Impacts of environmental stress on carbon and water exchange of flatwoods pine forests in Florida

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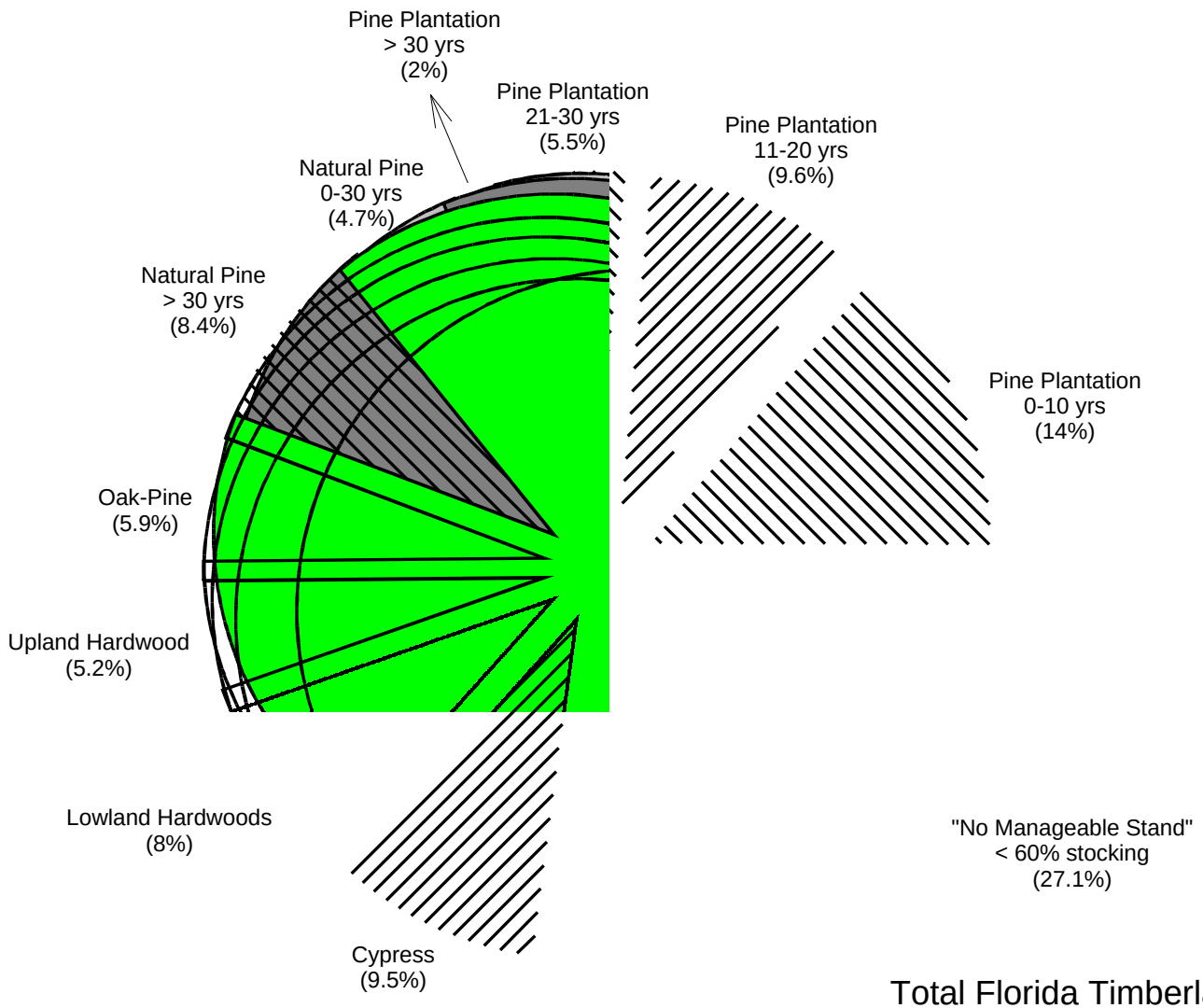
Distribution of Florida Timberland



Total Florida Timberland = 5.9×10^6 ha

Questions

- How do environmental stresses alter the carbon and water balance of flatwoods forests?
  - What sub-ecosystem scale processes are responsible for these responses?
  - At what time scales are ecosystem-, plant- and organ-level responses to stress expressed?

Regenerating Clearcut

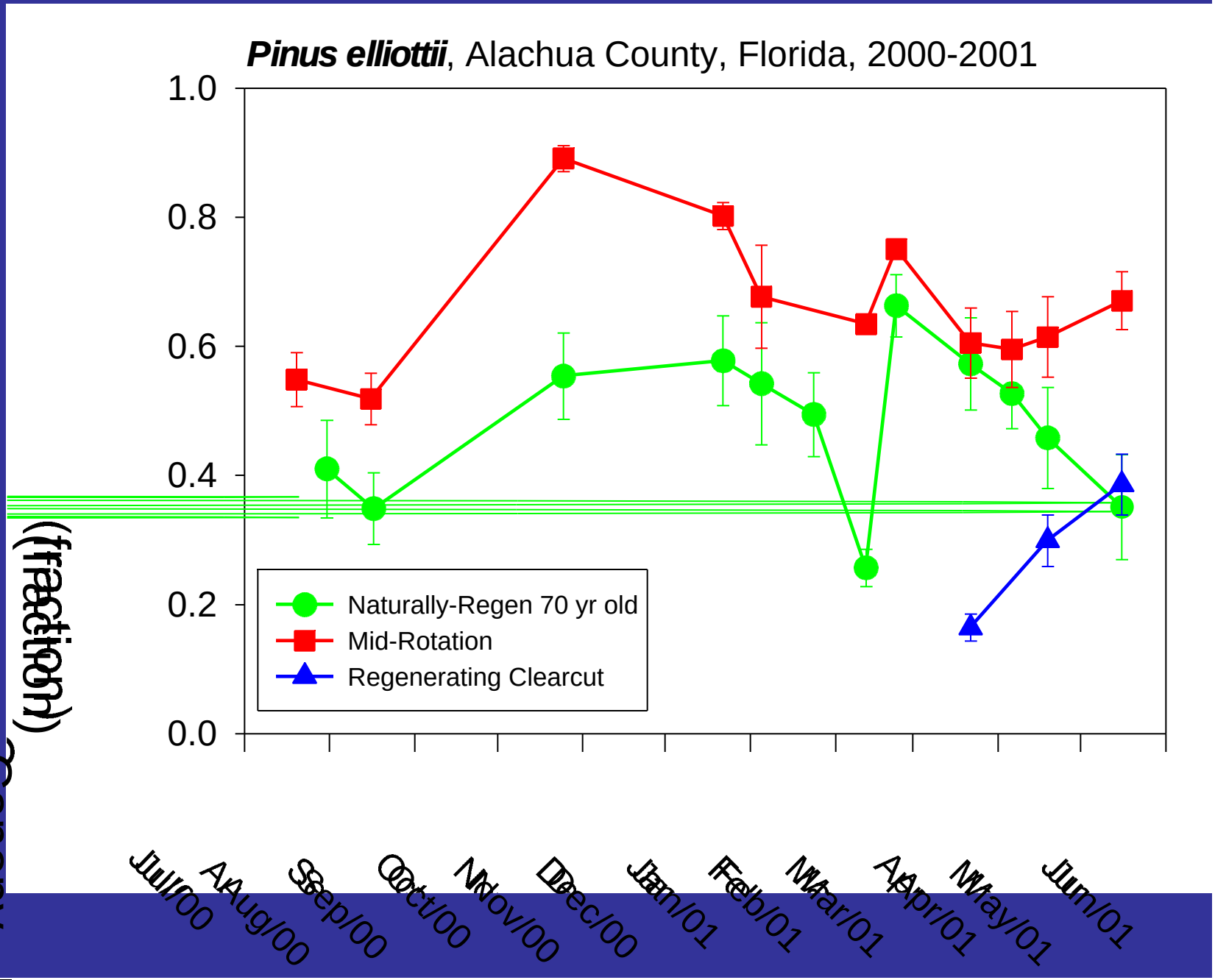
- Clearcut summer/fall 1997
- Double-bedded and planted winter 1998-1999
- Eddy covariance Feb 1998-present

Mid-Rotation Plantation

- Established 1990
- Double-bedded, site prep herbicide, N&P @ 3 years
- Mean DBH = 9.8 cm
- Stand BA = 16.1 m2 ha^{-1}
- Dominant height = 10 m
- 2032 trees ha^{-1}
- Peak all-sided LAI = 6.4

Naturally Regenerated Stand

- *Pinus palustris / Pinus elliottii*
- Mean age ~ 60 years
- 333 stems ha^{-1}
- Canopy height 22 m
- Mean tree DBH 25.3 cm
- Basal area 18 m^2 ha^{-1}
- All sided LAI
  - 2.6 summer
  - 2.0 winter



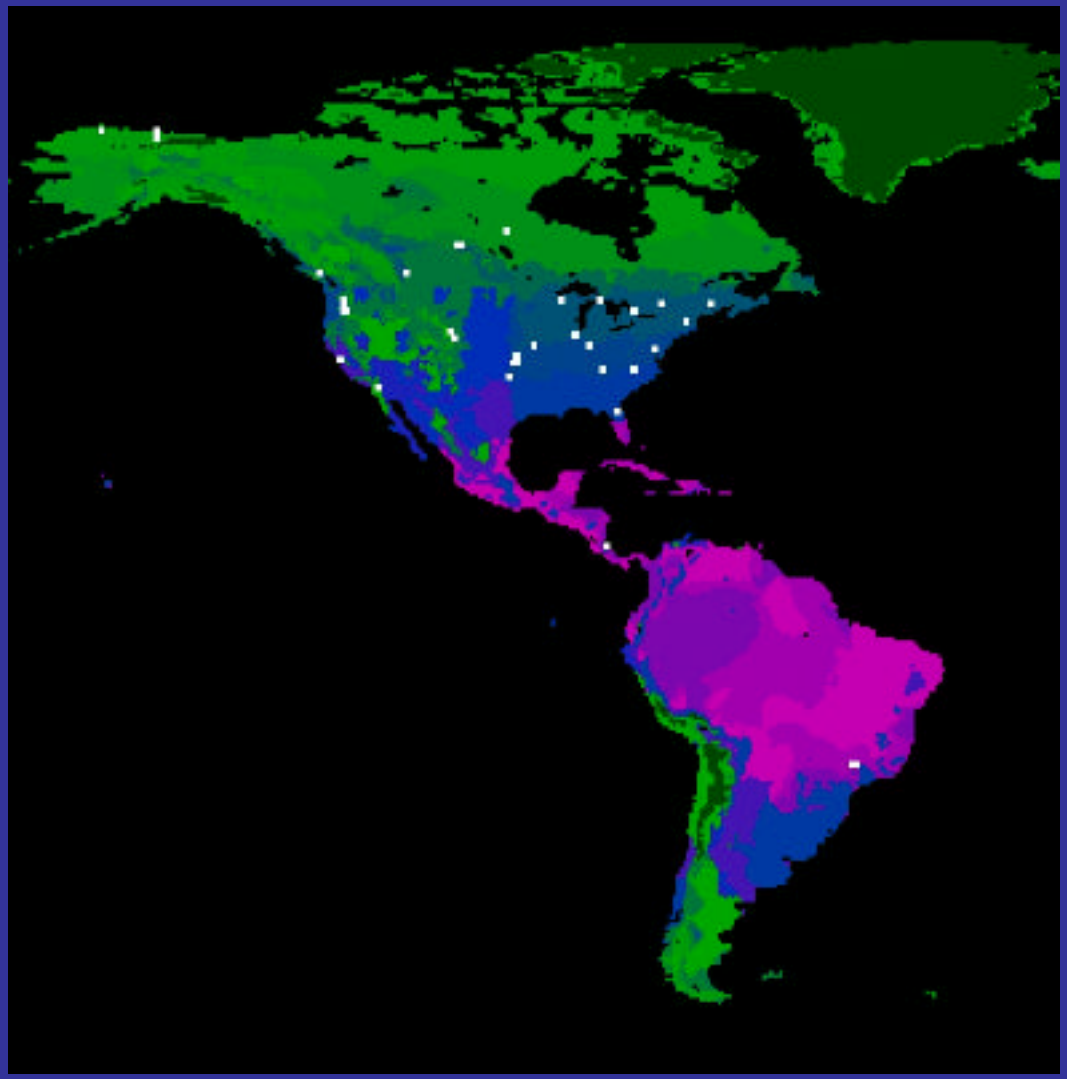
Pinus elliottii, Alachua County, Florida, 2000-2001
1.0
0.8
0.6
0.4
0.2
0.0
Naturally-Regen 70 yr old
Mid-Rotation
Regenerating Clearcut
Jul/00
Aug/00
Sep/00
Oct/00
Nov/00
Dec/00
Jan/01
Feb/01
Mar/01
Apr/01
May/01
Jun/01

