Factors controlling carbon sequestration at Howland Forest, Maine: Long-term trends, interannual variability, and forest management impacts

Neal A. Scott[1], David Y. Hollinger[2], Eric A. Davidson[1], D. Bryan Dail[3], Holly Hughes[1], John T. Lee[3], Chuck Rodrigues[3],

[1]Woods Hole Research Center, Woods Hole, MA

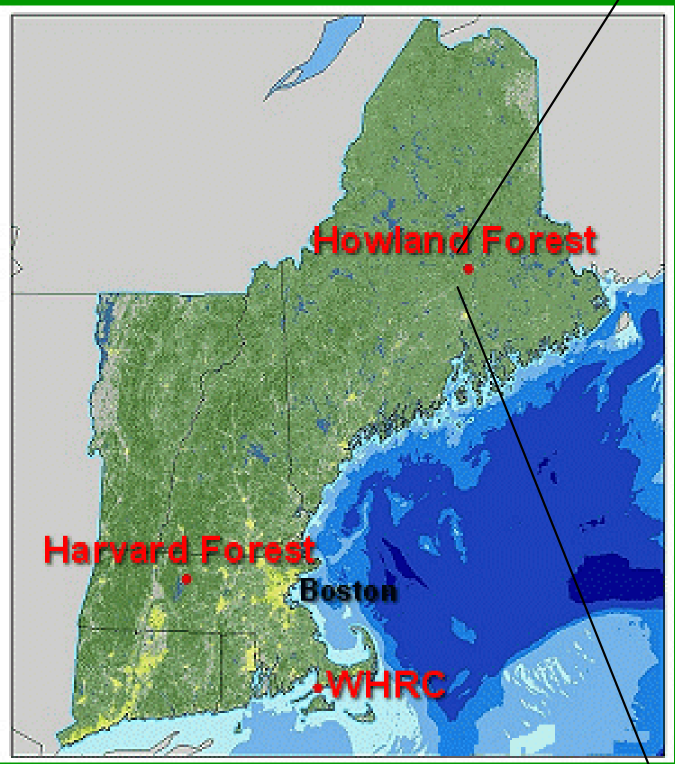
[2]USDA Forest Service, Durham, NH

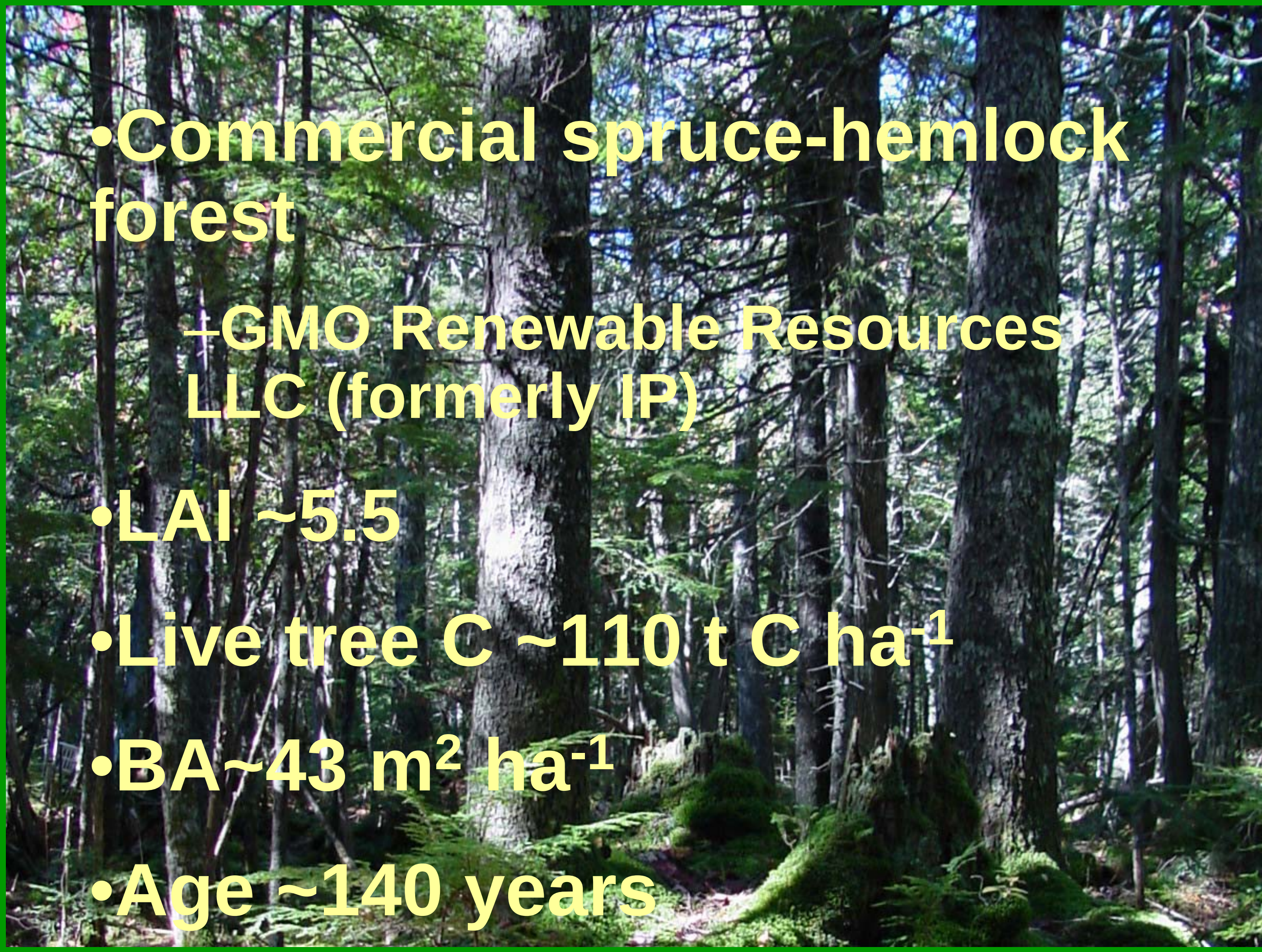
[3]Dept. of Plant, Soil and Environmental Sciences, University of Maine, Orono, ME

Overview

- Why care about carbon sequestration?
- Long-term trends in carbon sequestration in unmanaged forest
- Effects of shelterwood harvest on carbon sequestration
- Can a shelterwood regime enhance carbon sequestration?

