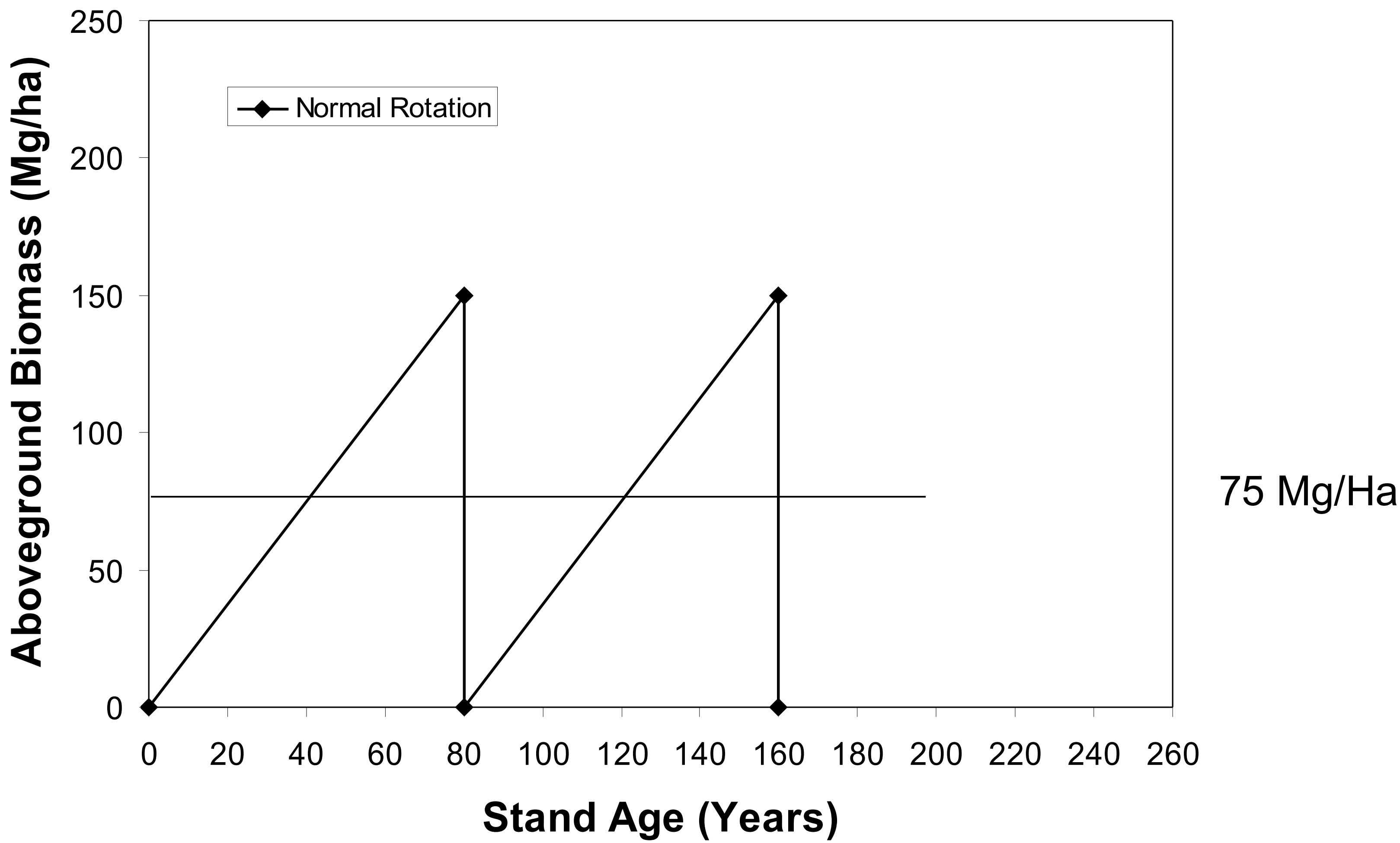


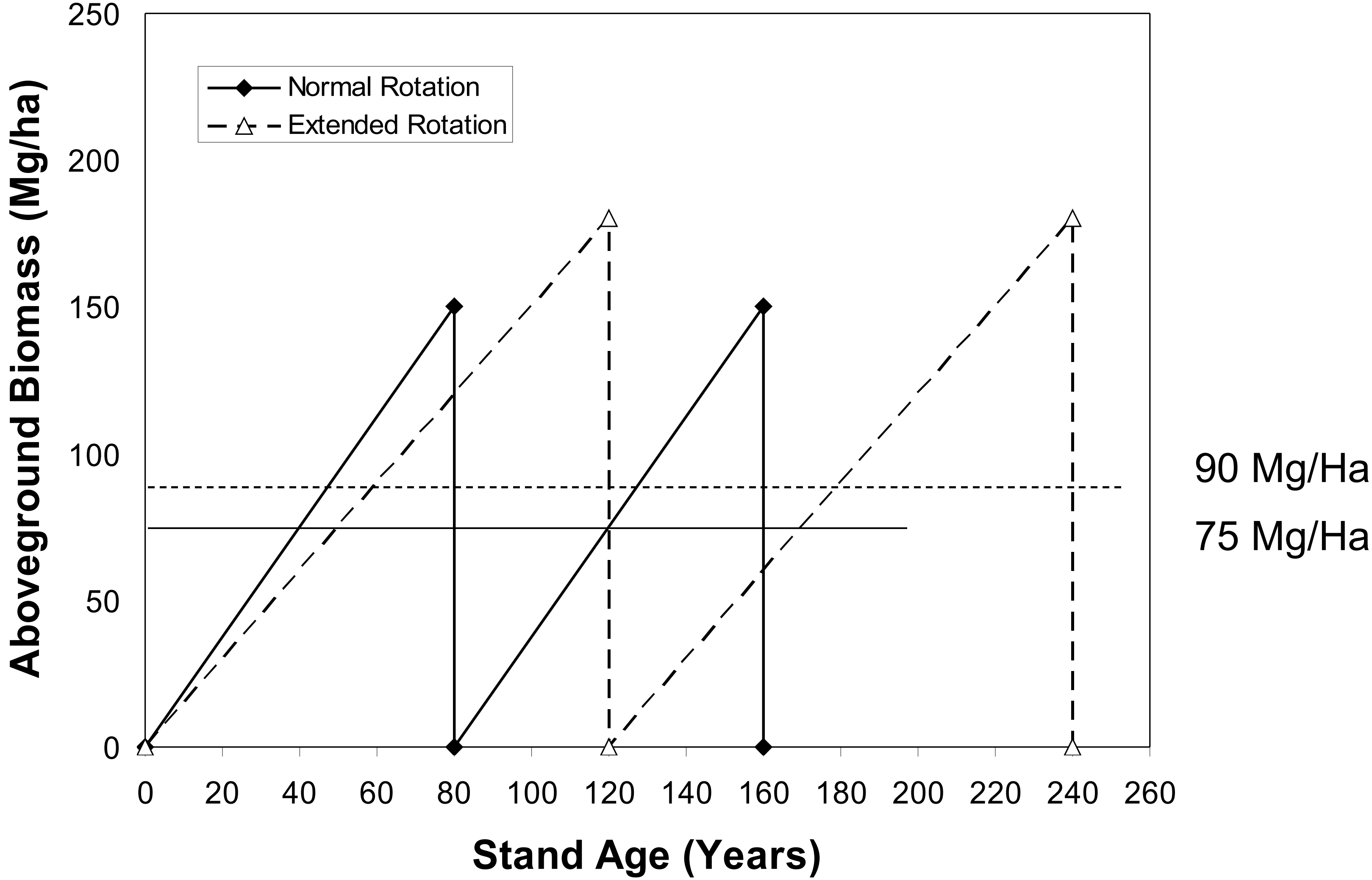

From Curtis (1997)