Canopy - Inte

Eddy Covariance

- Ecosystem-scale fluxes of
  - carbon
  - water
  - energy
- 3-D sonic anemometer
- Infrared gas analyzer

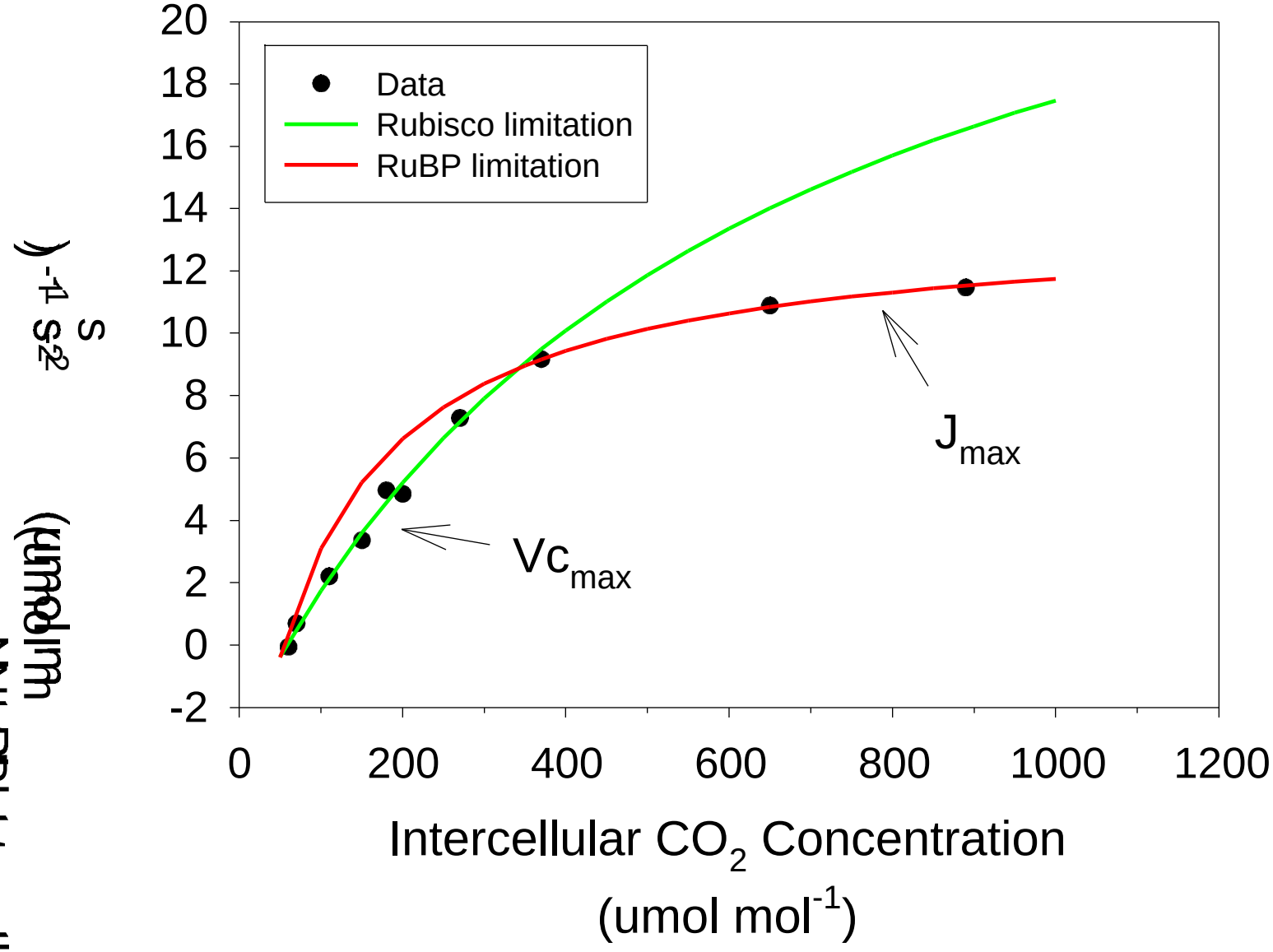
AMERIFLUX System

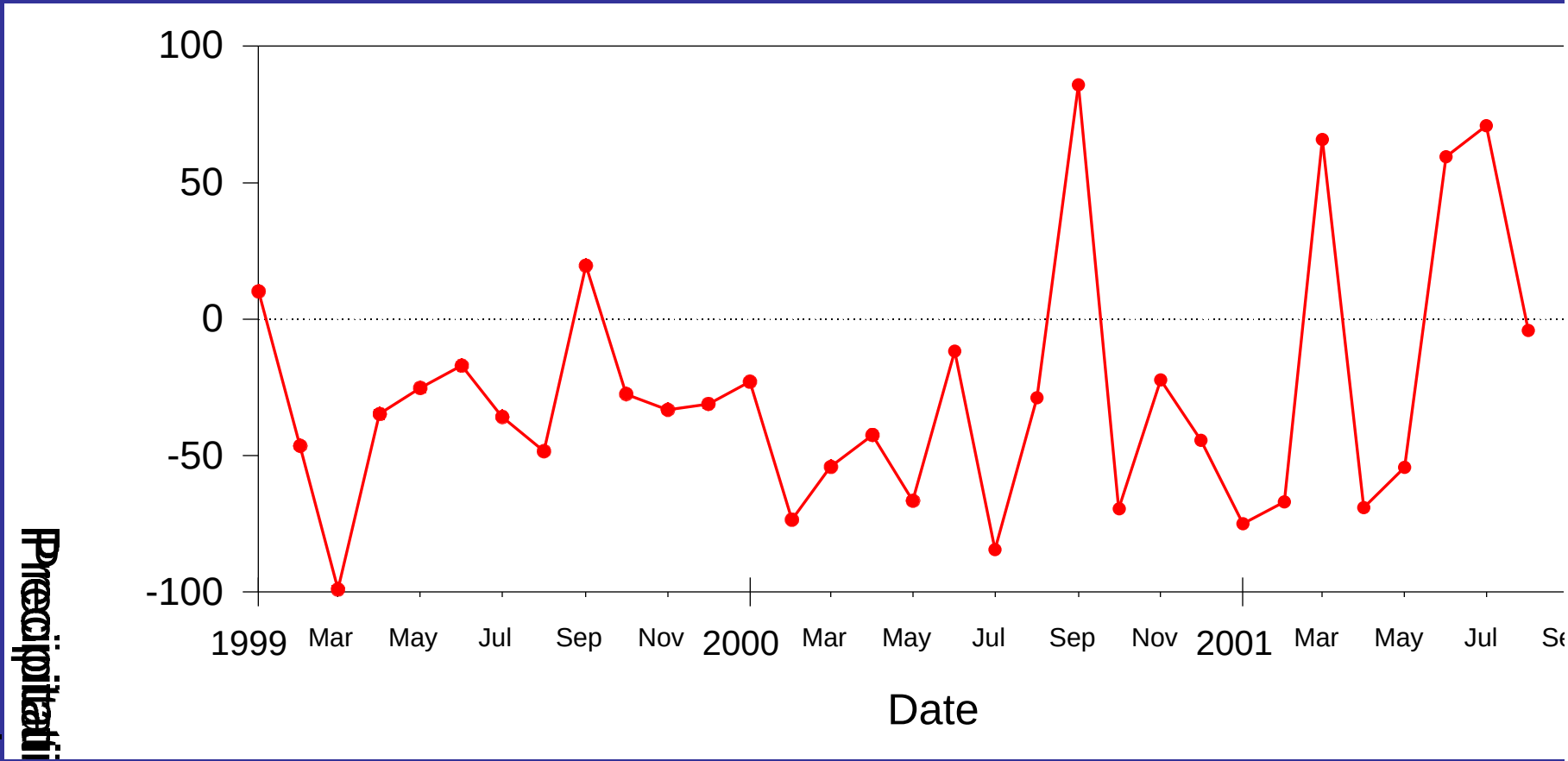


- Long-term measurements of CO_2, H_2O and energy exchange in various ecosystems
- Collect information to help define the global C budget
- Enhance understanding of C fluxes, NEP and carbon sequestration

Measurements

- Leaf-level
  - gas exchange
  - chl fluorescence
  - leaf water potential
  - nutrient concentration
- Tree-level
  - Granier sap flow probes
- Ecosystem-level
  - eddy covariance
  - PAR interception
  - soil CO_2 efflux
  - litterfall and other ecological meas.


Data
Rubisco limitation
RuBP limitation
Vc_{max}
J_{max}
Net Photosynthesis Rate
(umol m^{-2} s^{-1})
Intercellular CO_2 Concentration
(umol mol^{-1})
20
18
16
14
12
10
8
6
4
2
0
-2
0
200
400
600
800
1000
1200

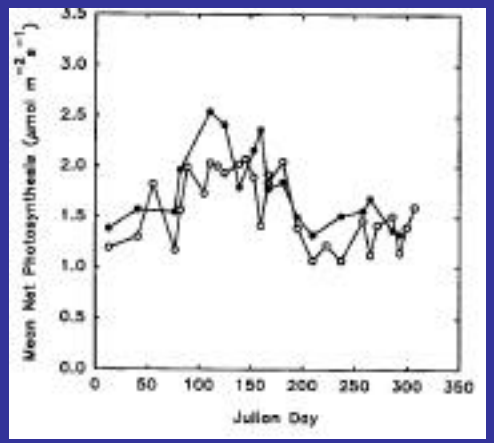

100
50
0
-50
-100
1999
Mar
May
Jul
Sep
Nov
2000
Mar
May
Jul
Sep
Nov
2001
Mar
May
Jul
Date
Precipitation (mm)
Actual - 16 yr average

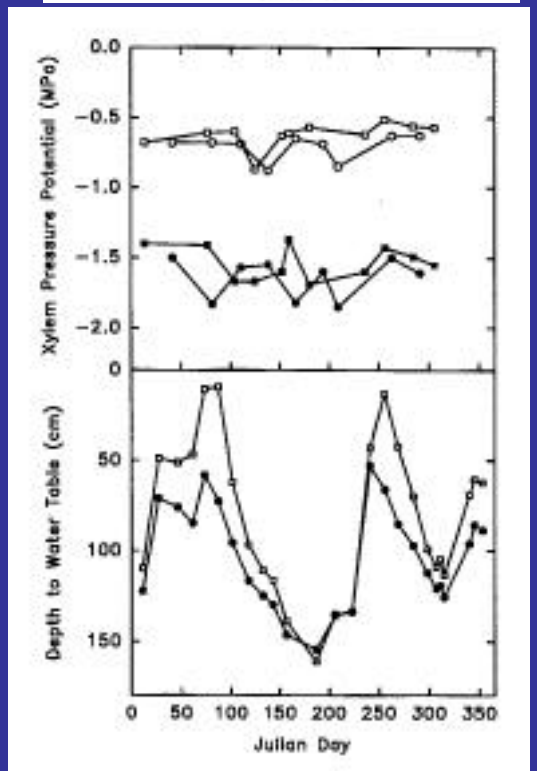
Previous flatwoods research

- Intensive Management Practices Assessment Center (IMPAC)
  - early slash and loblolly pine growth not affected by irrigation