Howland Forest

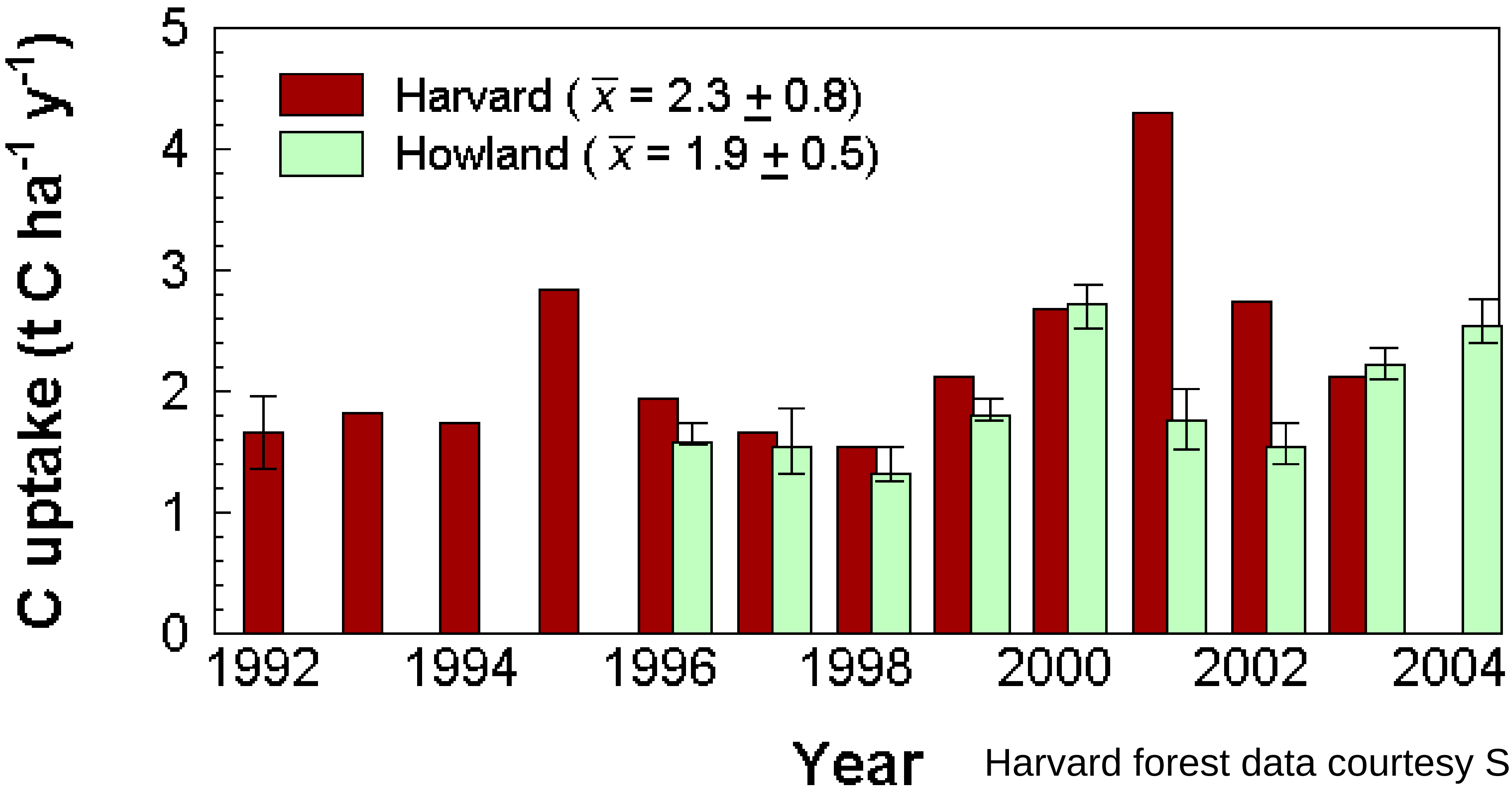




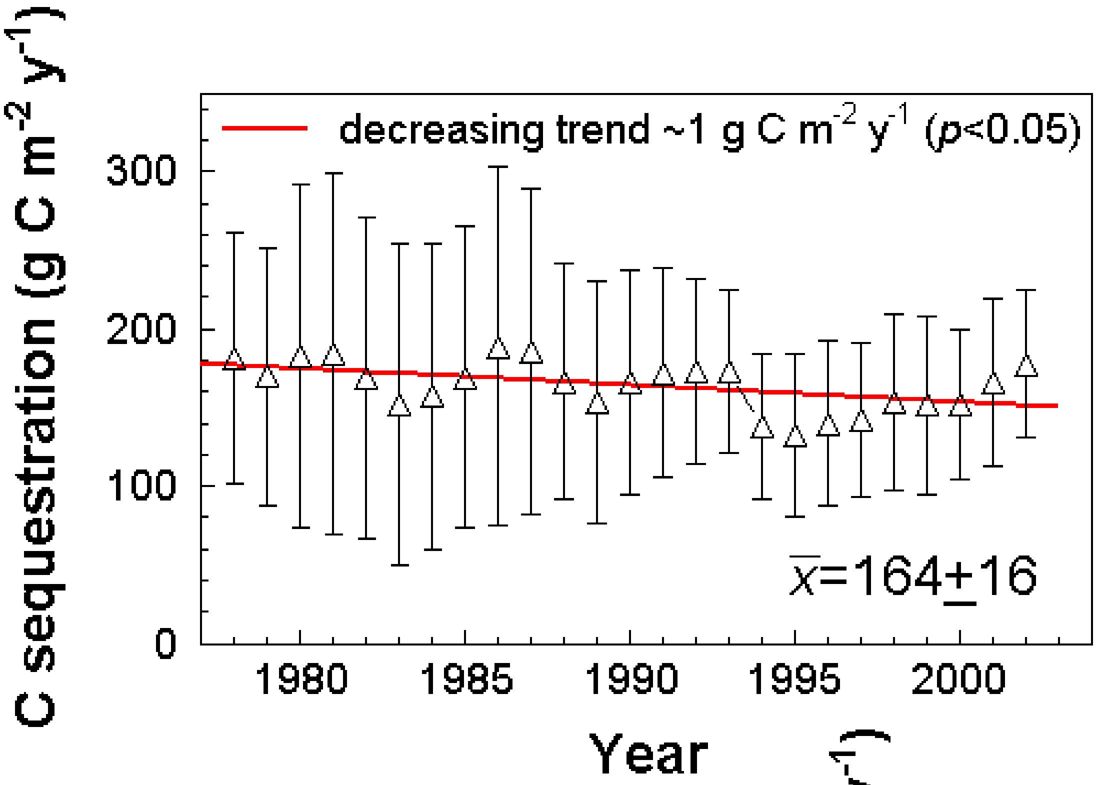
- Commercial spruce-hemlock forest
  - GMO Renewable Resources LLC (formerly IP)
- LAI ~5.5
- Live tree C ~110 t C ha^{-1}
- BA~43 m^2 ha^{-1}
- Age ~140 years

Interannual variability in carbon uptake

•Interannual variability of forest C sequestration is high (if you do an experiment you need a control!)