# Silvicultural Options:

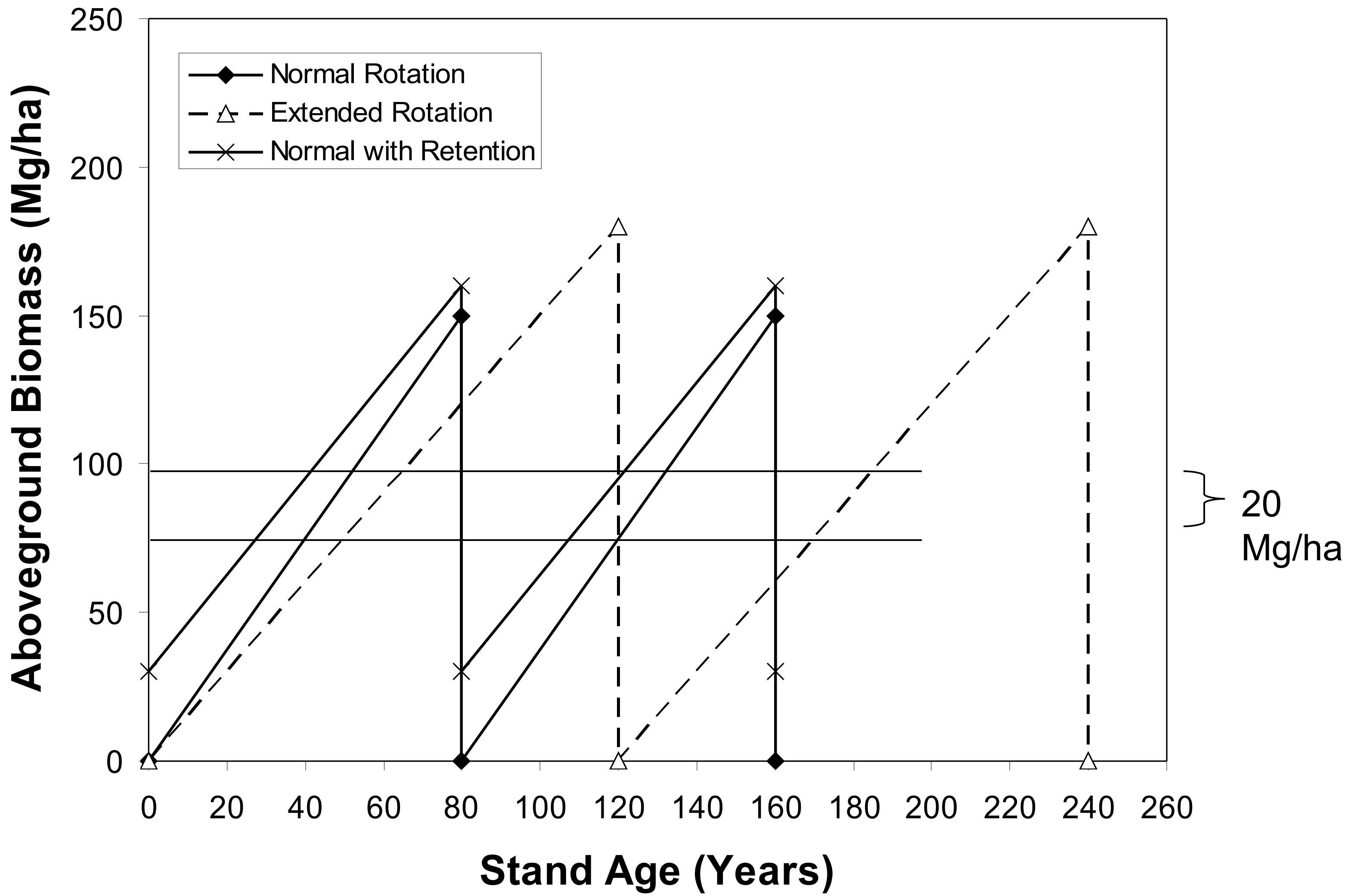
- Disturbance-based/retention forestry



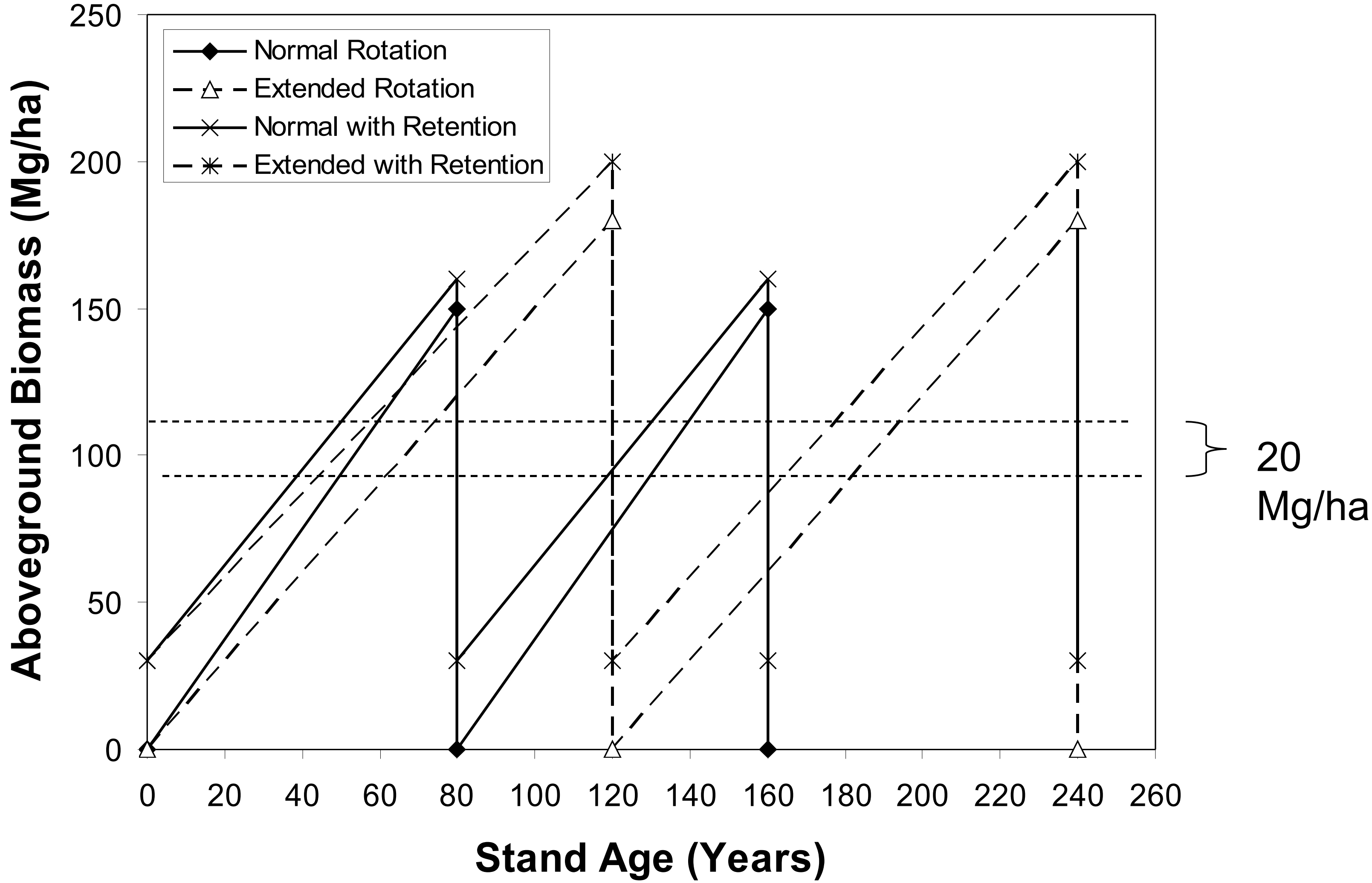

Normal Rotation
Aboveground Biomass (Mg/ha)
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
Stand Age (Years)
75 Mg/Ha



250
200
150
100
50
0
Aboveground Biomass (Mg/ha)
Normal Rotation
Extended Rotation
0
20
40
60
80
100
120
140
160
180
200
220
240
260
Stand Age (Years)
90 Mg/Ha
75 Mg/Ha



Normal Rotation
Extended Rotation
Normal with Retention
Aboveground Biomass (Mg/ha)
Stand Age (Years)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180
200
220
240
260
20
Mg/ha



250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
Aboveground Biomass (Mg/ha)
Stand Age (Years)
Normal Rotation
Extended Rotation
Normal with Retention
Extended with Retention
20
Mg/ha