Previous flatwoods research

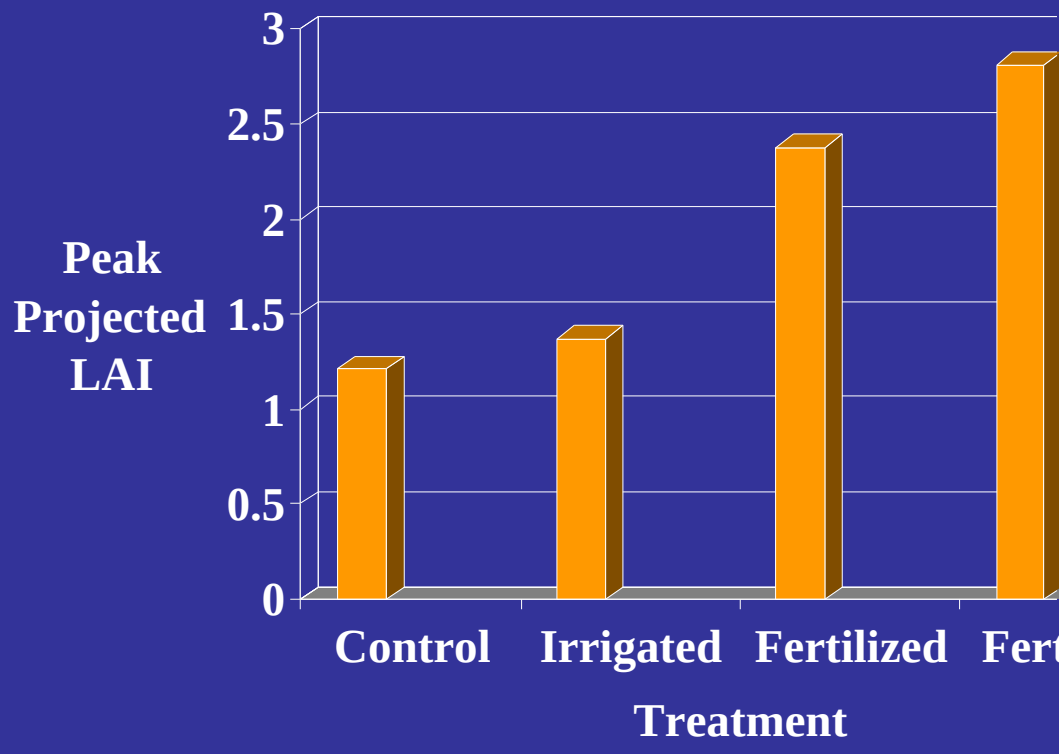
- Teskey *et al.* 1994:
  - Slash pine net photosynthesis not impacted by water table drop < 1.5 m





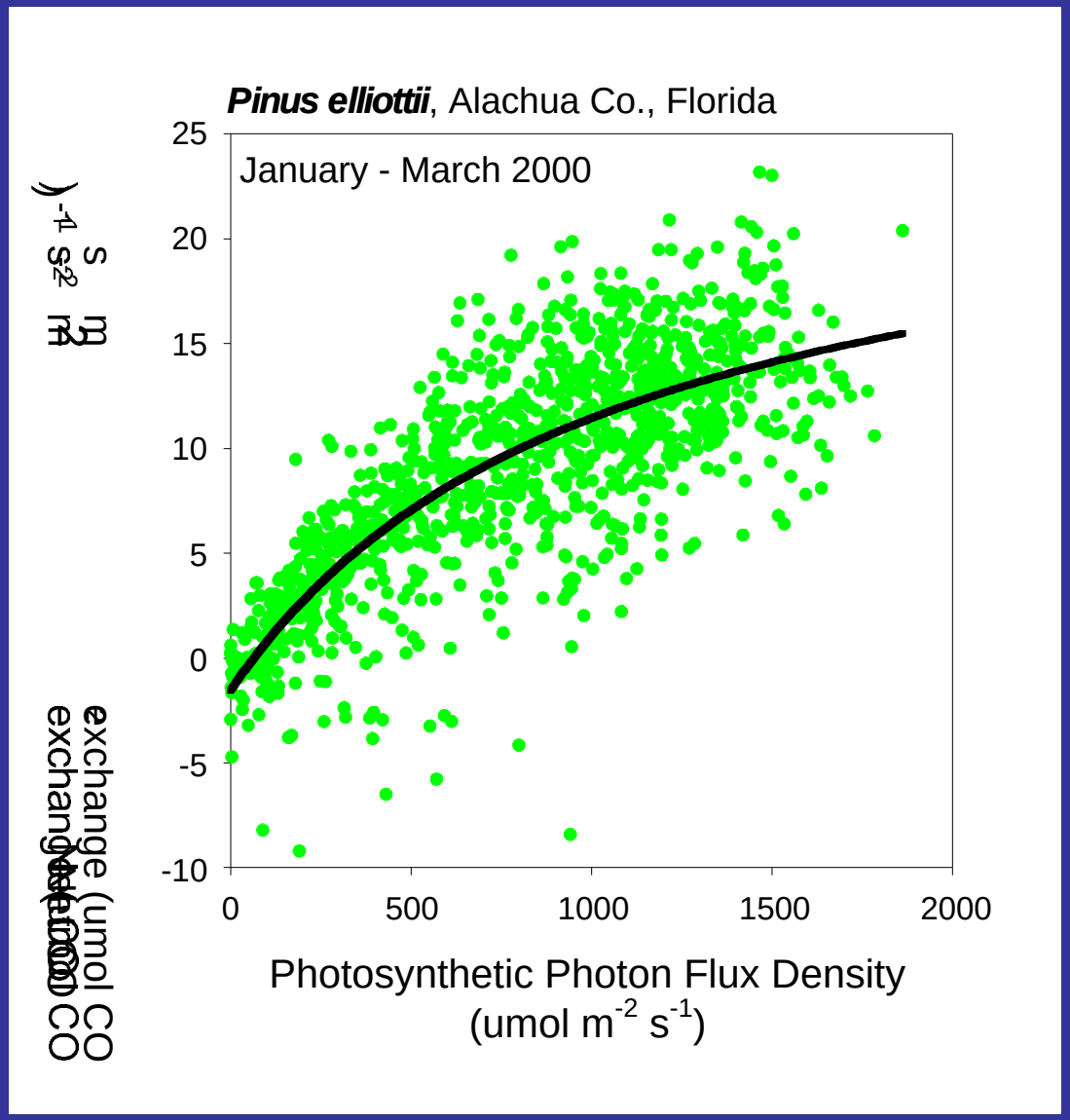
Previous southern pine research

- Albaugh *et al.* 1998:
  - Loblolly pine growing on a North Carolina sandhill is primarily nutrient limited