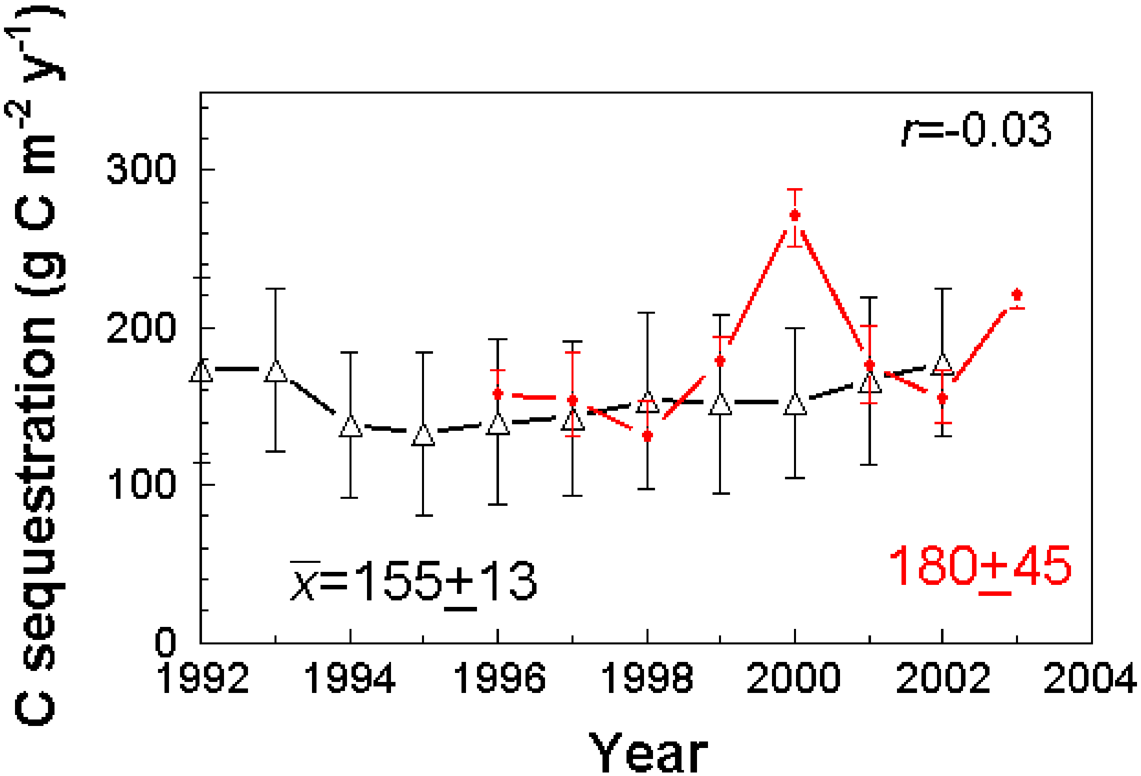


Harvard forest data courtesy S. Wofsy



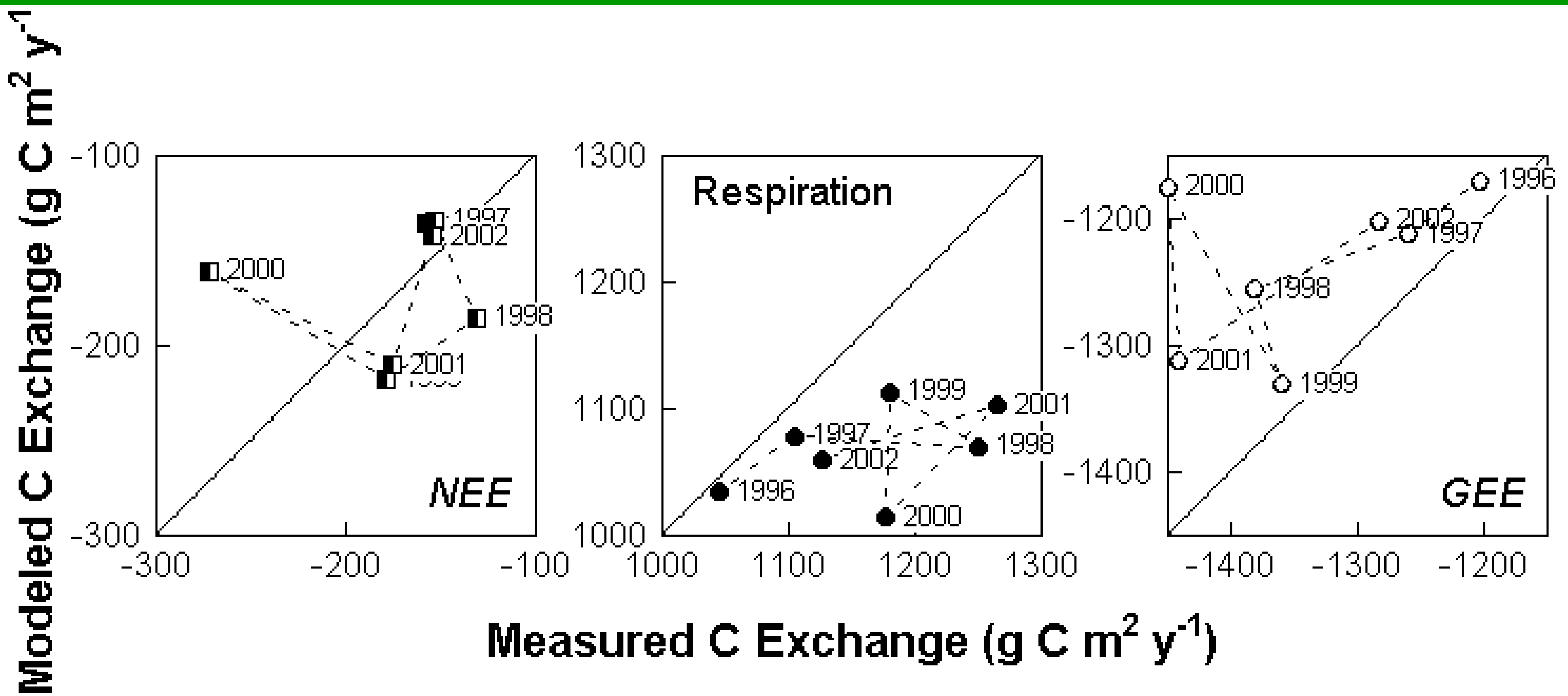
- Reconstructed diameters indicate a mean tree sink of 164 g C m^{-2} y^{-1}
- Uptake decreasing by 1 g m^{-2} y^{-1}

- Tree C sink not correlated with variations in tower flux, but consistent with tower data

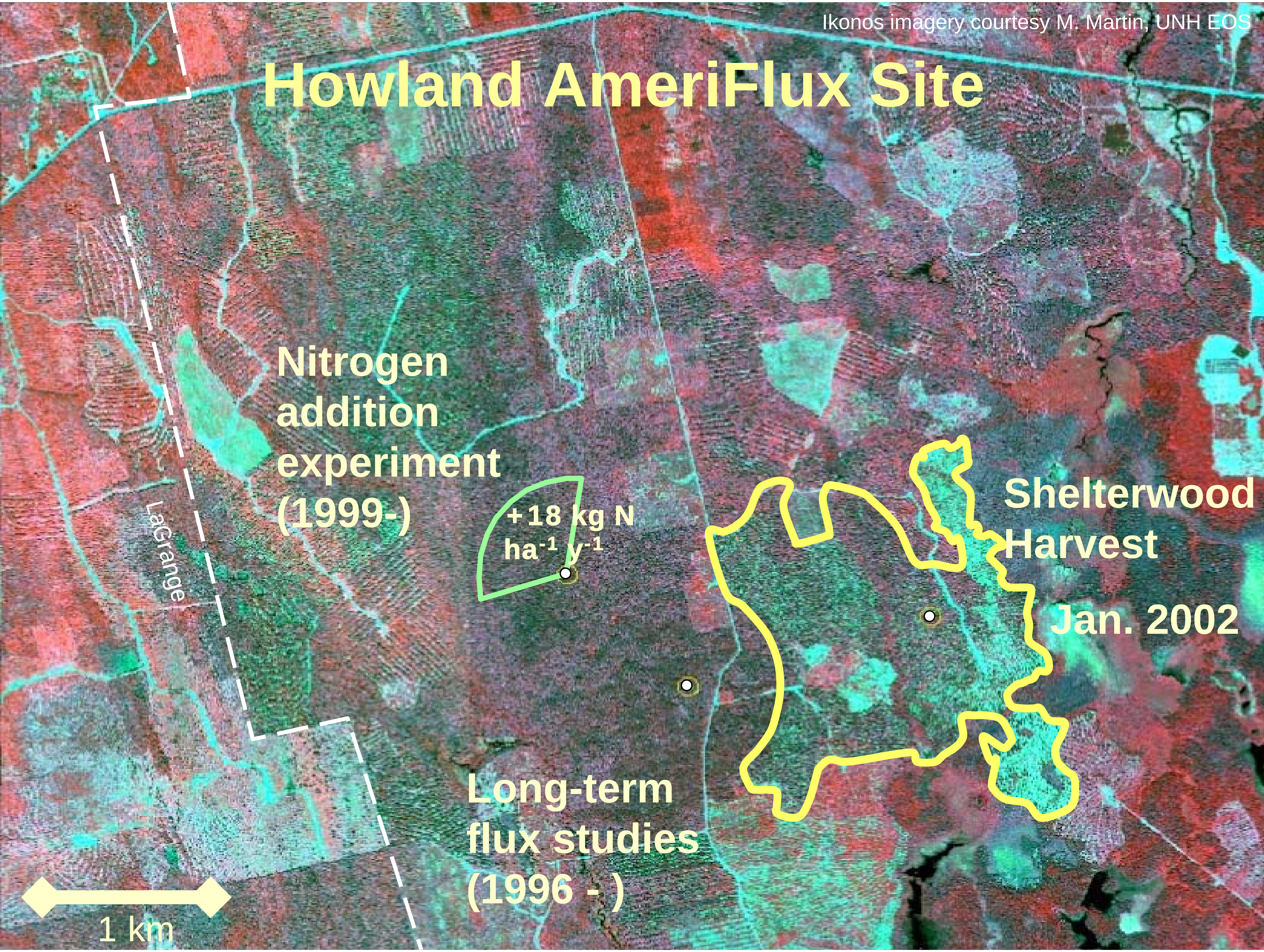


Modeling net ecosystem carbon exchange

$$NEE = R_{max} e^{\frac{-E_0}{(246-T_a)}} + \frac{P_{max} I}{K_m + I} + A e^{-E_a/(T_{soil}-T_o)}$$