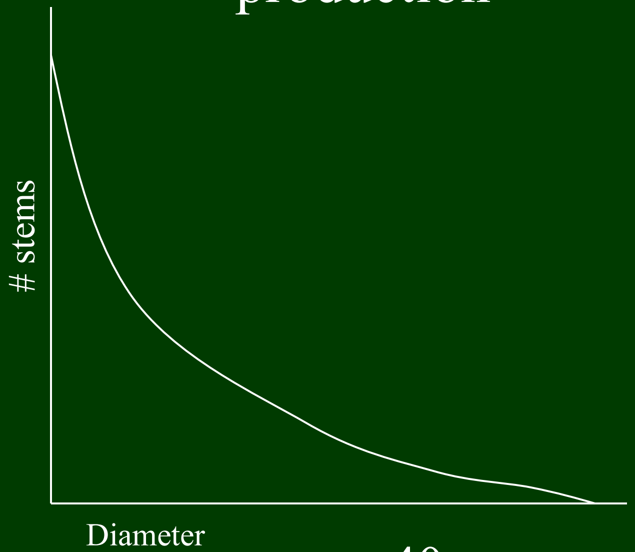
# Silvicultural Options:

- Uneven-Aged


# Stand Structural Complexity

Low — Intermediate — High

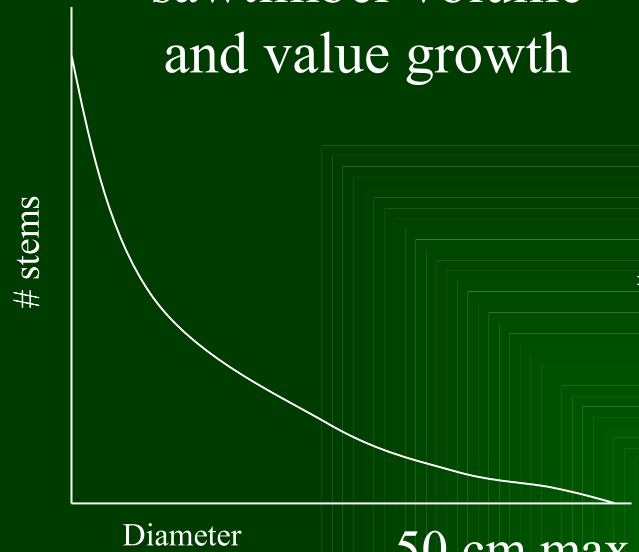
## Maximized volume production




40 cm max.

**Low Carbon**

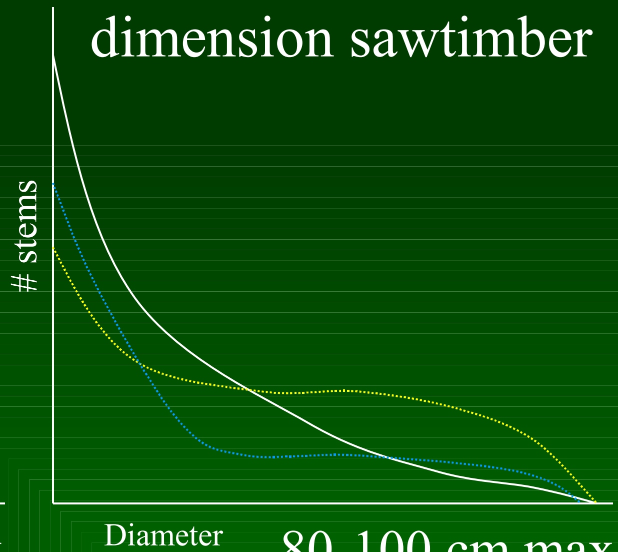
## Maximized large sawtimber volume and value growth




50 cm max.