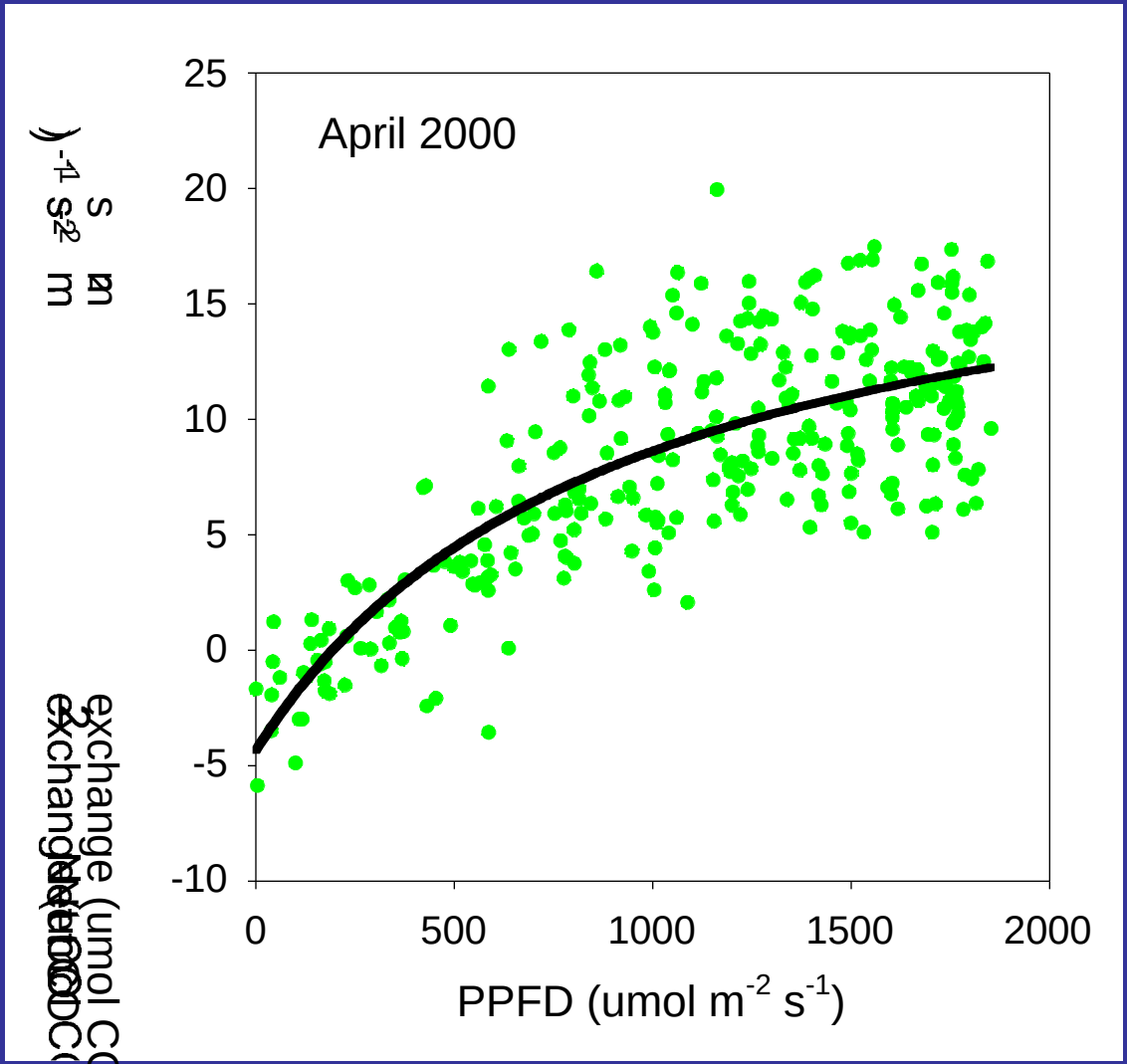


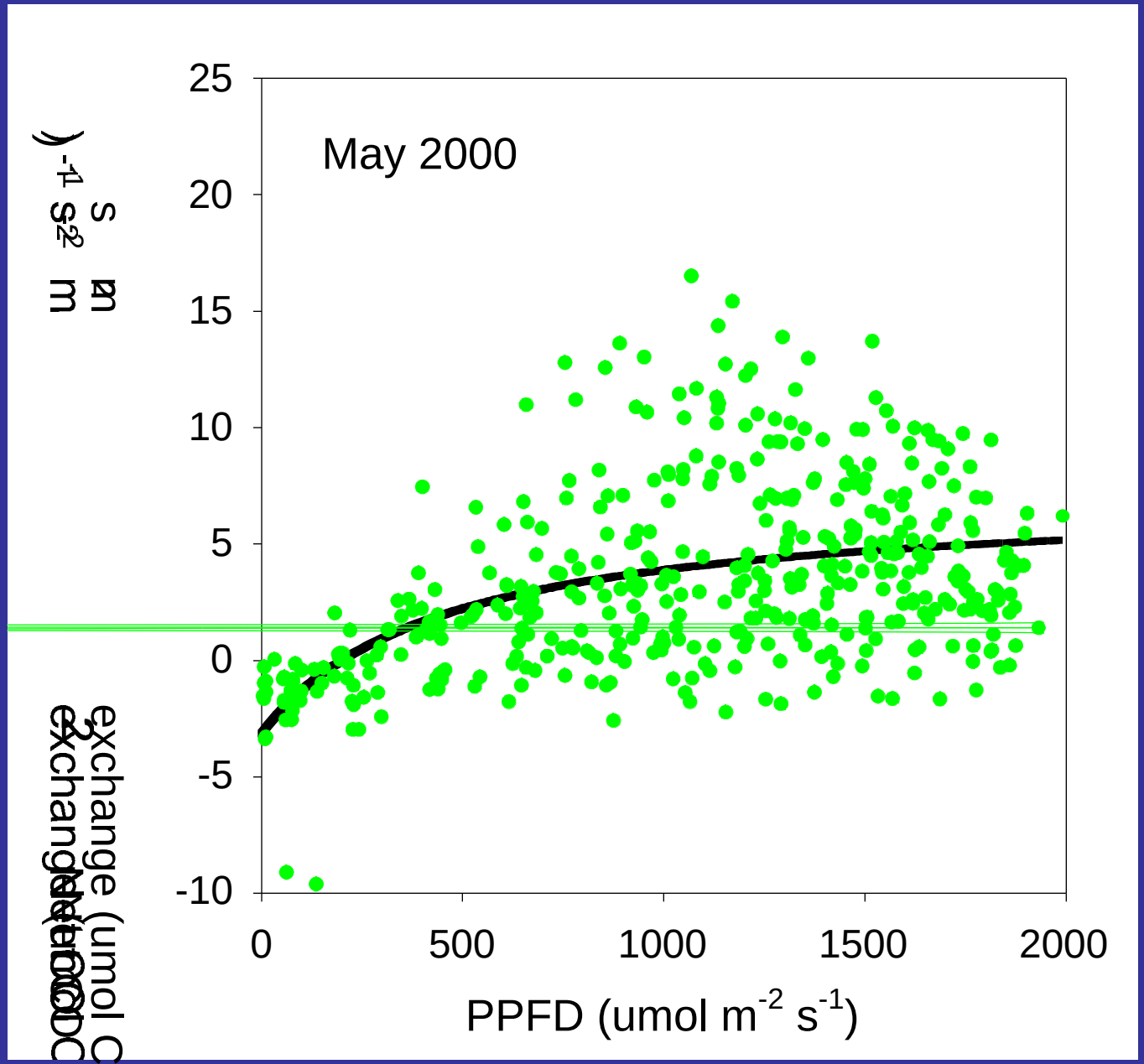
Previous Research

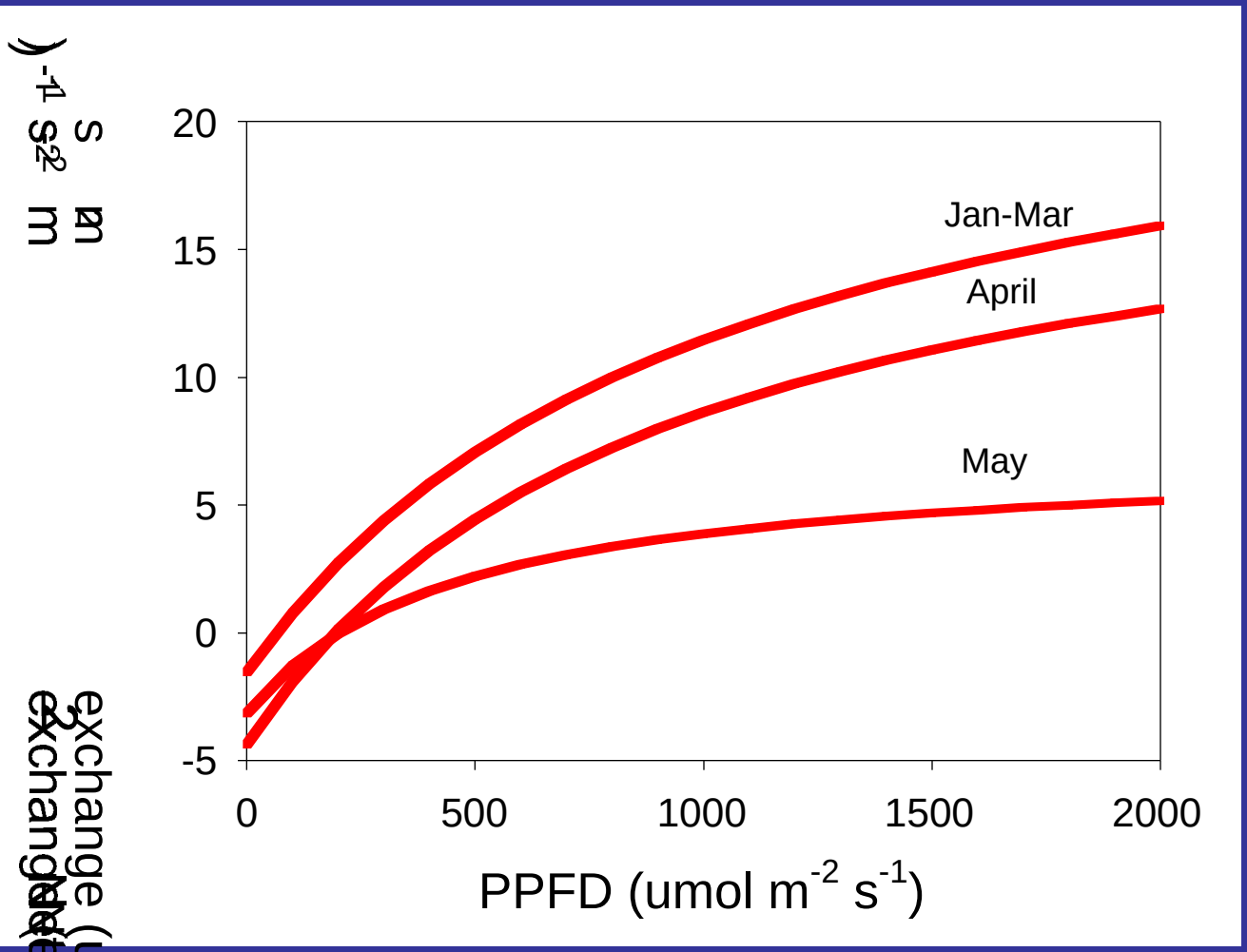
- Cropper's Slash Pine Model successfully modeled carbon relations without water limitation functions



Pinus elliottii, Alachua Co., Florida
January - March 2000
25
20
15
10
5
0
-5
-10
0
500
1000
1500
2000
Photosynthetic Photon Flux Density
(umol m-2 s-1)


April 2000
25
20
15
10
5
0
-5
-10
0
500
1000
1500
2000
PPFD (umol m-2 s-1)


May 2000
25
20
15
10
5
0
-5
-10
0
500
1000
1500
2000
PPFD (umol m-2 s-1)
exchange (umol CO2 m-2 s-1)



January - March

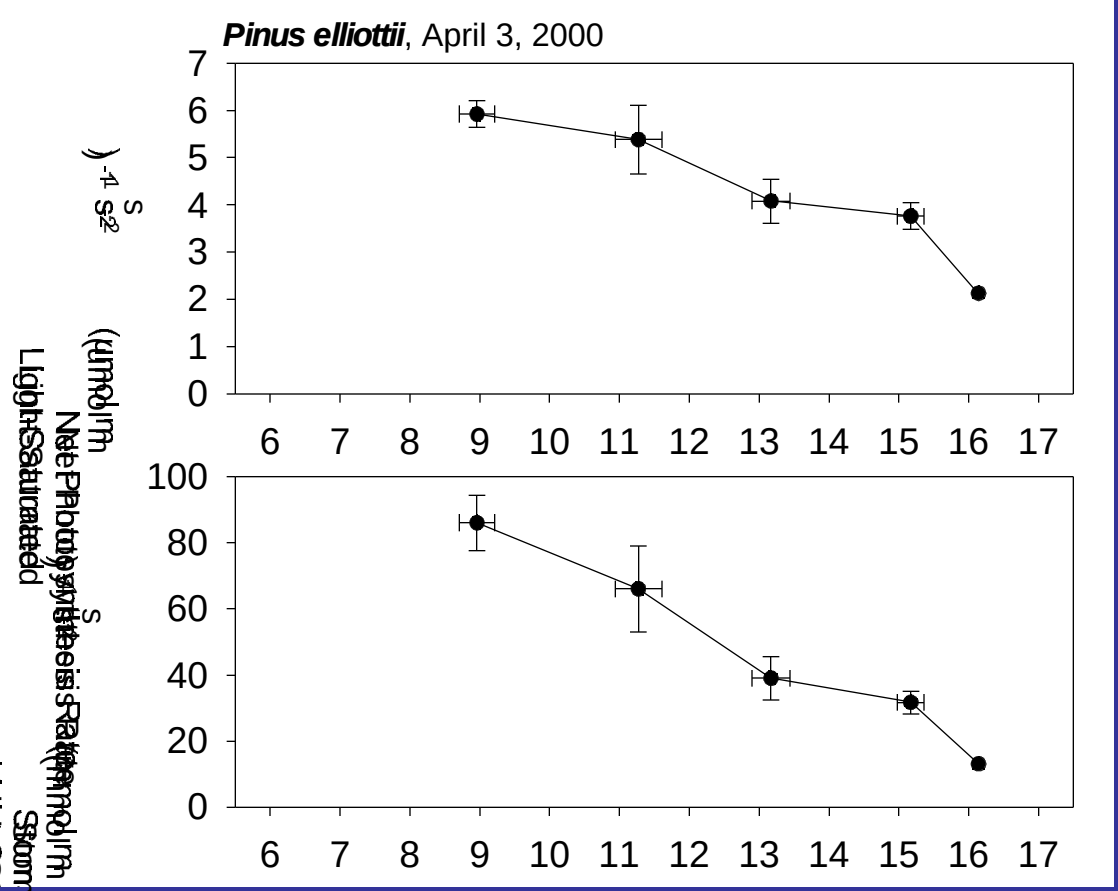
$$\frac{0.0254 * PPFD * 26.56}{0.0254 * PPFD + 26.56}$$

April

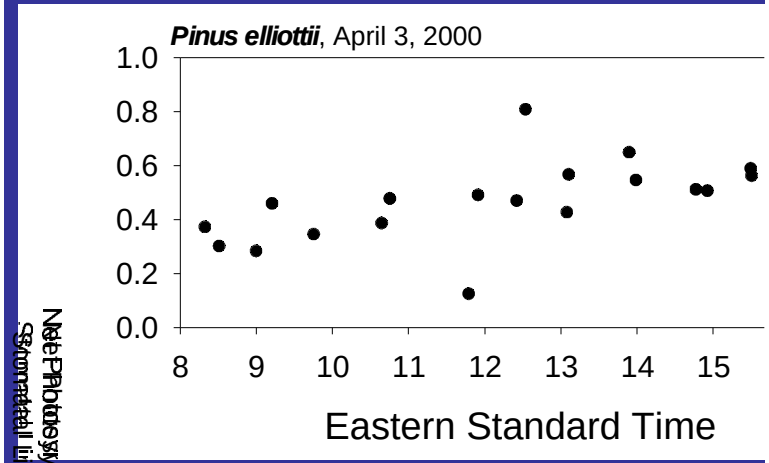
$$\frac{0.0274 * PPFD * 24.72}{0.0274 * PPFD + 24.72}$$