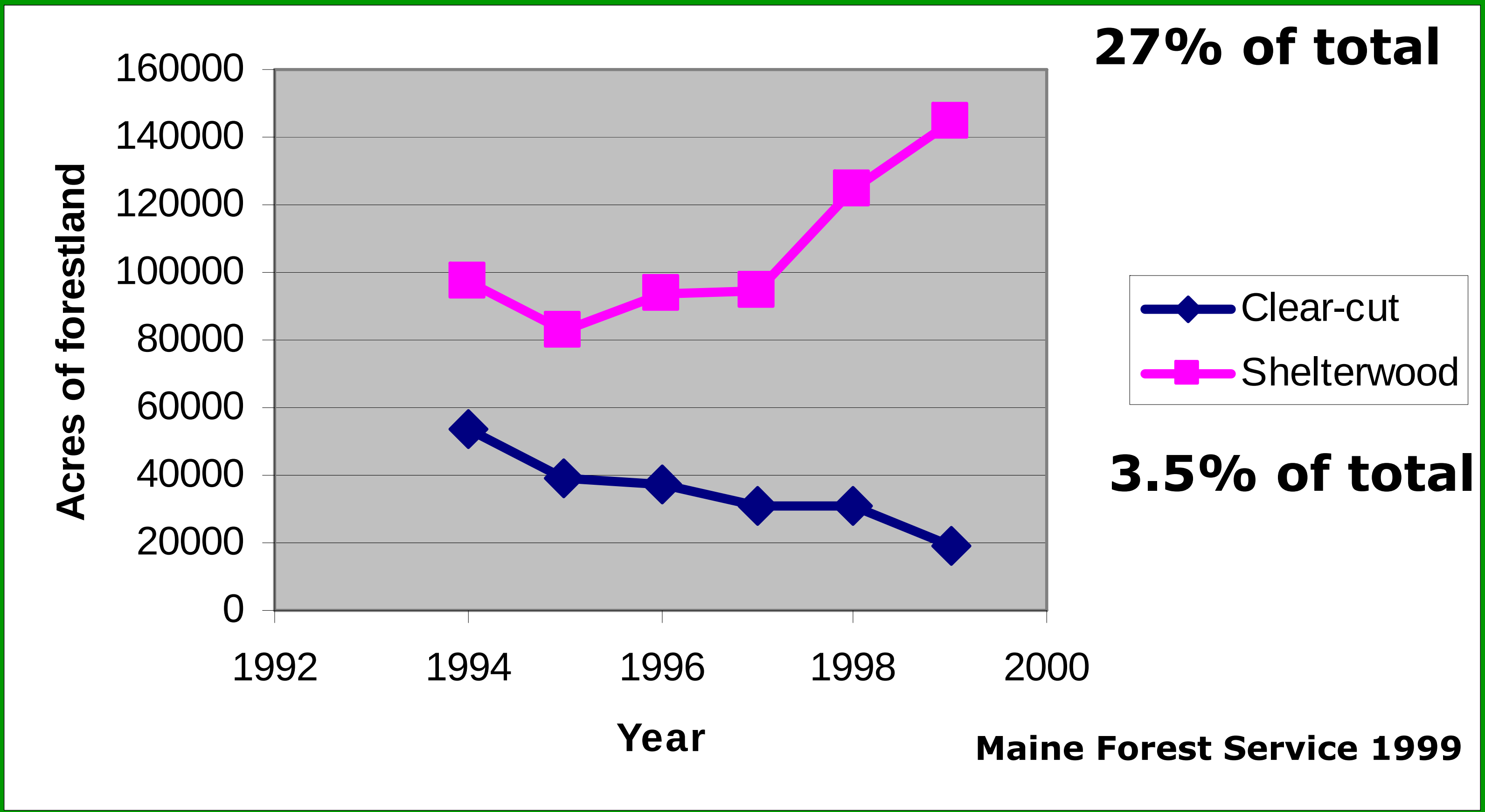
Annual predictions require carbon pool information!



Ikonos imagery courtesy M. Martin, UNH EOS
Howland AmeriFlux Site
Nitrogen addition experiment (1999-)
+18 kg N ha-1 y-1
LaGrange
Shelterwood Harvest
Jan. 2002
Long-term flux studies (1996 -)
1 km

Changes in forest management practices in Maine (1994-1999)

Total harvested area in 1999: 536,219 acres (6% increase from 1994)



Shelterwood system – 2-3 harvests, 5-15 years apart, enhances natural conifer regeneration

How forest management alters carbon sequestration:

- Affects age structure
- Modify carbon distribution in the forest (e.g. more dead wood)
- Change in soil C:N ratio
- Changes in carbon allocation within trees (e.g. leaves vs. roots vs. stems)
- Can change stand structure (light interception)
- Can change growth efficiency (? - linked to changes in age-structure, nutrient availability)
- Types of wood influences types of products

Shelterwood harvest

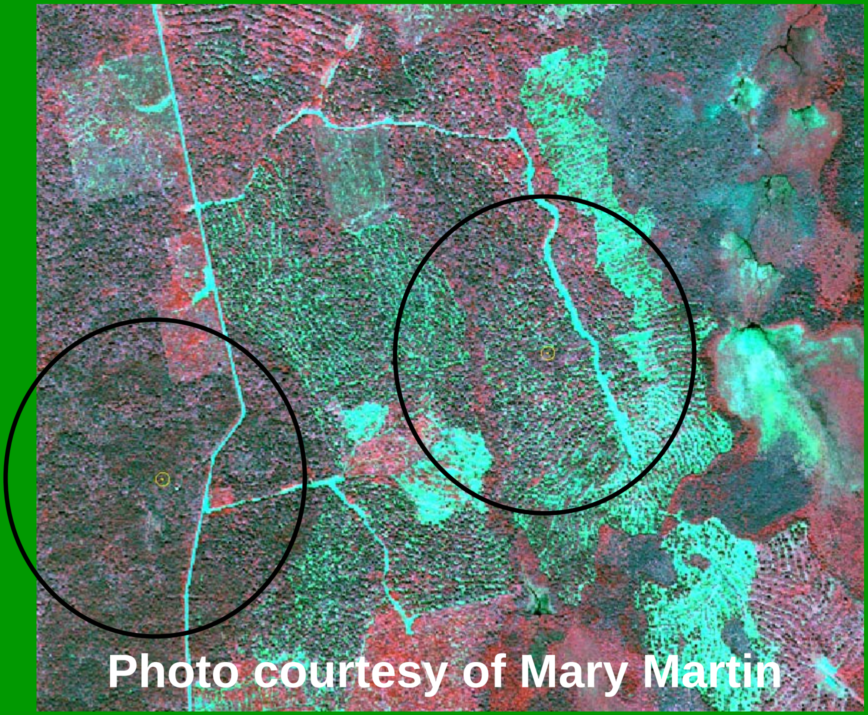


Photo courtesy of Mary Martin

The impact of a harvest on forest C sequestration depends on several things:

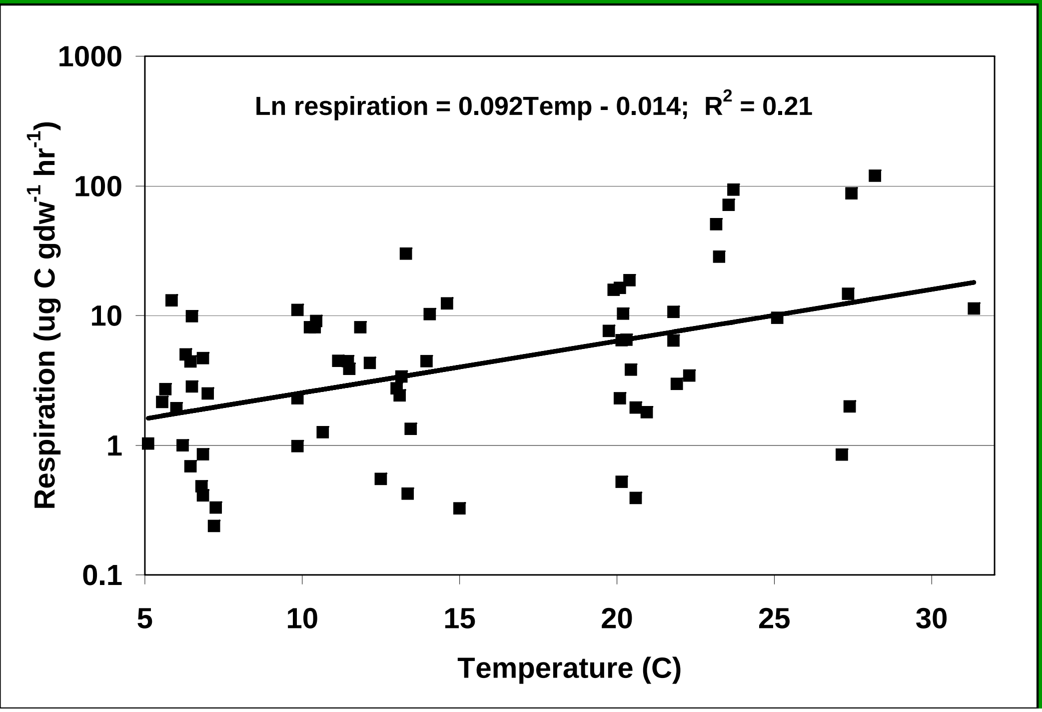
- What happens to C uptake & loss in the remaining forest?
  - How does photosynthesis change? Compensation?
  - How does soil respiration change? Reduction?
- How much slash is produced & how quickly does it decay?
  - Belowground versus aboveground losses
- How much wood is removed and what is its fate?