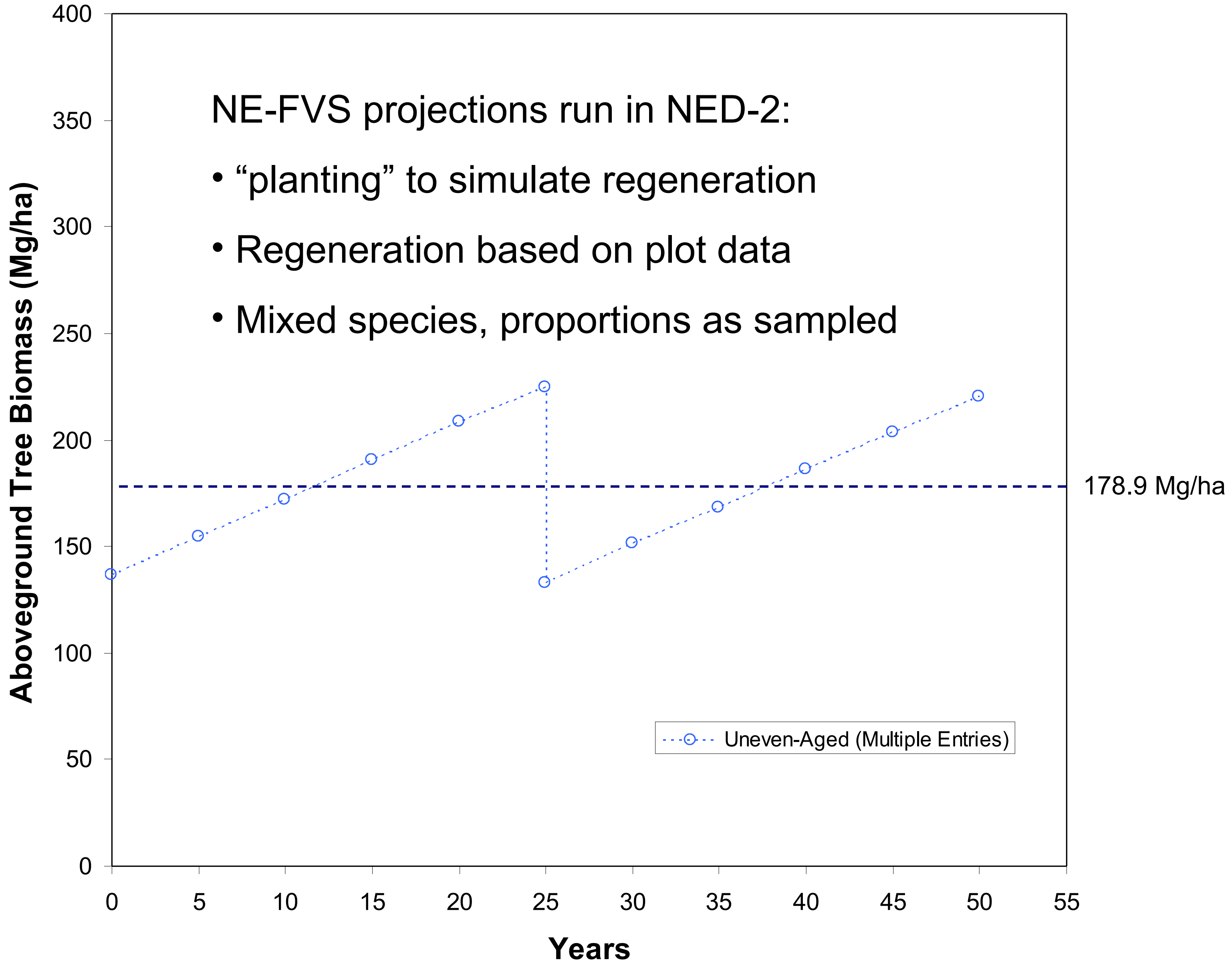
**Medium Carbon**

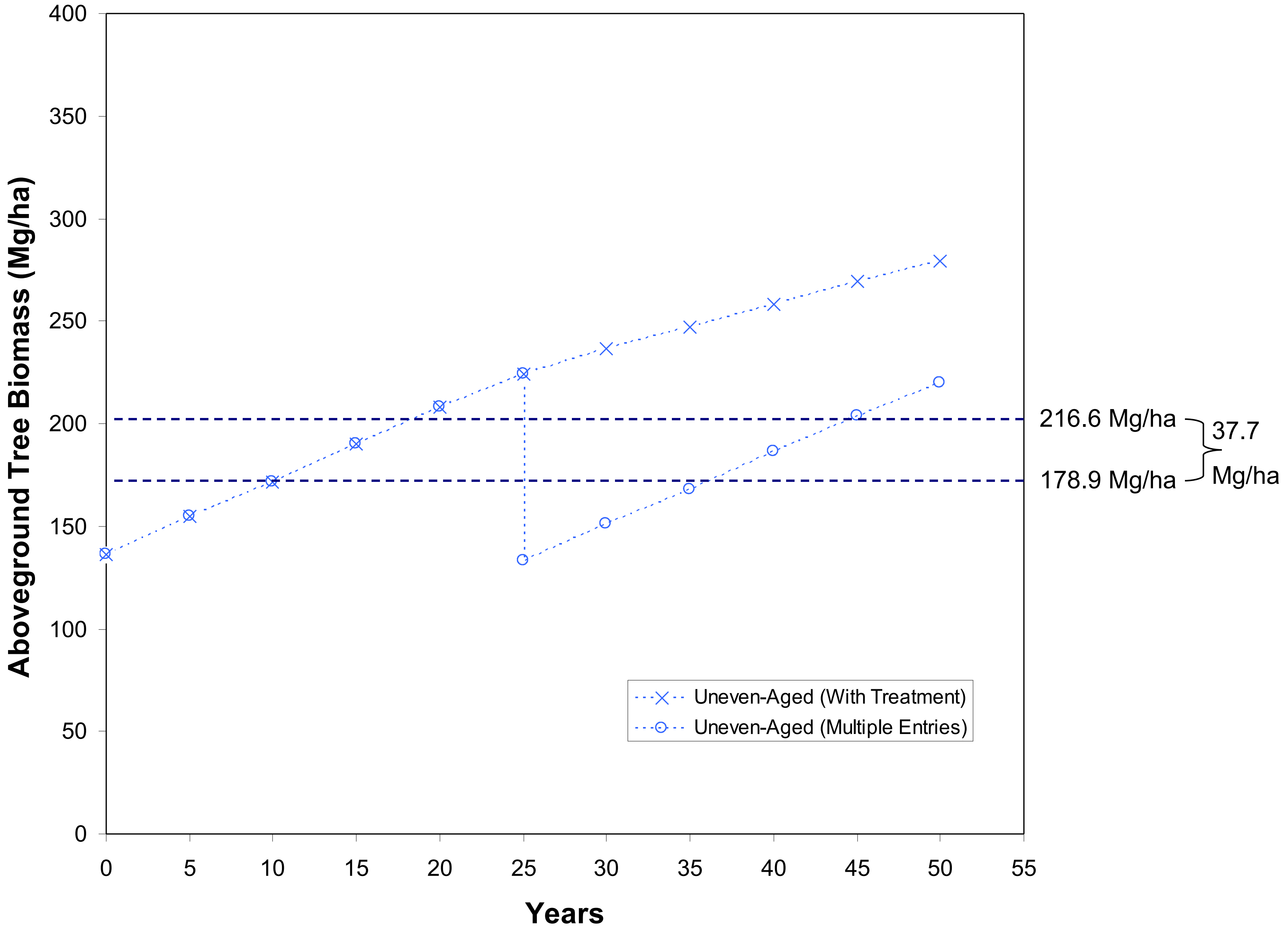
## Lower vol. production but large dimension sawtimber



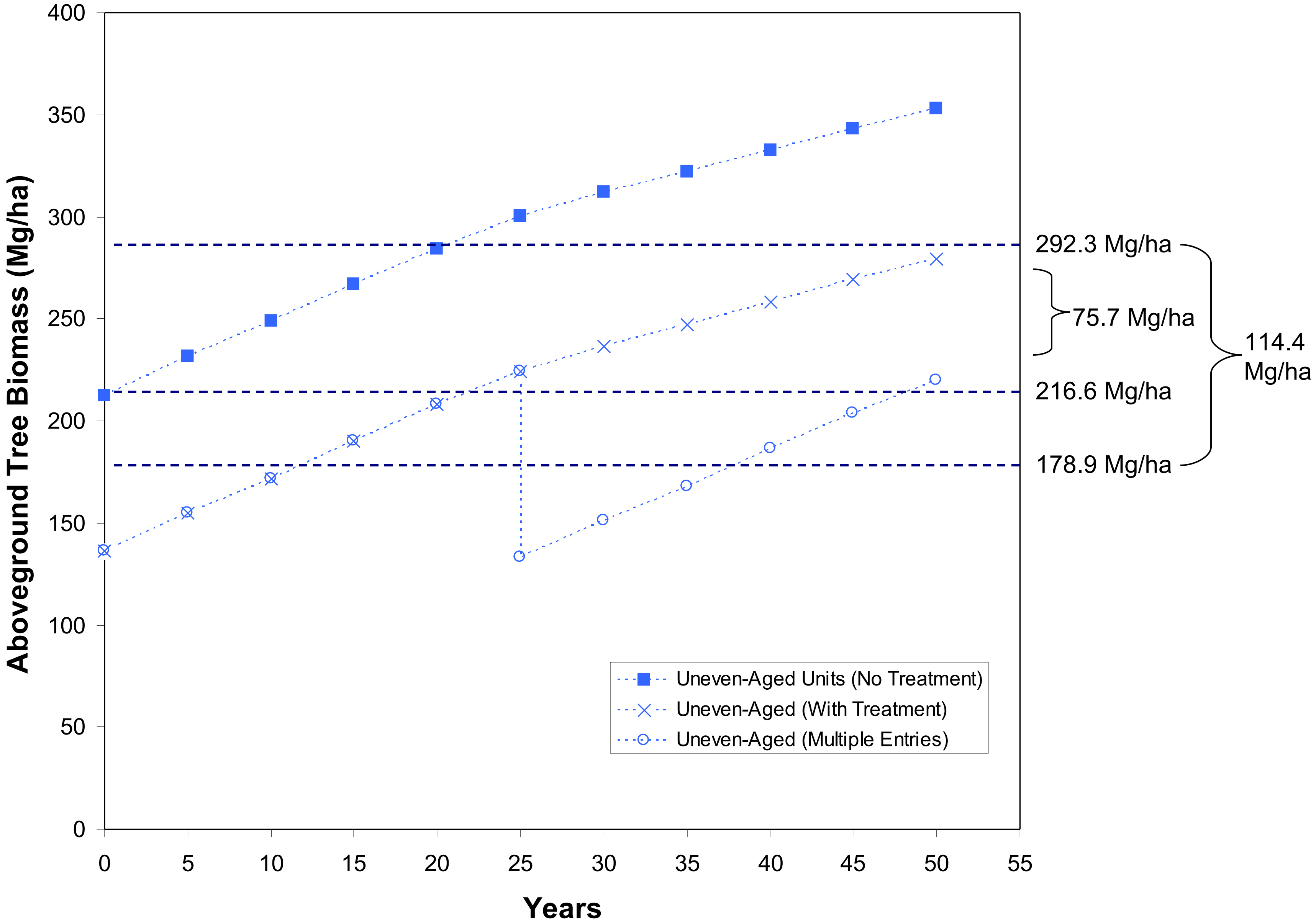

80-100 cm max.