May

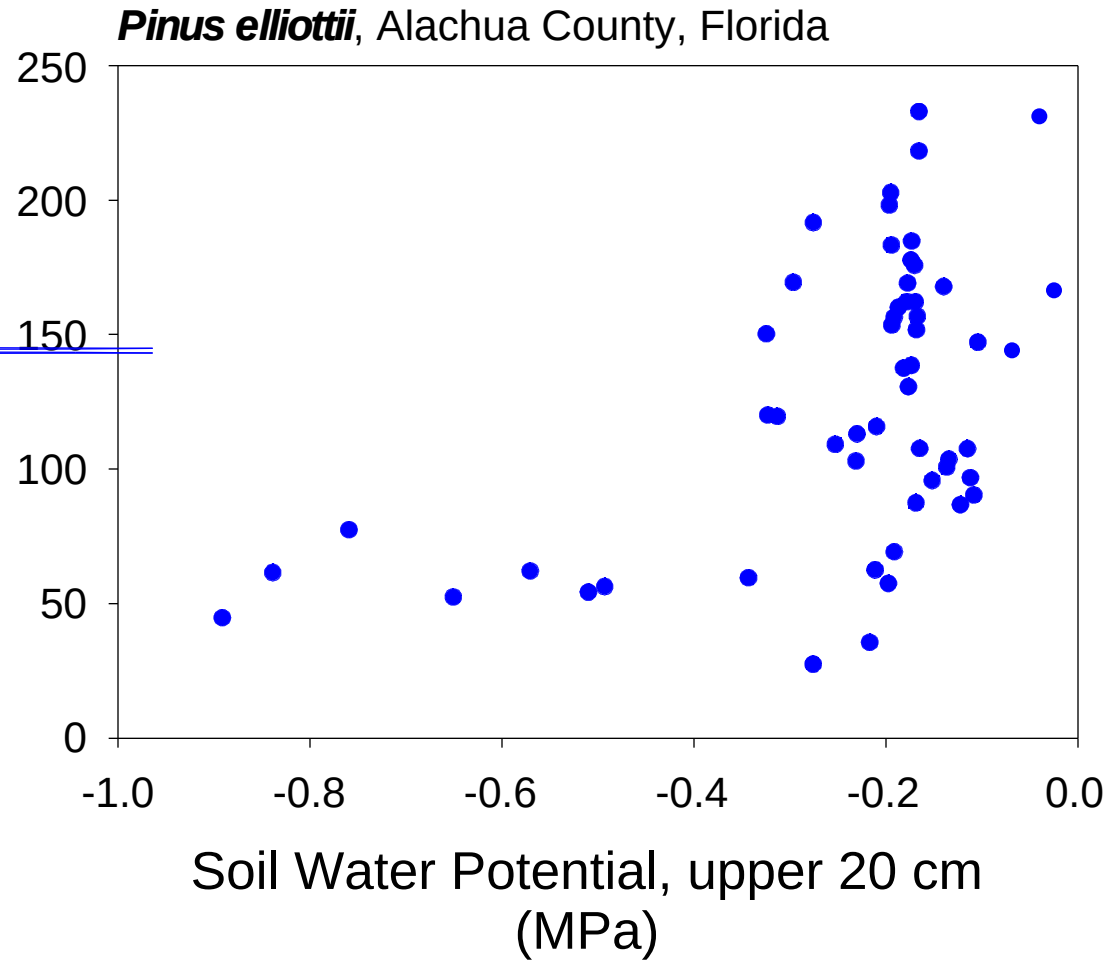
$$\frac{0.0227 * PPFD * 10.18}{0.0227 * PPFD + 10.18}$$

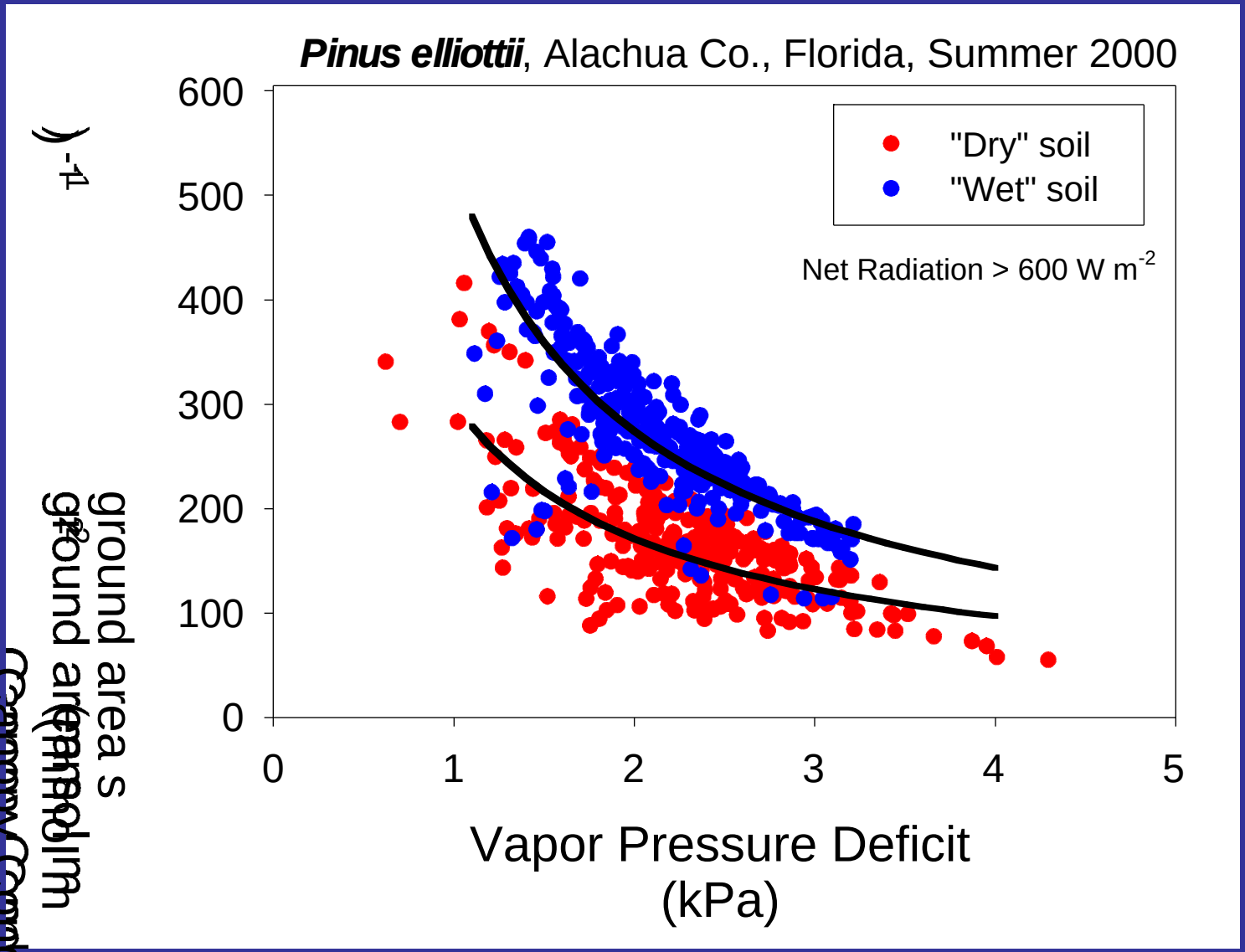


Pinus elliottii, April 3, 2000
7
6
5
4
3
2
1
0
6 7 8 9 10 11 12 13 14 15 16 17
100
80
60
40
20
0
6 7 8 9 10 11 12 13 14 15 16 17

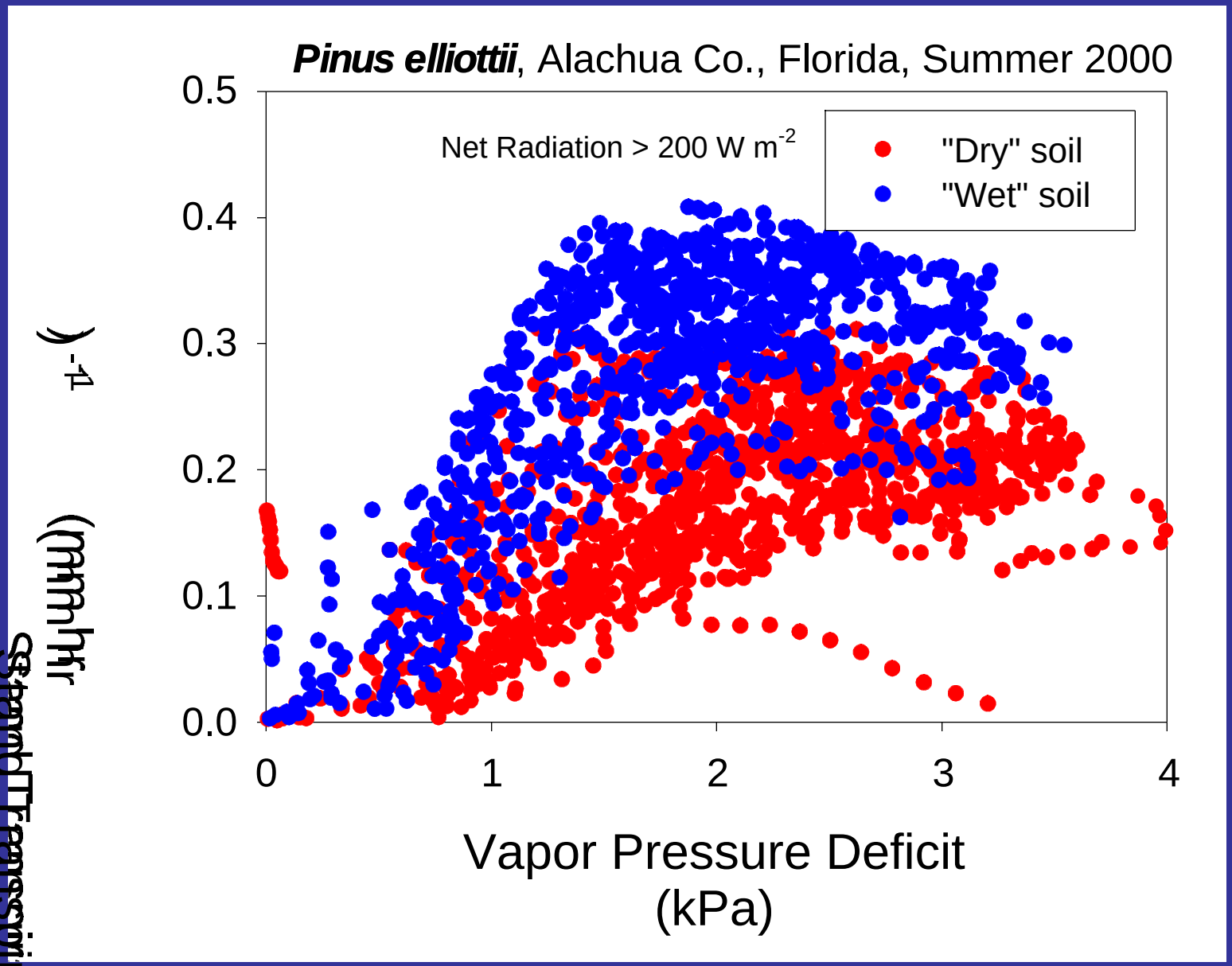


Pinus elliottii, April 3, 2000
1.0
0.8
0.6
0.4
0.2
0.0
8 9 10 11 12 13 14 15
Eastern Standard Time


Pinus elliottii, Alachua County, Florida
250
200
150
100
50
0
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
Soil Water Potential, upper 20 cm
(MPa)