Carbon pools and harvest C fluxes:

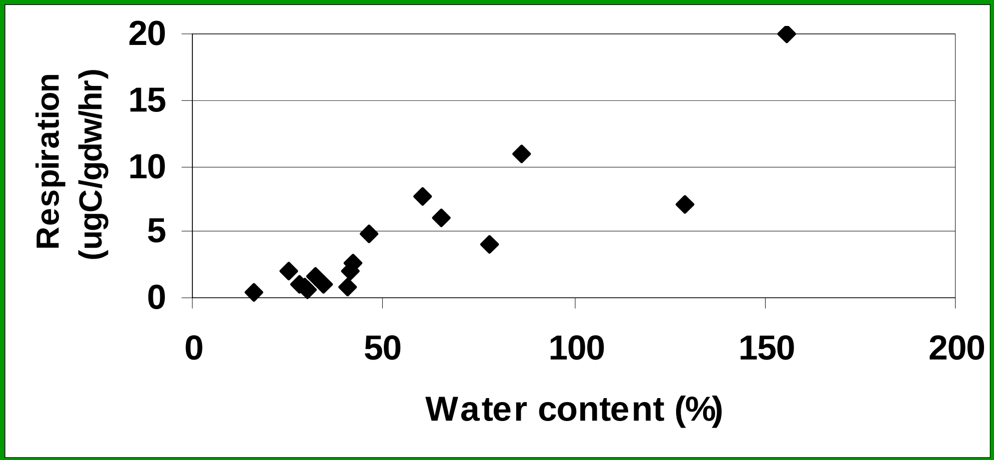
Carbon pool	Control	Harvested (pre-)	Harvest C fluxes
Live basal area (m^2 ha^{-1})	43(2.4)	30 (1.7)	22
Live biomass (t C ha^{-1})	109 (6.6)	77.3 (4.7)	
Standing dead (t C ha^{-1})	10.8 (1.2)	3.3 (0.8)	
Down-dead (t C ha^{-1})	4.1	16.1 (3.9)	
Soil	110		
Wood removal (t C ha^{-1})			14.9 (2.1)
AG detritus (t C ha^{-1})			5.3 (1.1)
BG detritus (t C ha^{-1})			5.2 (0.7)

Detritus production and decay (II)

Dead wood respiration is related to temperature…

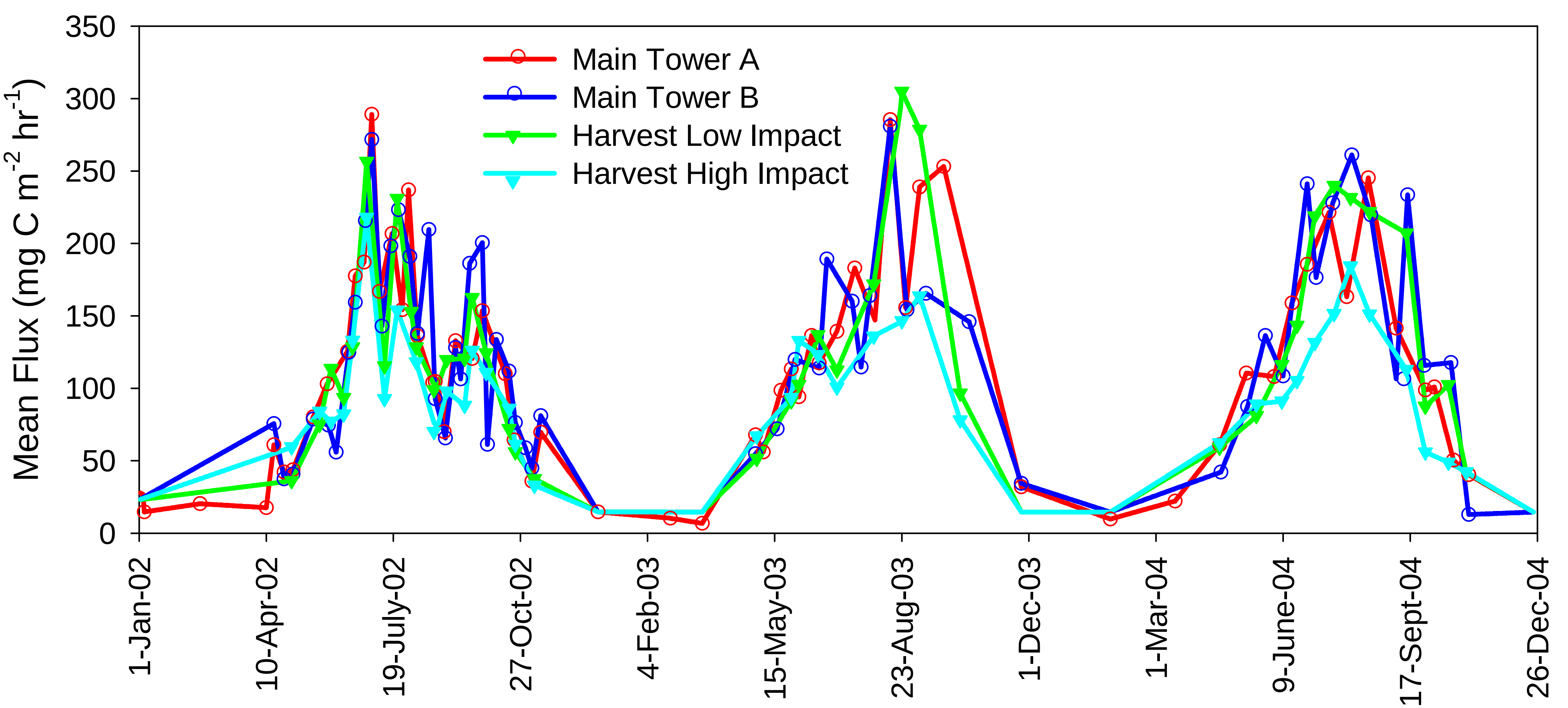


….but also to water content



Result: Half life ~ 2.5 years

Soil respiration in harvested and control stands



Respiration rates lower after harvest (2003 and 2004)

Impact of harvest on net carbon exchange

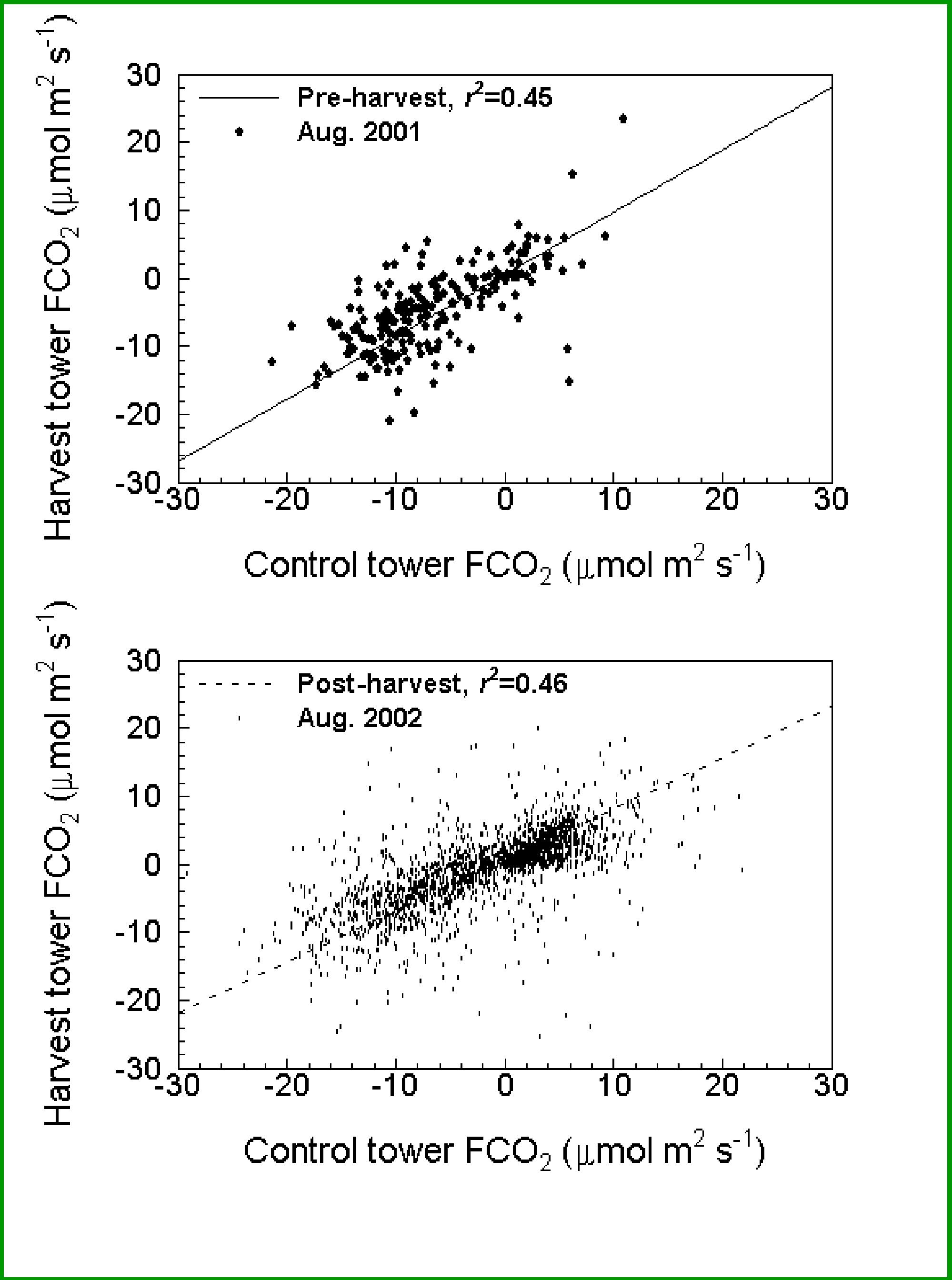
To examine the impact of harvest on net C flux, we compared fluxes from the control and harvested tower both pre- and postharvest