**High Carbon**

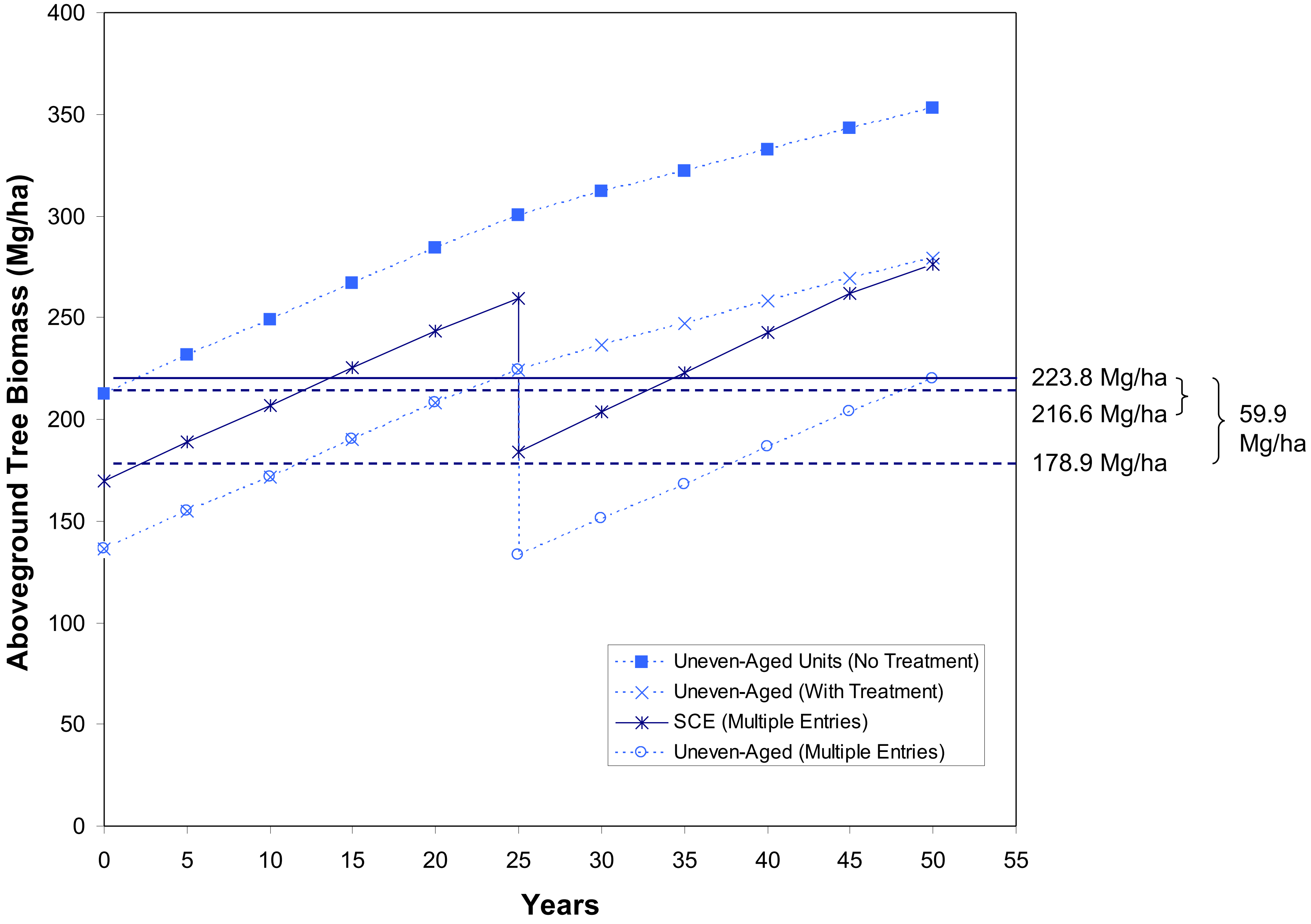

NE-FVS projections run in NED-2:
• “planting” to simulate regeneration
• Regeneration based on plot data
• Mixed species, proportions as sampled
Aboveground Tree Biomass (Mg/ha)
Years
178.9 Mg/ha
Uneven-Aged (Multiple Entries)
0
50
100
150
200
250
300
350
400
0
5
10
15
20
25
30
35
40
45
50
55



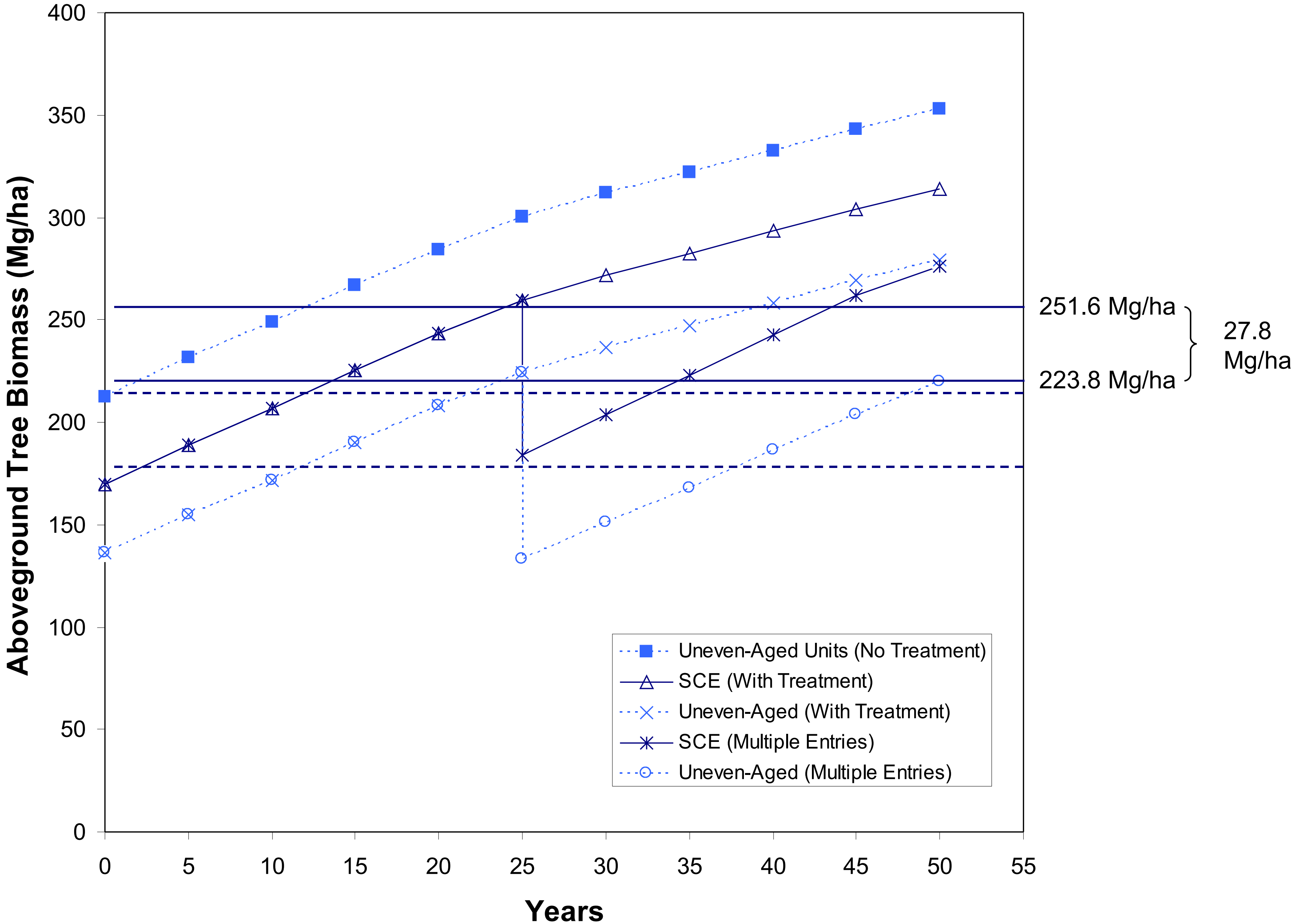
Aboveground Tree Biomass (Mg/ha)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
45
50
55
Years
216.6 Mg/ha
178.9 Mg/ha
37.7
Mg/ha
Uneven-Aged (With Treatment)
Uneven-Aged (Multiple Entries)