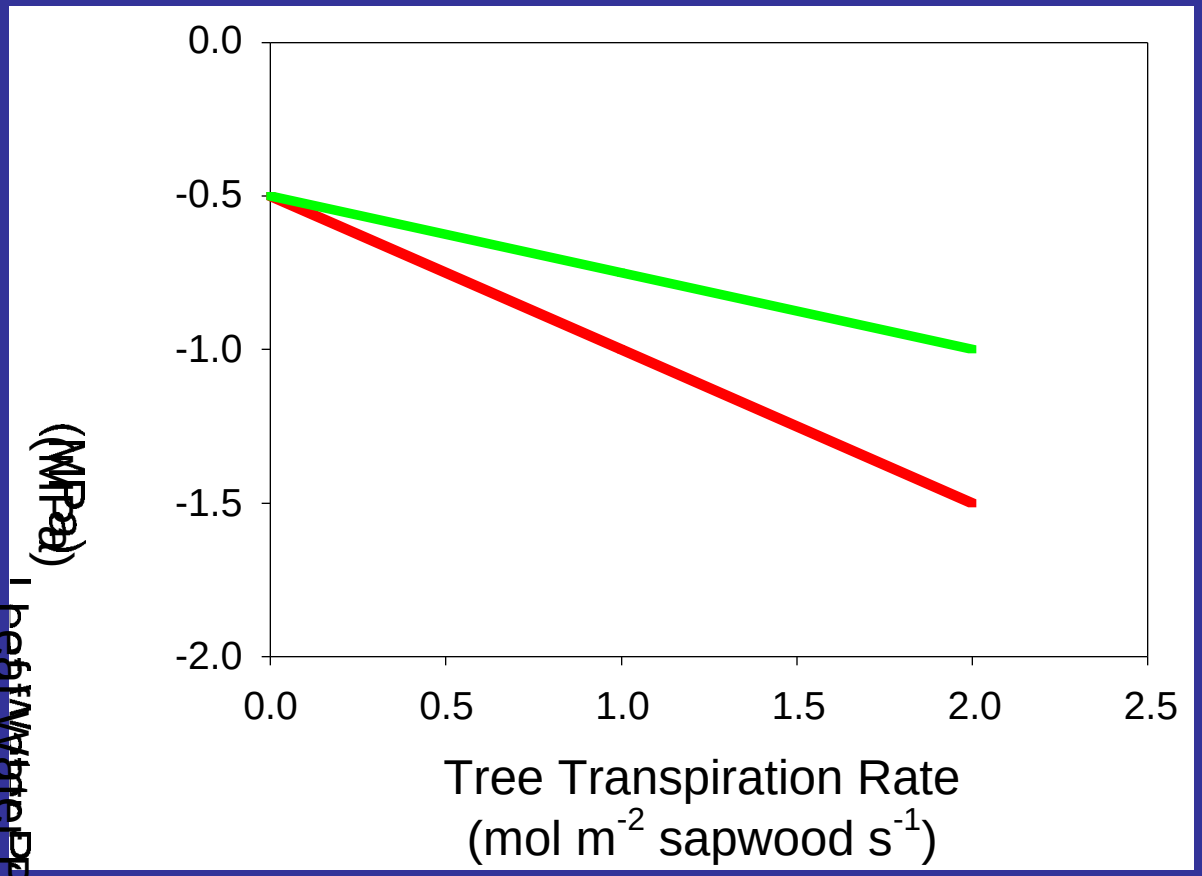


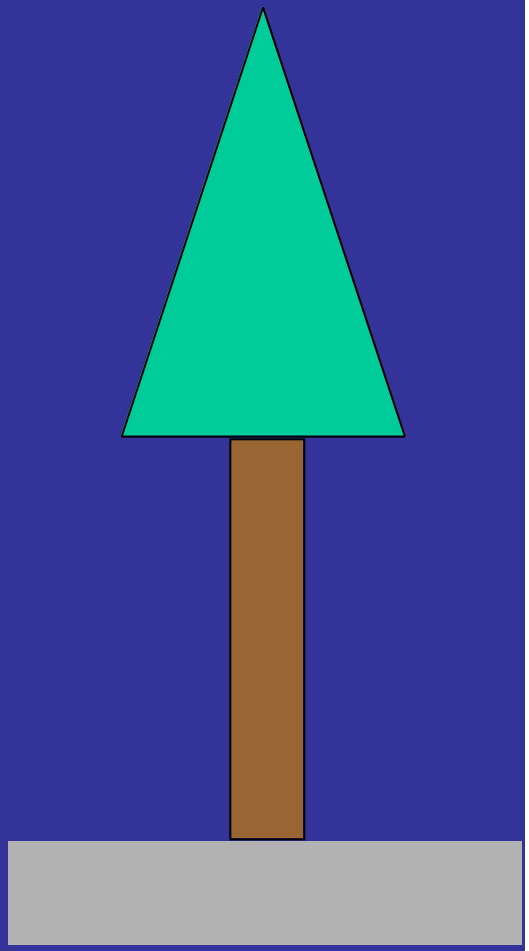
Pinus elliottii, Alachua Co., Florida, Summer 2000
"Dry" soil
"Wet" soil
Net Radiation > 600 W m-2
600
500
400
300
200
100
0
0
1
2
3
4
5
Vapor Pressure Deficit
(kPa)