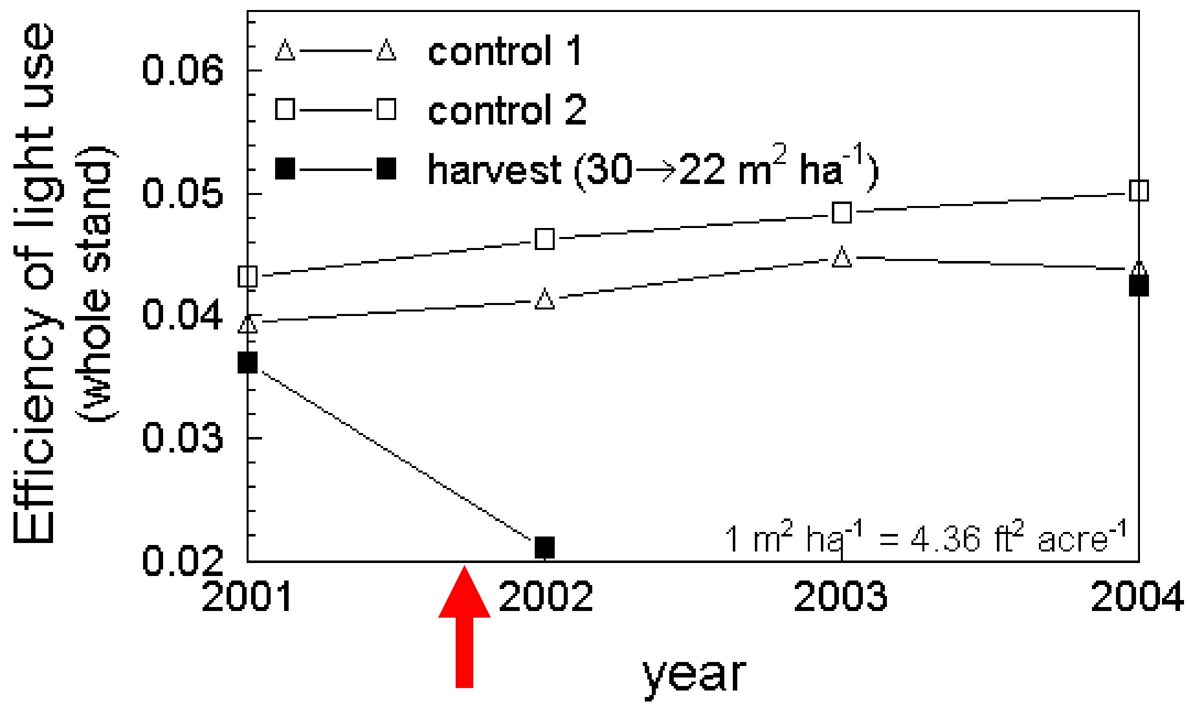
Preharvest slope (2001) = 0.92

Postharvest slope (2002) = 0.75

Postharvest slope (2004) = 0.89

Suggest an initial 18% reduction in net C storage as a result of harvest (30% BA removed) but then a recovery.





Impact of harvest on carbon uptake efficiency

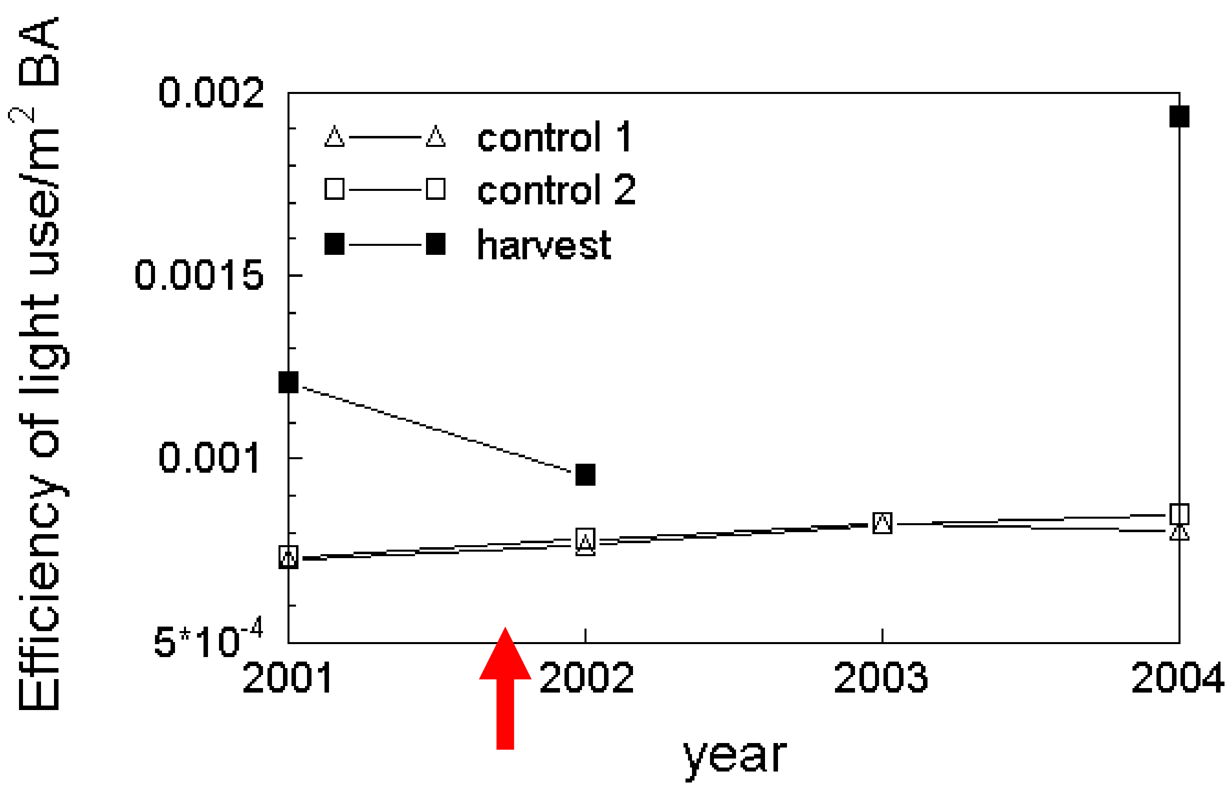
(growing season)

Whole stand:

Drops then recovers

Per unit BA:

Slight drop and then big increase by 3rd year

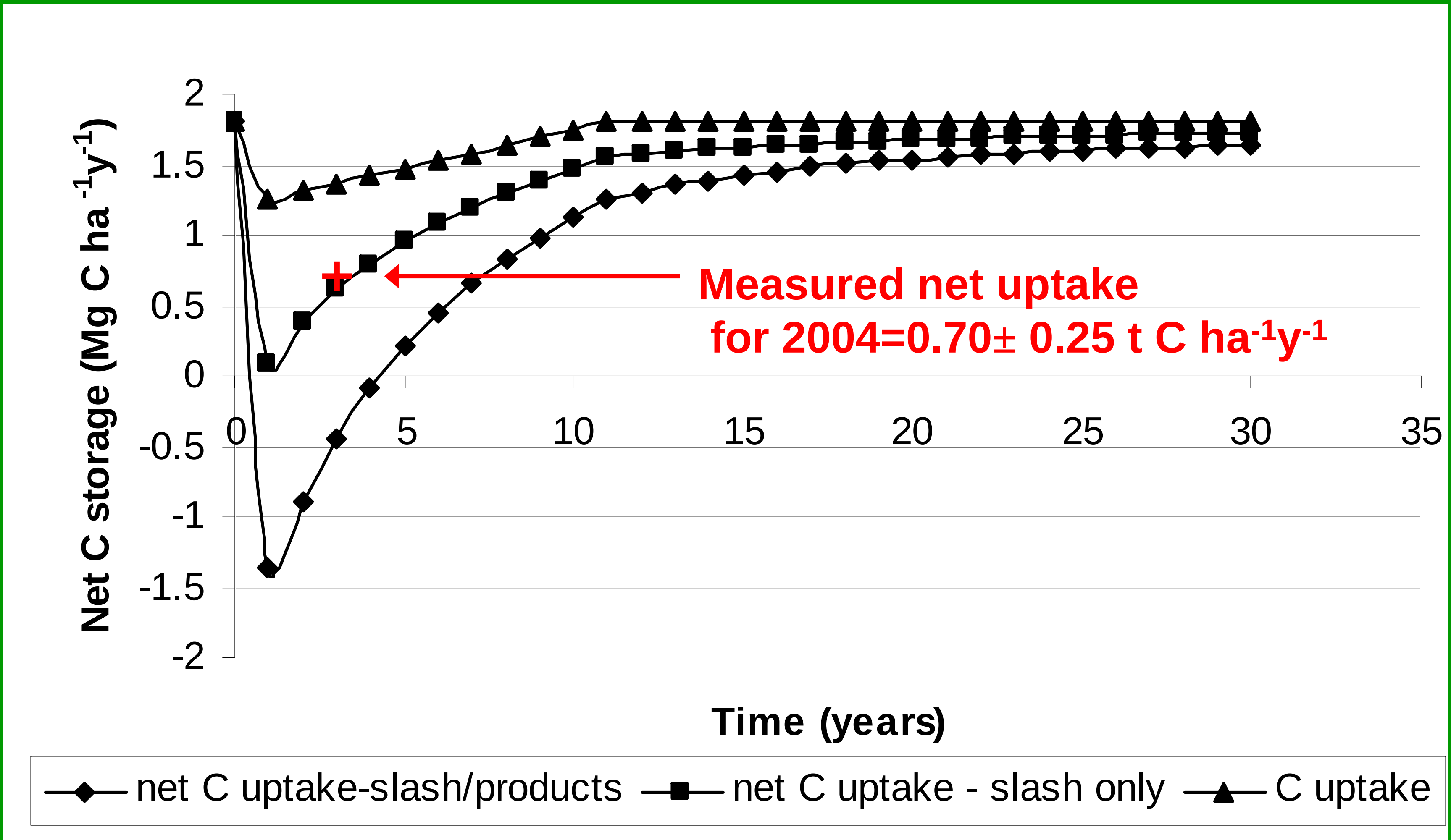


Inventory-based measurement of carbon sequestration (2001 – 2003)

Control: 1.99 Mg C ha^{-1} y^{-1} (95% CI=0.5)

Harvested: 1.79 Mg C ha^{-1} y^{-1} (95% CI=0.5)

Simulated carbon losses following harvest
(with and without wood products)



Without harvest:	54 Mg C ha^{-1} (30y)
With harvest, assuming no enhanced uptake:	34 Mg C ha^{-1} (30y)
With harvest, 40% enhancement in net uptake:	54 Mg C ha^{-1} (30y)

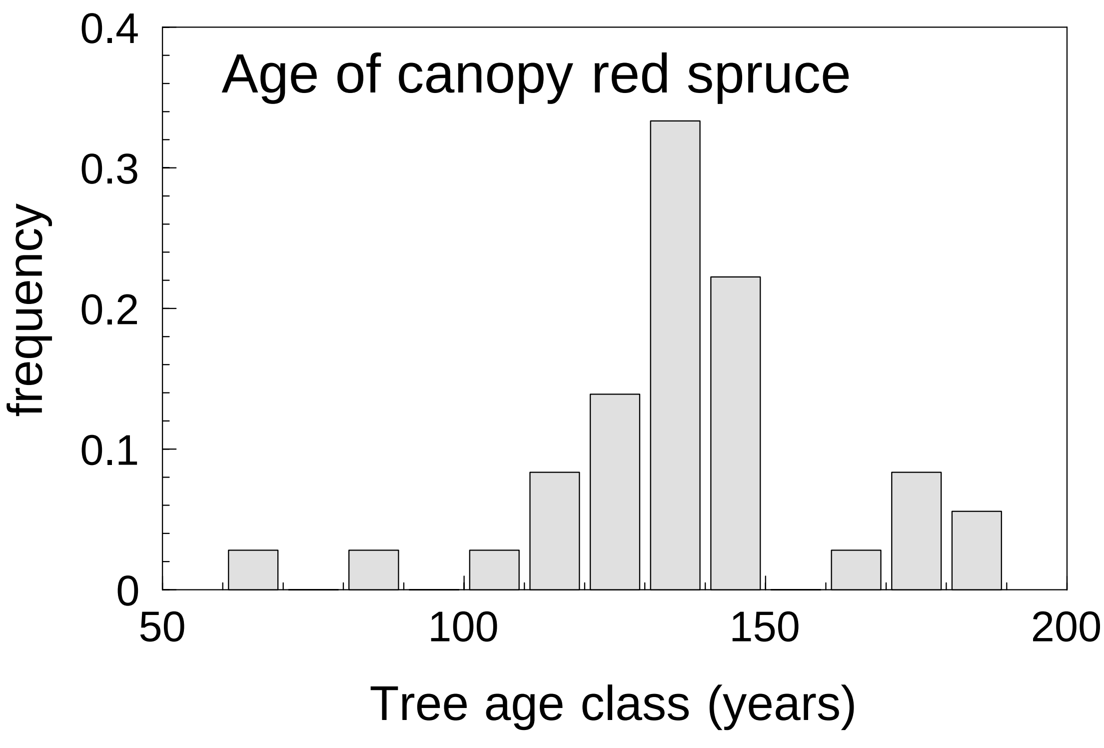
Summary

- Mature, relatively undisturbed forests at Howland, Maine sequester about 1.9 t C ha^{-1} y^{-1}, primarily in bole wood
- Shelterwood harvest removed about 30% of stand biomass, and created detritus containing ~10 t C ha^{-1}
- Soil respiration is lower two years after harvest, and respiration from slash is strongly related to BOTH temperature and moisture content
- Simulated net C uptake 3 years after harvest (0.6 t C $ha^{-1}y^{-1}$ agrees closely with measured net uptake (0.7 t C $ha^{-1}y^{-1}$) that year - Strong Growth Enhancement in the Remaining Trees

This research was supported by Office of Science (BER), US Department of Energy under Interagency Agreement No. DE-AI02-00ER63028 to the USDA Forest Service, by *Grant No. DE-FG02-00ER63002 to WHRC and DE-FG02-00ER63001 to U. Maine and by the USDA Foest Service NE Research Station*

Site age from land use reconstruction:

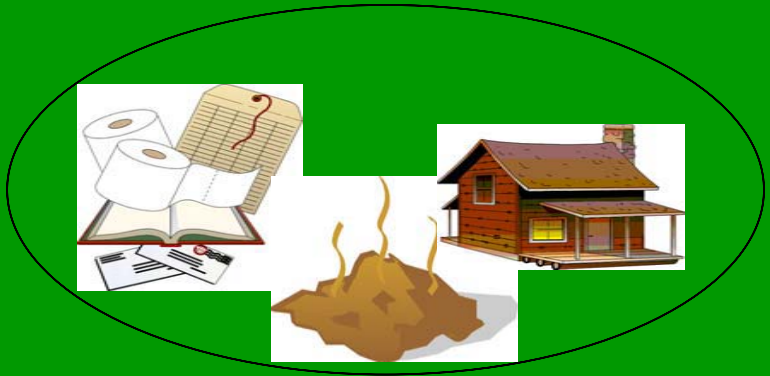
- Near navigable river, flat land → Colonial use
- Charcoal in soil → Site burned
- Soil horizons intact → Not plowed, grazed
- Age synchrony → Pasture abandoned ~1860, forest age 140