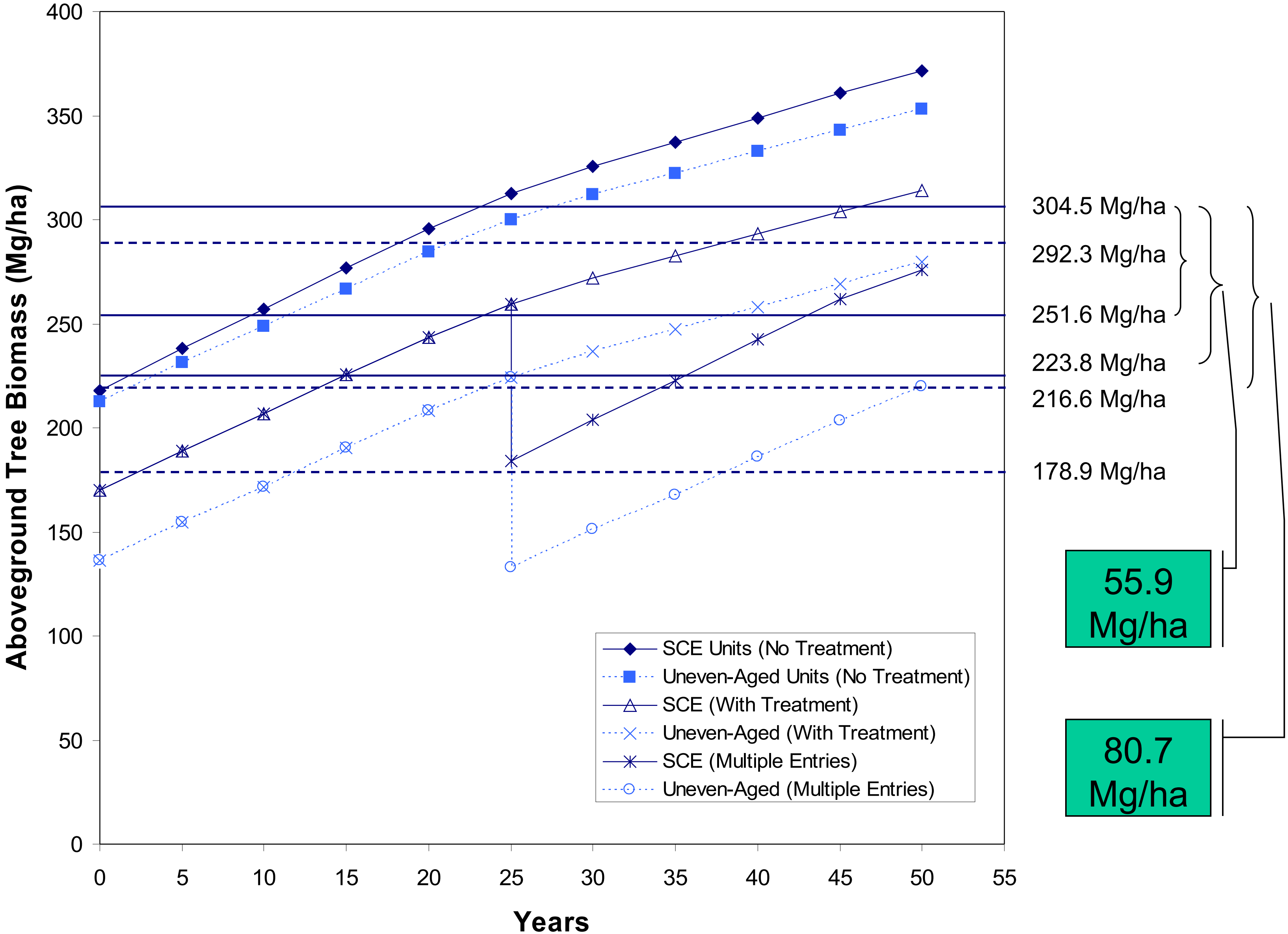
Aboveground Tree Biomass (Mg/ha)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
45
50
55
Years
292.3 Mg/ha
75.7 Mg/ha
114.4 Mg/ha
216.6 Mg/ha
178.9 Mg/ha
Uneven-Aged Units (No Treatment)
Uneven-Aged (With Treatment)
Uneven-Aged (Multiple Entries)



Aboveground Tree Biomass (Mg/ha)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
45
50
55
Years
223.8 Mg/ha
216.6 Mg/ha
178.9 Mg/ha
59.9 Mg/ha
Uneven-Aged Units (No Treatment)
Uneven-Aged (With Treatment)
SCE (Multiple Entries)
Uneven-Aged (Multiple Entries)

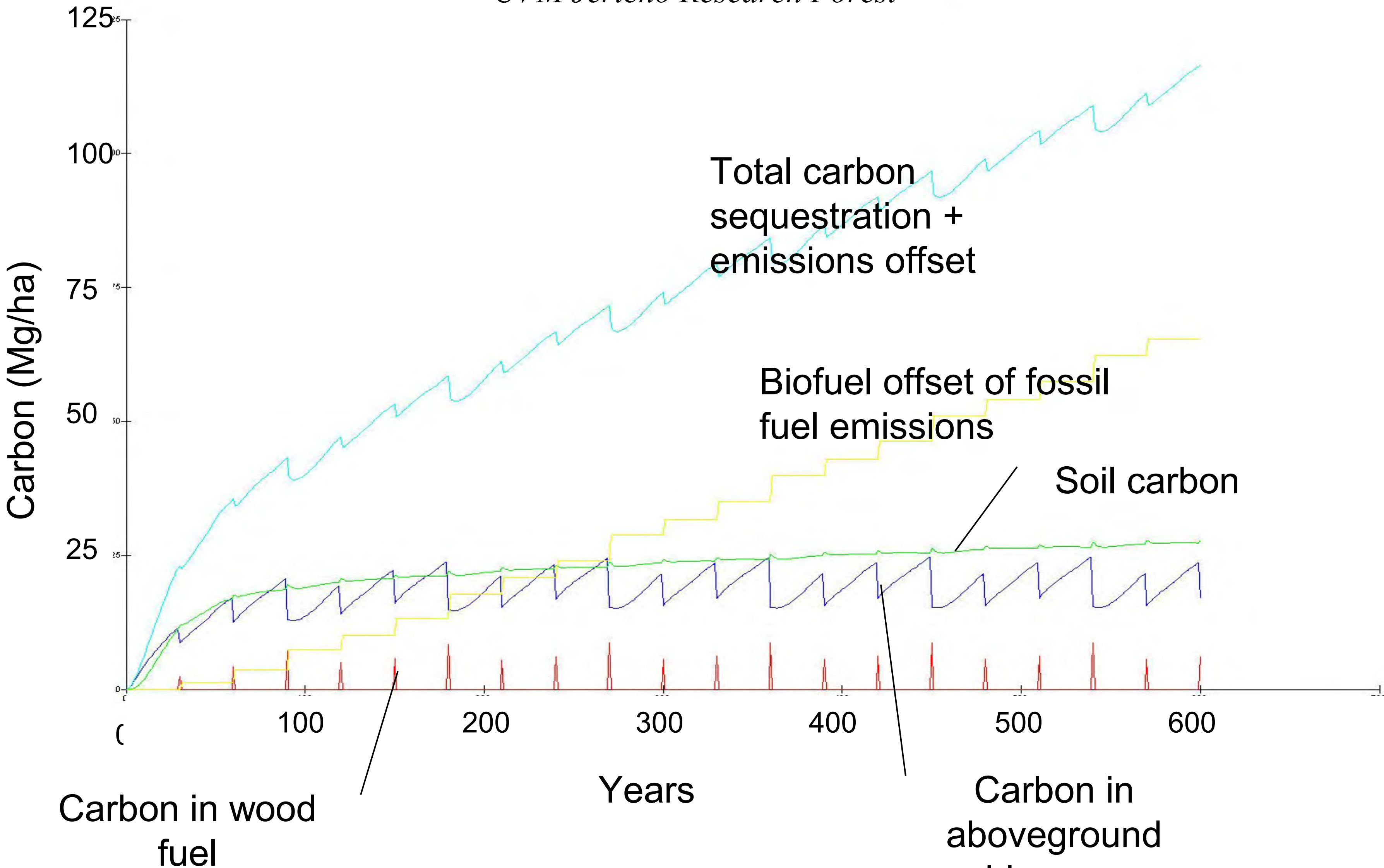


Aboveground Tree Biomass (Mg/ha)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
45
50
55
Years
251.6 Mg/ha
223.8 Mg/ha
27.8 Mg/ha
Uneven-Aged Units (No Treatment)
SCE (With Treatment)
Uneven-Aged (With Treatment)
SCE (Multiple Entries)
Uneven-Aged (Multiple Entries)


Aboveground Tree Biomass (Mg/ha)
Years
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
45
50
55
SCE Units (No Treatment)
Uneven-Aged Units (No Treatment)
SCE (With Treatment)
Uneven-Aged (With Treatment)
SCE (Multiple Entries)
Uneven-Aged (Multiple Entries)
304.5 Mg/ha
292.3 Mg/ha
251.6 Mg/ha
223.8 Mg/ha
216.6 Mg/ha
178.9 Mg/ha
55.9 Mg/ha
80.7 Mg/ha