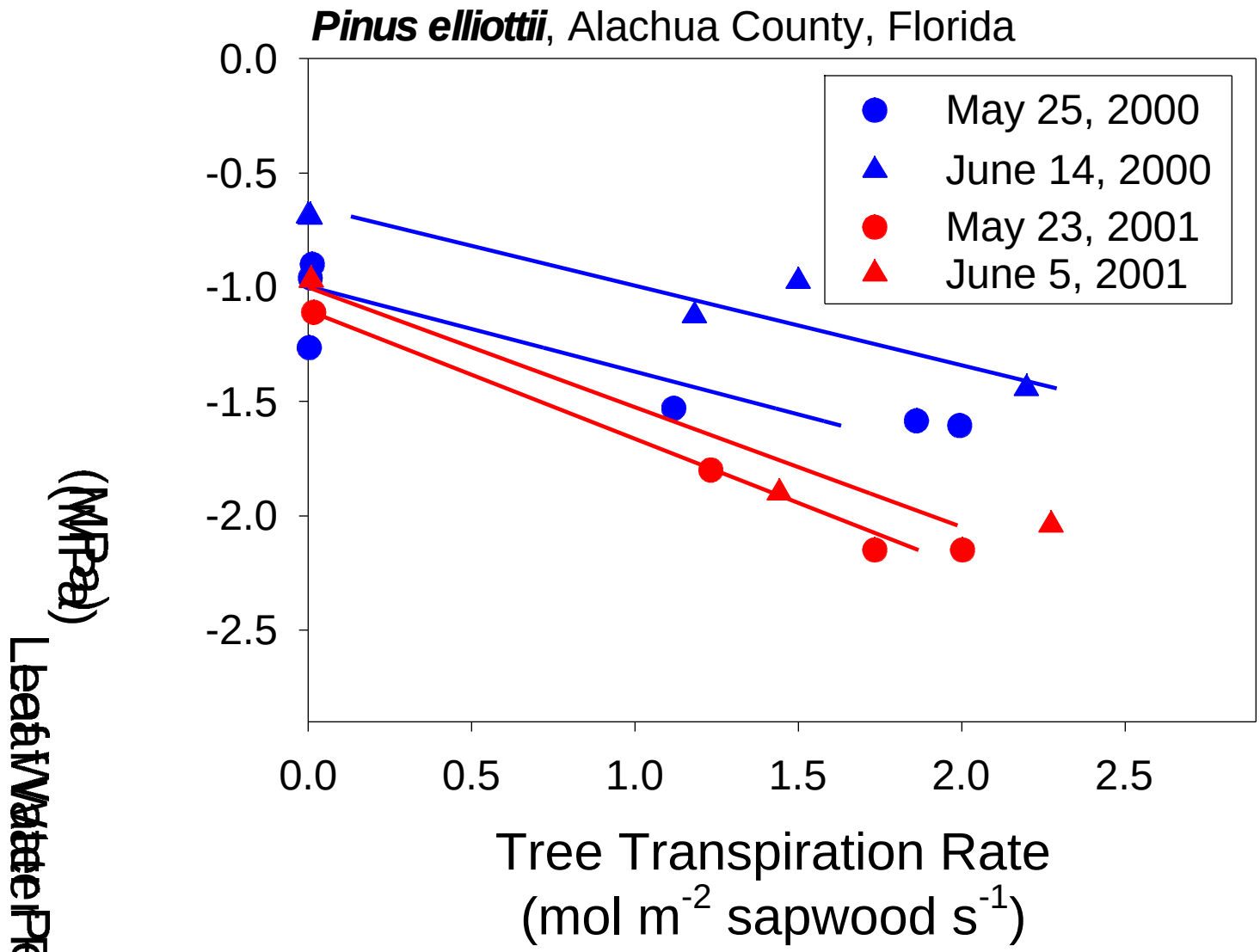


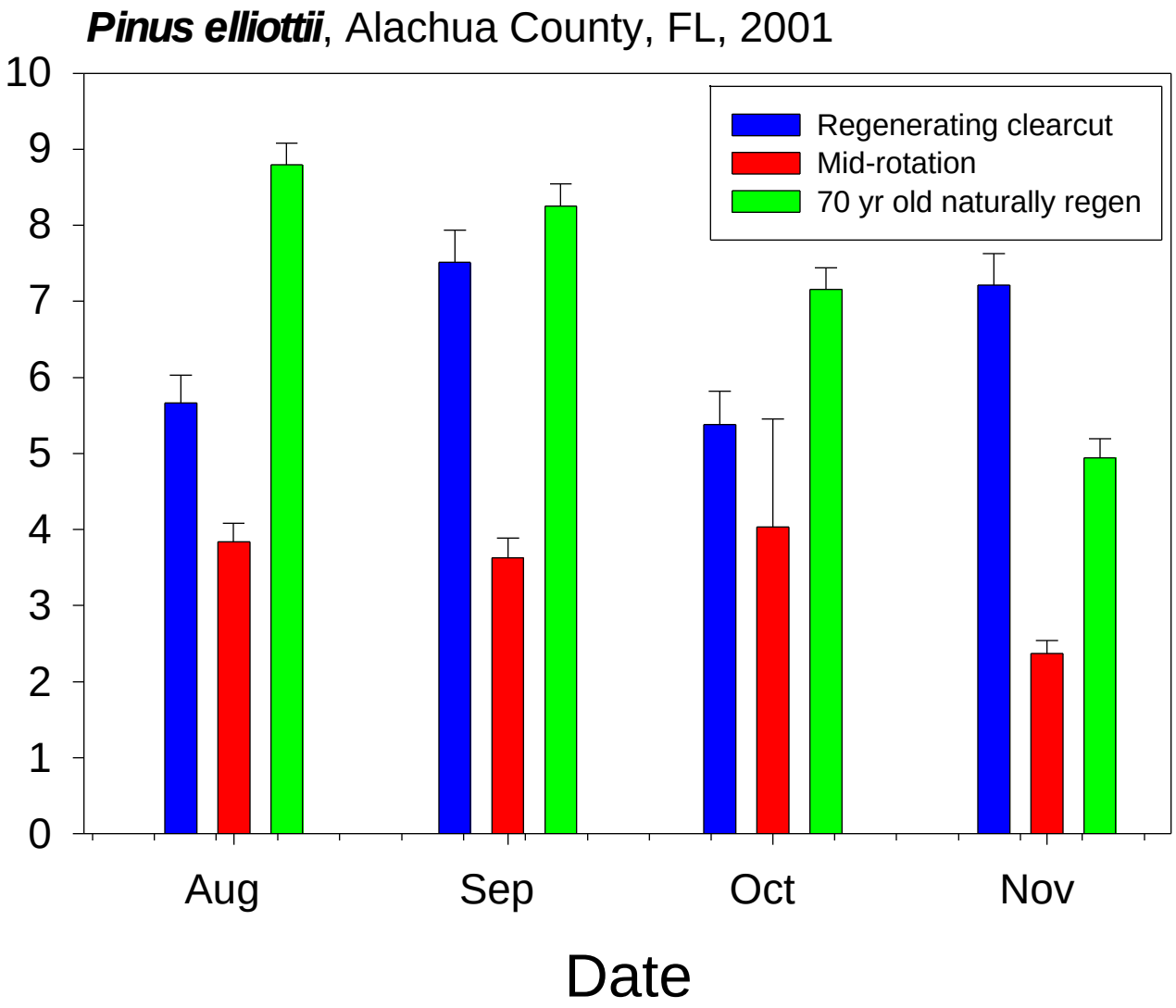
Stand Transpiration

Hydraulic Conductance

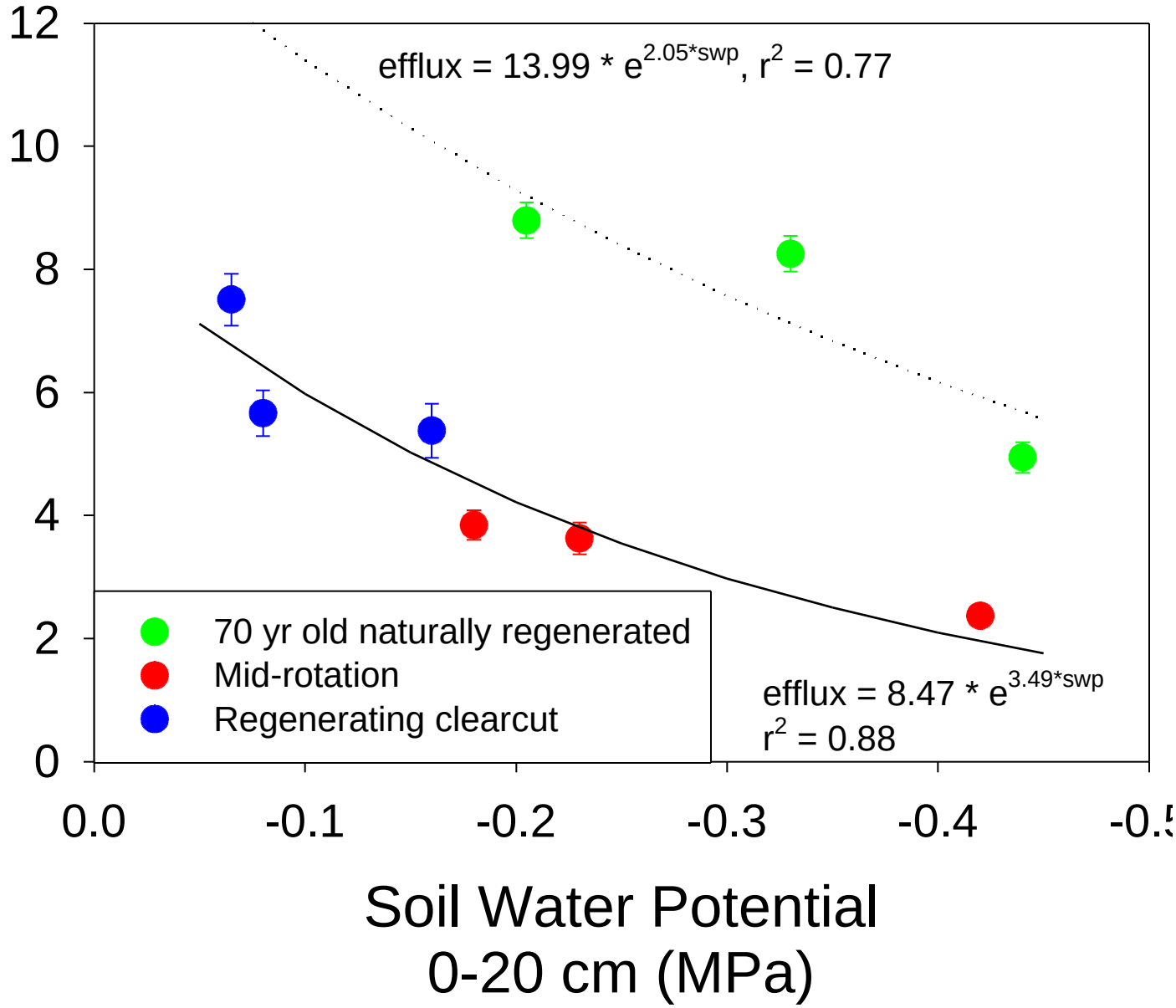




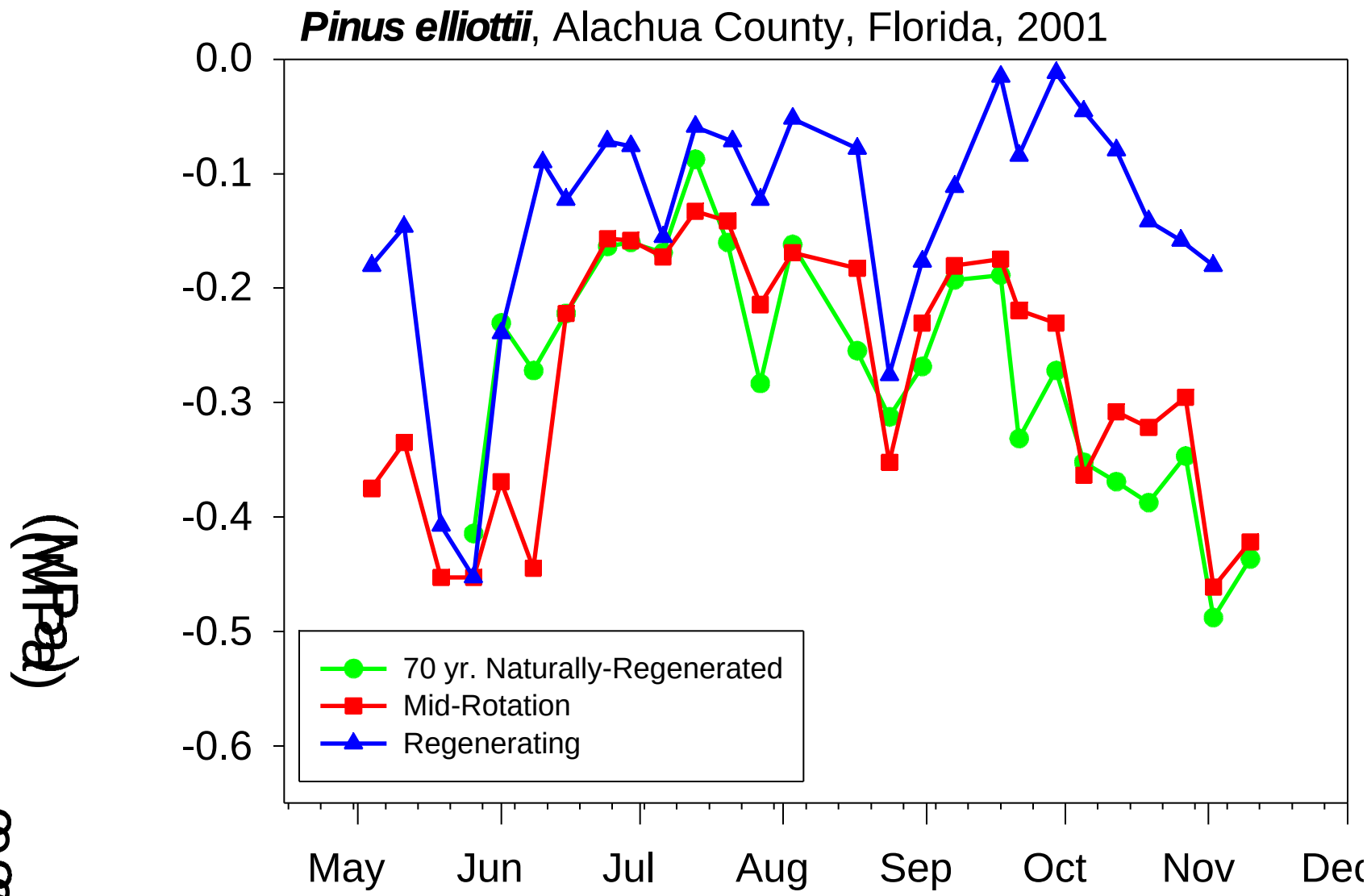

Pinus elliottii, Alachua County, Florida
May 25, 2000
June 14, 2000
May 23, 2001
June 5, 2001
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
0.0
0.5
1.0
1.5
2.0
2.5
Tree Transpiration Rate
(mol m-2 sapwood s-1)
Leaf Water Potential
(MPa)



Average Diur


efflux = 13.99 * e^2.05*swp, r^2 = 0.77
efflux = 8.47 * e^3.49*swp
r^2 = 0.88
70 yr old naturally regenerated
Mid-rotation
Regenerating clearcut
12
10
8
6
4
2
0
0.0
-0.1
-0.2
-0.3
-0.4
Soil Water Potential
0-20 cm (MPa)

Average Diu


Pinus elliottii, Alachua County, Florida, 2001
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
(MPa)
70 yr. Naturally-Regenerated
Mid-Rotation
Regenerating
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