Old for eastern US

Fate of harvested wood:

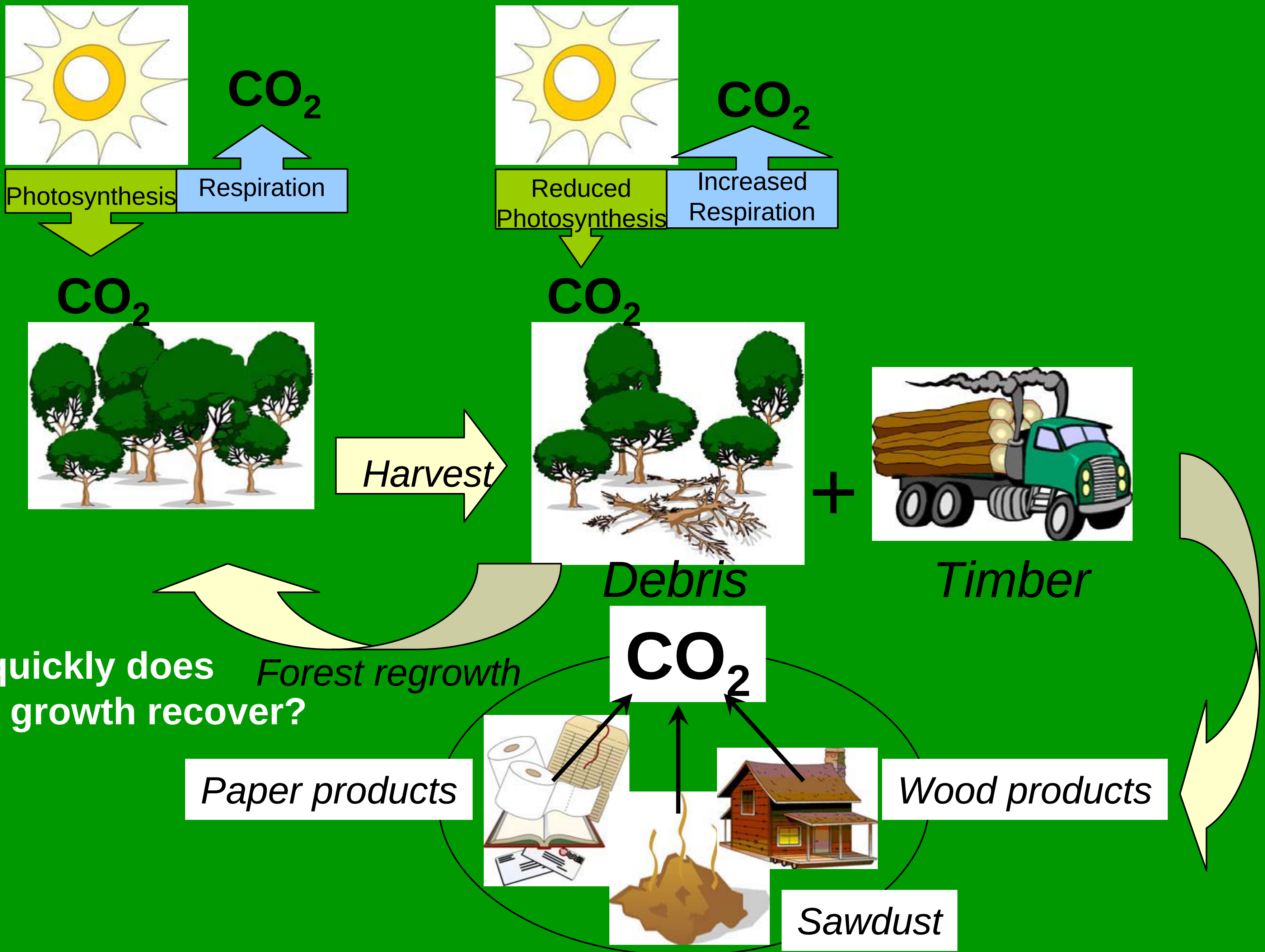
Wood products produced, and their longevity, affects the net C balance of the shelterwood harvest regime



Product	Wet mass (tons)	% total	Half-life (y)
Boltwood	232	2	20
Chipwood	364	3	3.5
Groundwood	199	2	3.5
Logs	4771	40	45
Pulp	4265	36	3.5
Studs	463	4	45
'Tree length'	1511	13	3.5

Skog and Nicholson 1998

Carbon consequences of forest management



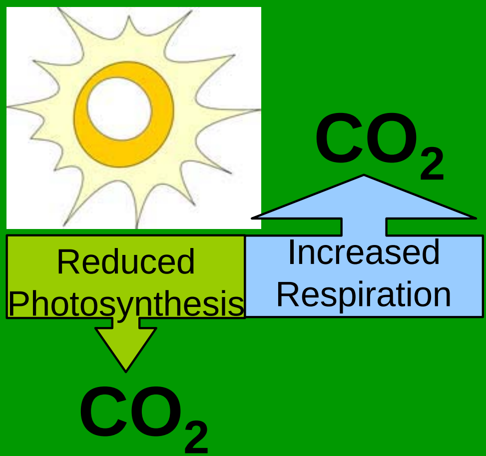
How quickly does forest growth recover?

Factors influencing Forest C Sequestration:

- Historical land-use (age structure and (perhaps) growth rates)
- Climate Change (season length, precipitation)
- CO_2 fertilization
- Nitrogen deposition

- Forest use/management
  - Current land-use assessments include logging (clear-cutting and regrowth), fire suppression, cropland, pasture (Houghton et al. 1997).
  - Subtle management practices not included (e.g. thinning, low-intensity logging; lead to changes in species composition, carbon distribution in ecosystem pools).

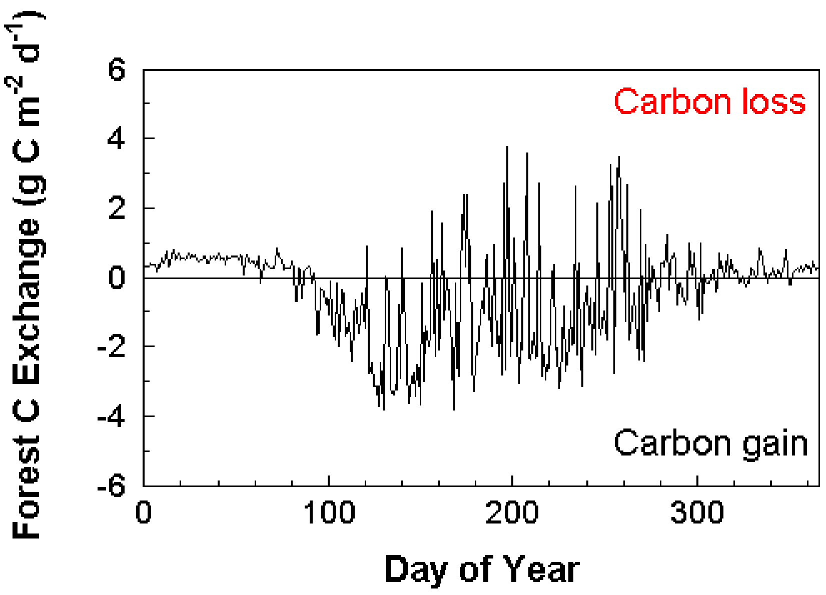
Impact of harvest on net carbon exchange (I)



Initial predictions

Decreased uptake
Increased respiration

Ecosystem Exchange Characteristics	Control Tower μmol m^{-2} s^{-1} (mean ± std dev, n)	Harvest Tower μmol m^{-2} s^{-1} (mean ± std dev, n)
6 months postharvest		
Day	-9.3 ± 5.1, n=502	-5.9 ± 5.7, n=490
Night	5.5 ± 4.0, n=497	3.0 ± 4.8, n=506
30 months post		
Day	-7.6 ± 7.8, n=711	-6.4 ± 7.7, n=538
Night	6.0 ± 3.0, n=277	6.9 ± 4.0, n=191



<u>Flux data</u> show that forests can switch between sink & source depending on weather

- Mean uptake 188 g C m^{-2} y^{-1}
- High variability
- Uncertainty ~20 g C m^{-2} y^{-1}