# CO2fix Model Simulation:

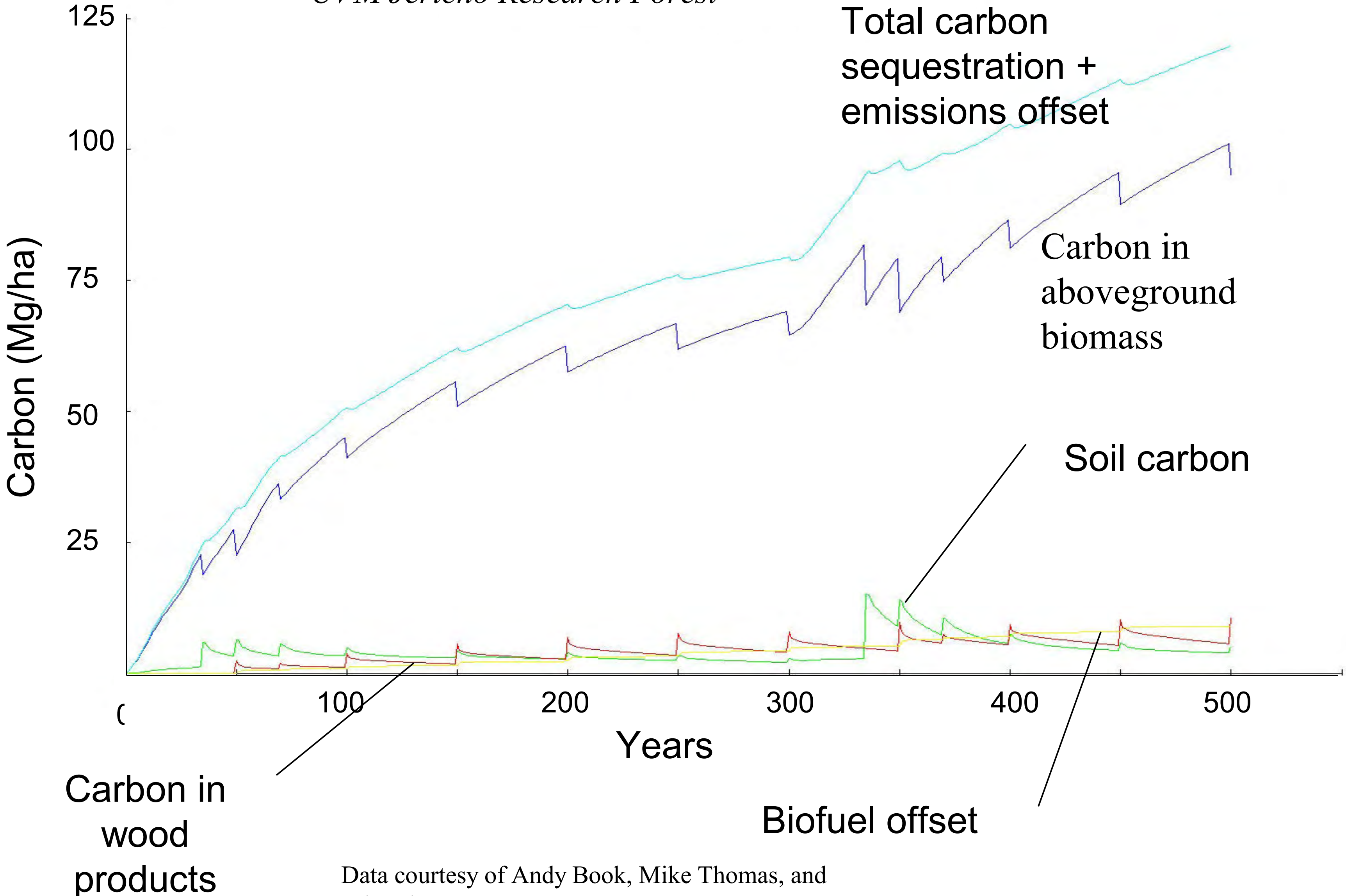
*Scenario = harvest for biomass only, northern hardwood stand, UVM Jericho Research Forest*




Data courtesy of Andy Book, Mike Thomas, and John Shane

# CO2fix Model Simulation

*Scenario = low intensity selection harvest for durable wood products and biomass, northern hardwood stand, UVM Jericho Research Forest*



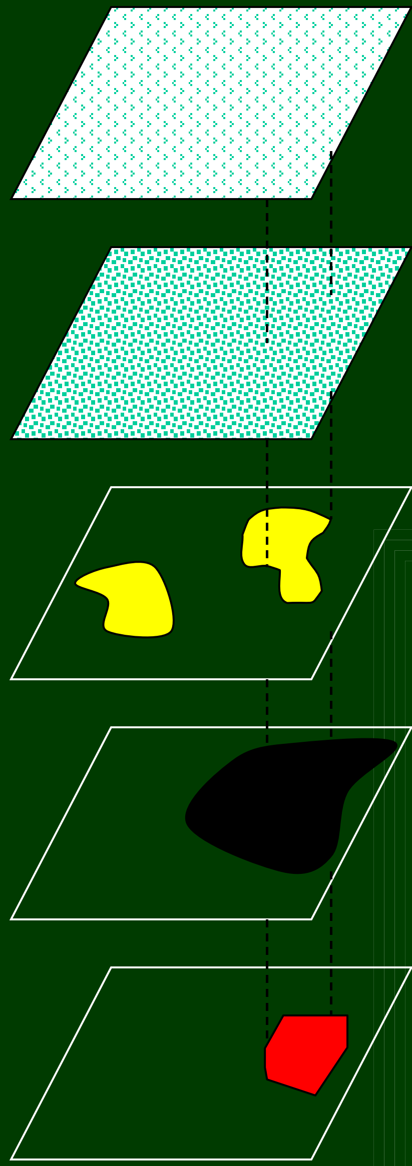

Data courtesy of Andy Book, Mike Thomas, and John Shane

# Conclusions

- Even, multi-aged, and uneven-aged silvicultural options are available for increasing net carbon storage in managed stands.

- Options include:
  - Longer rotations or entry cycles
  - Post-harvest retention
  - Modified uneven-aged approaches that promote structural complexity and high biomass conditions
  - Passive management: reserves that will develop high levels of biomass

# Multiple stressors produce a vulnerable landscape



Climate change

Atmospheric pollution/acid deposition

Altered natural disturbance regimes, spread of exotic organisms

Human modified biophysical environment, ex-urban sprawl and development

Vulnerable landscapes and ecosystems

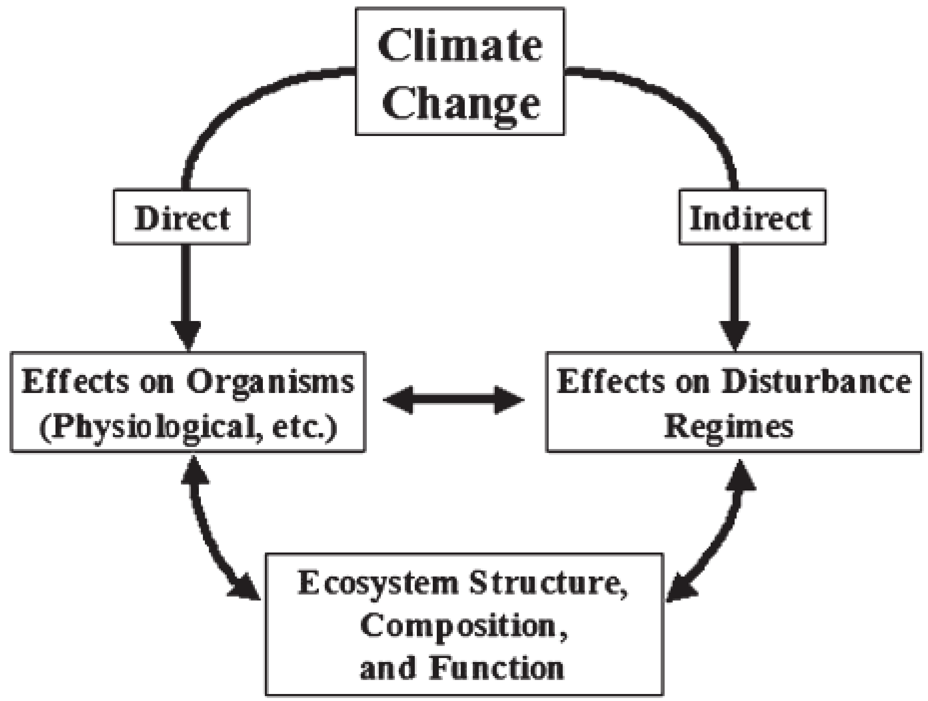



*Fig. 2.* Climate Change is Predicted to Impact Forested Ecosystems both through Direct Effects on Organisms and Indirect Effects on Natural Disturbance Regimes (e.g., Fire, Insects, Pathogens, and Wind). Feedback relationships among these pathways of change contribute collectively to increased fire risks in the urban–wildland interface.

From: Keeton et al. 2007. Elsevier Sciences.

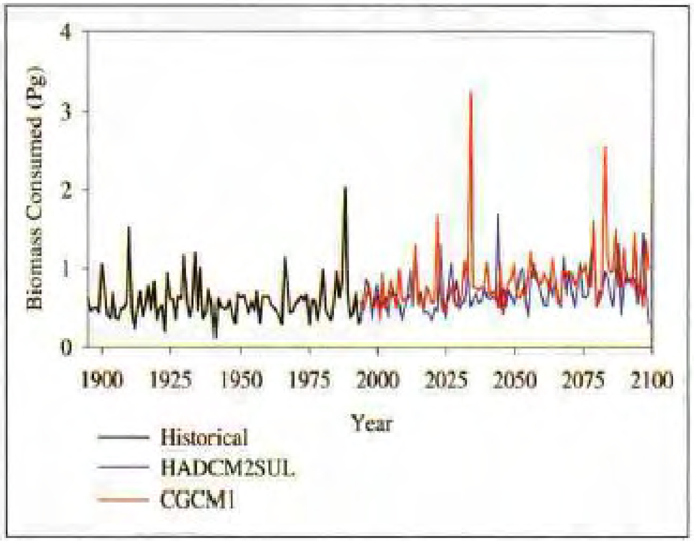



*Figure 5. Simulated (MC1) total biomass consumed by fire over the coterminous United States under historic and two future climates. The fire simulations are for potential vegetation and do not consider historic fire suppression activities. However, grid cells with more than 40% agriculture have been excluded from the calculation (Bachelet et al. 2001).*

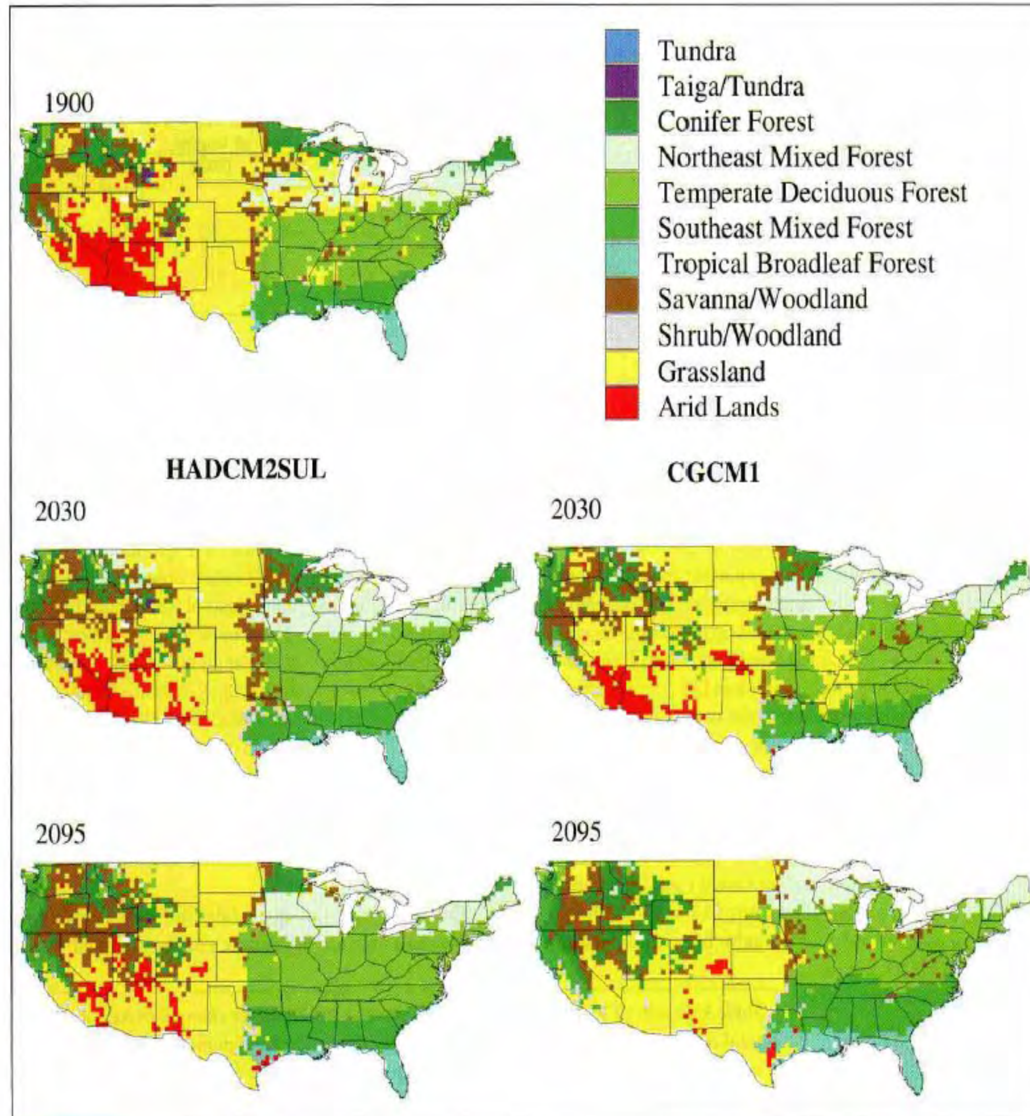


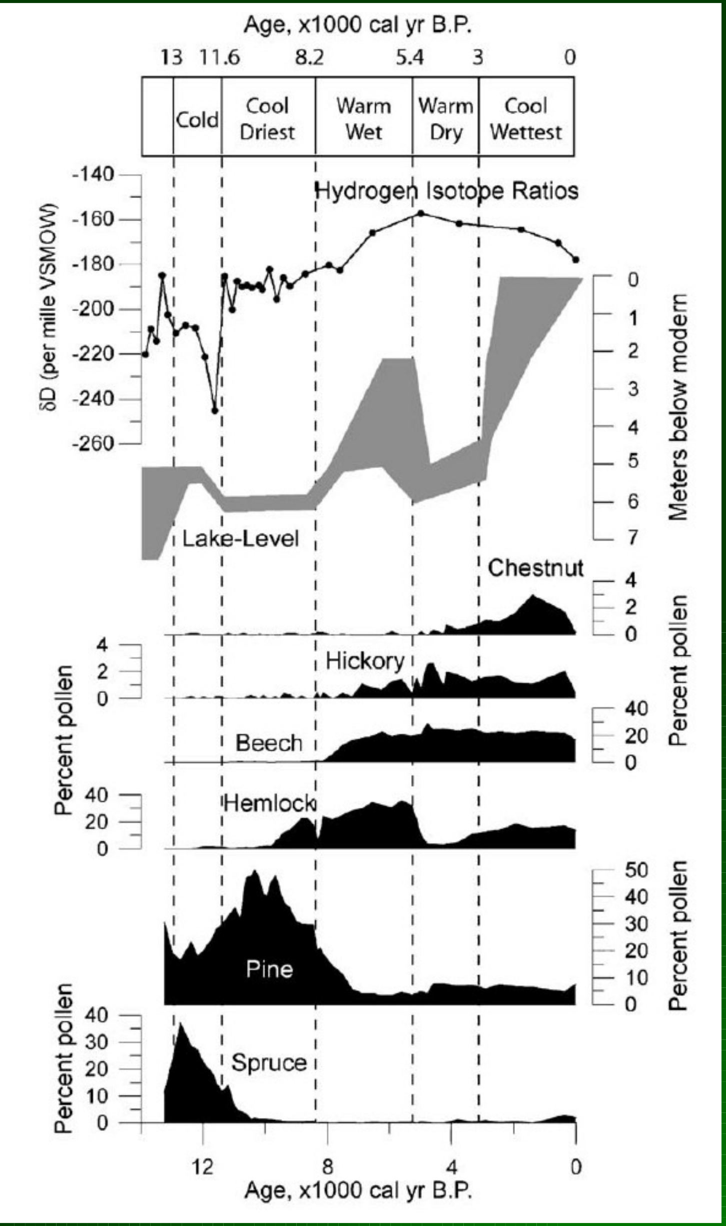

*Figure 2. MC1-simulated change in vegetation distribution for 11 major vegetation types under two future climate scenarios.*

Dynamic General Vegetation Models:
Biogeography + Biogeochemistry

From: Aber et al. 2001

# Summary of Vegetation Change, Western, MA

From: Webb et al. 2003. Development in Quaternary Science



# Managing for resilience

- Address interactive stressors (e.g. exotics, sprawl, etc.)
- Maintain diversity (e.g. genetic, species, etc.) in managed forests
- Maintain landscape connectivity
- Practice “continuous cover forestry” where needed
- Establish a redundant reserve system with broad representation of geophysical diversity

# ACKNOWLEDGEMENTS

- Vermont Monitoring Cooperative
- USDA CSREES National Research Initiative
- Northeastern States Research Cooperative
- USDA McIntire-Stennis Forest Research Program