0-20 cm Sc

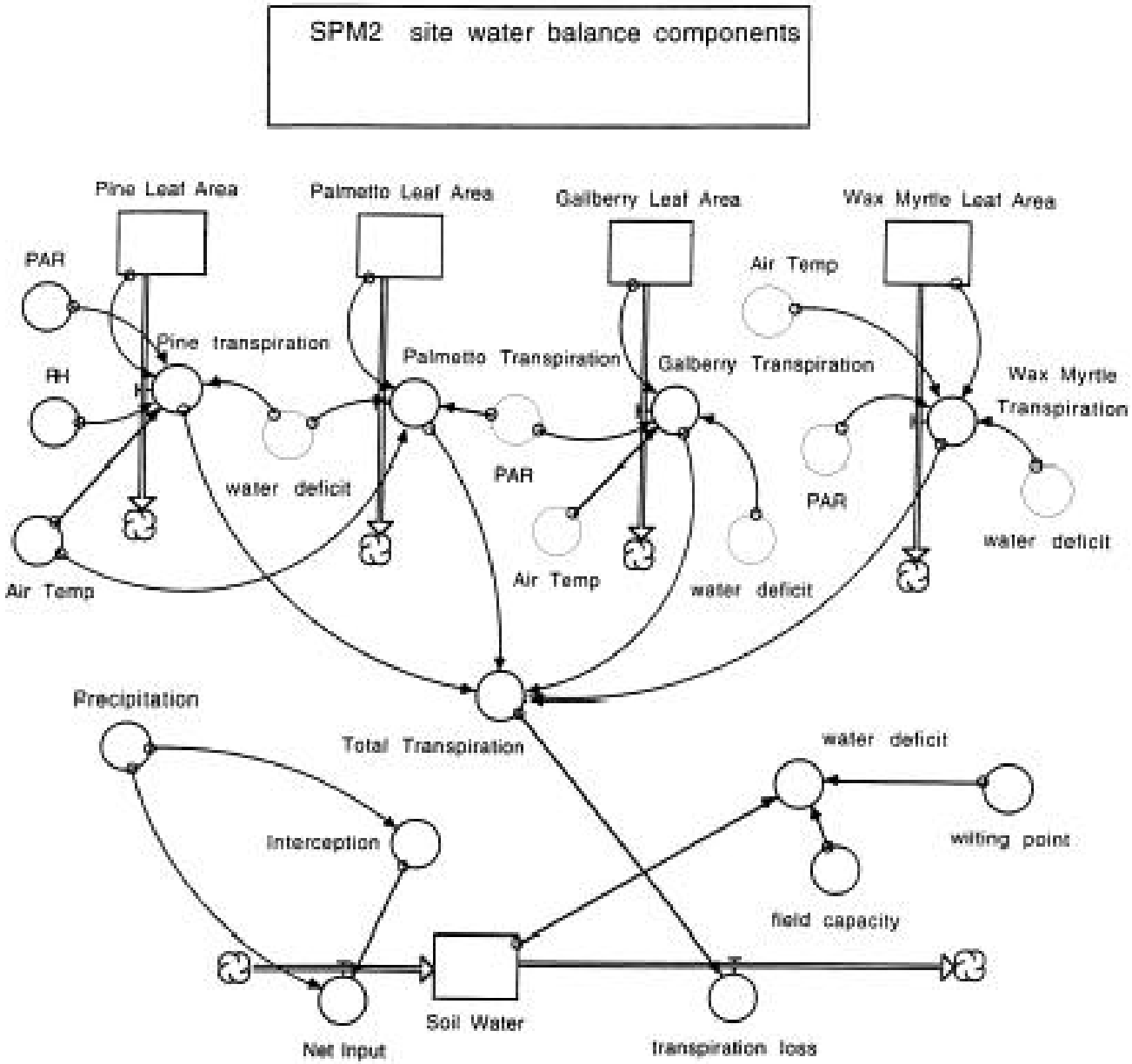
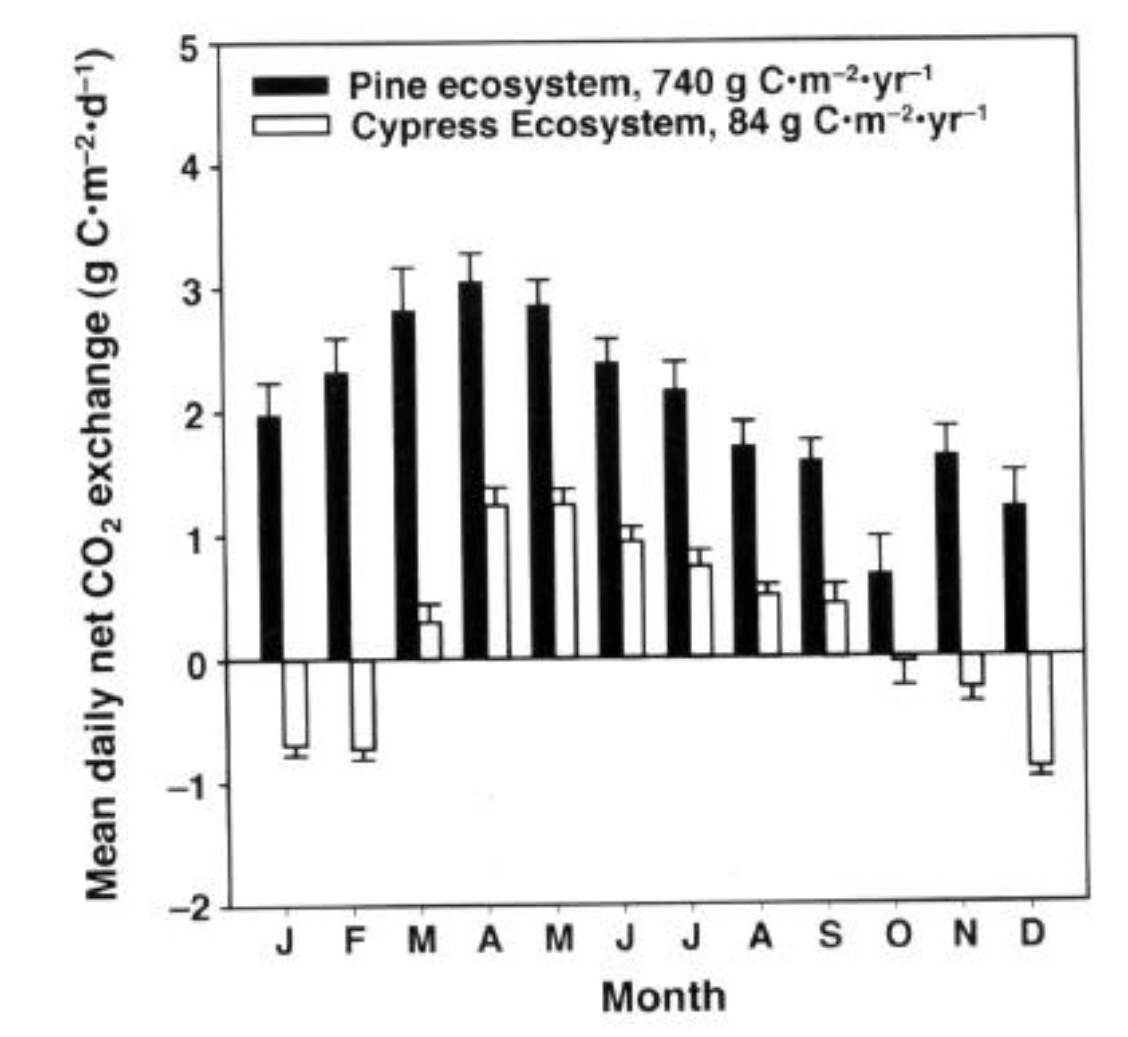


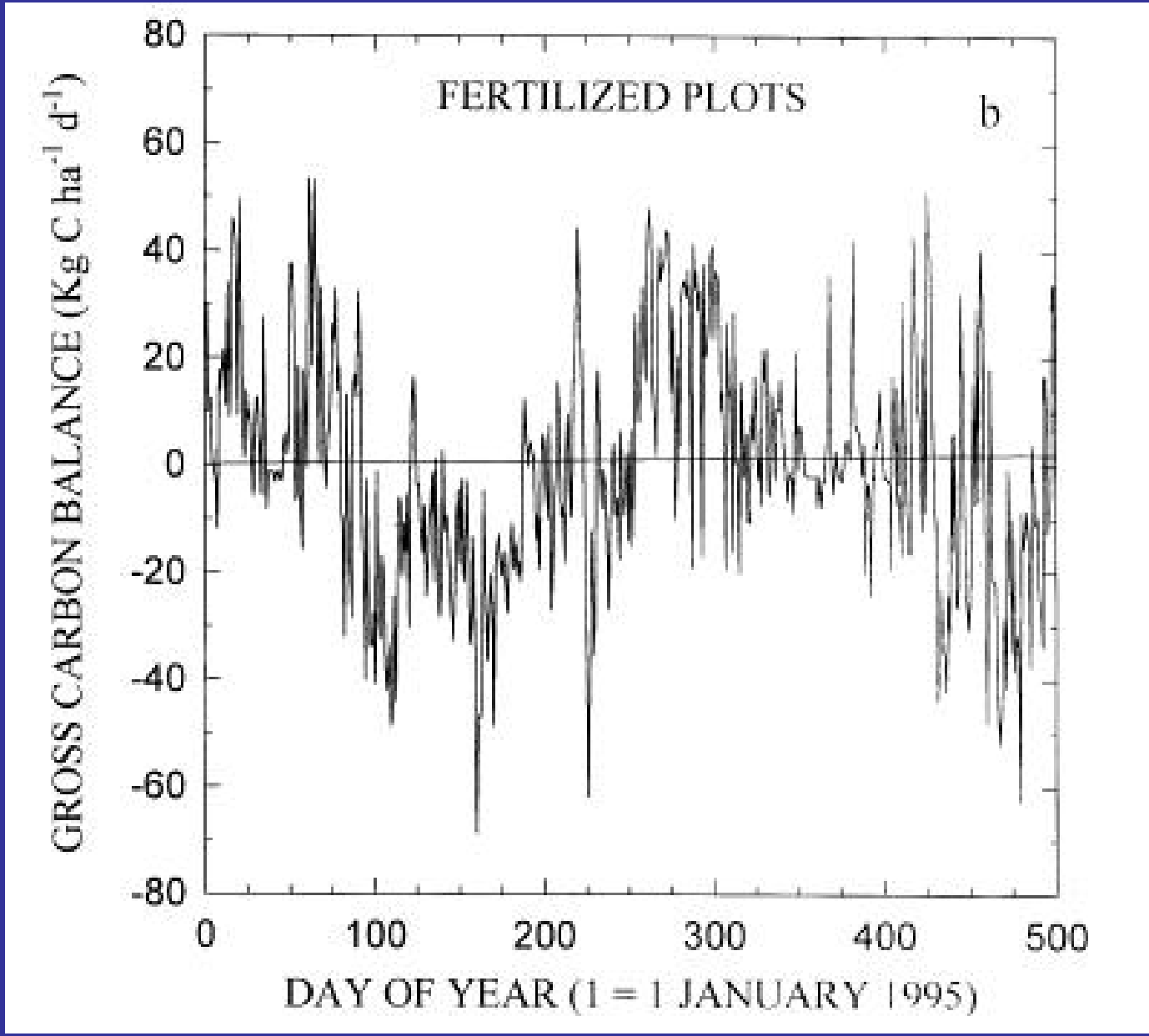
Fig. 2. Site water balance components of the SPM2 model.

Cropper 2000

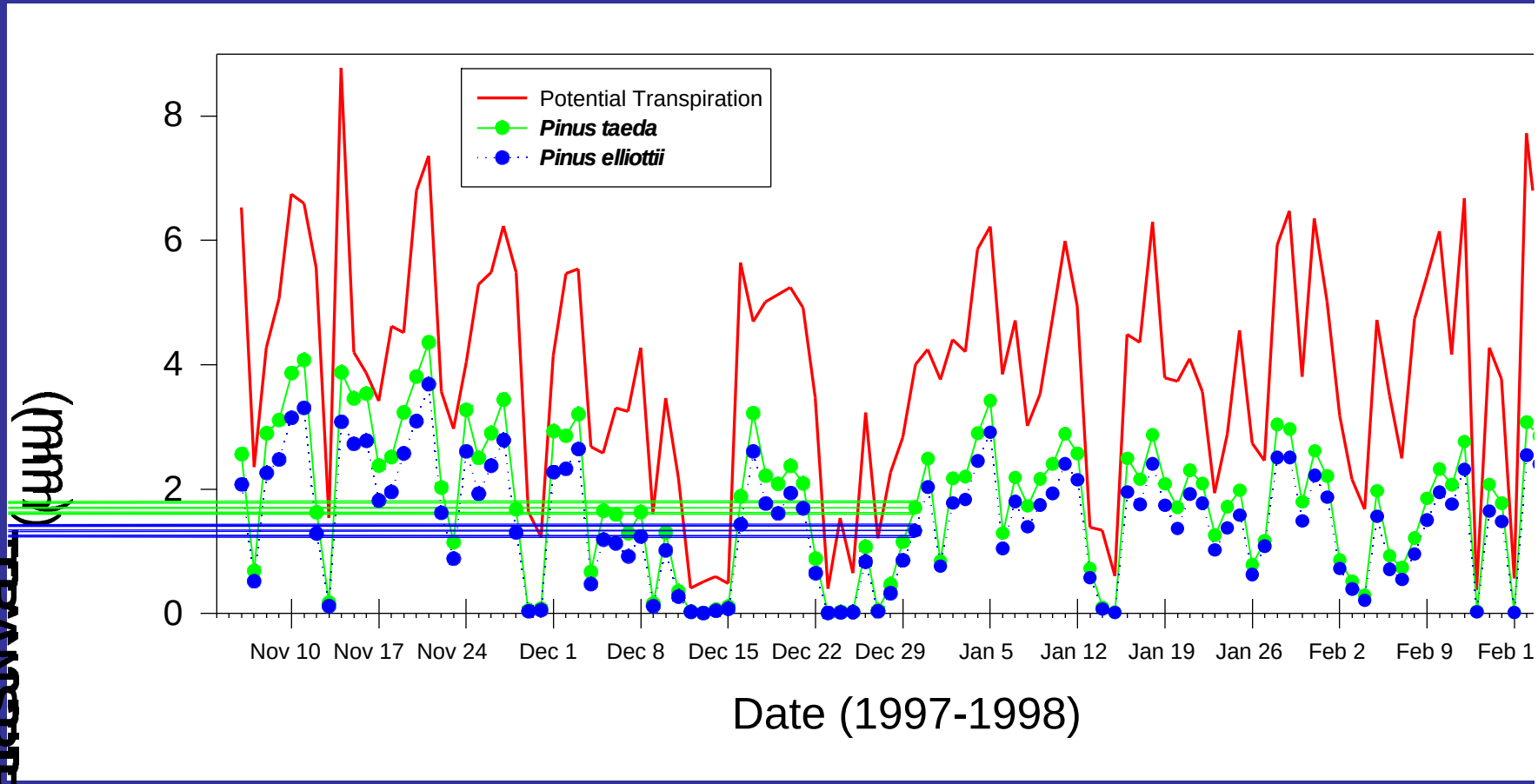
Significance of winter C gain in southern pine systems



Clark et al. 1999

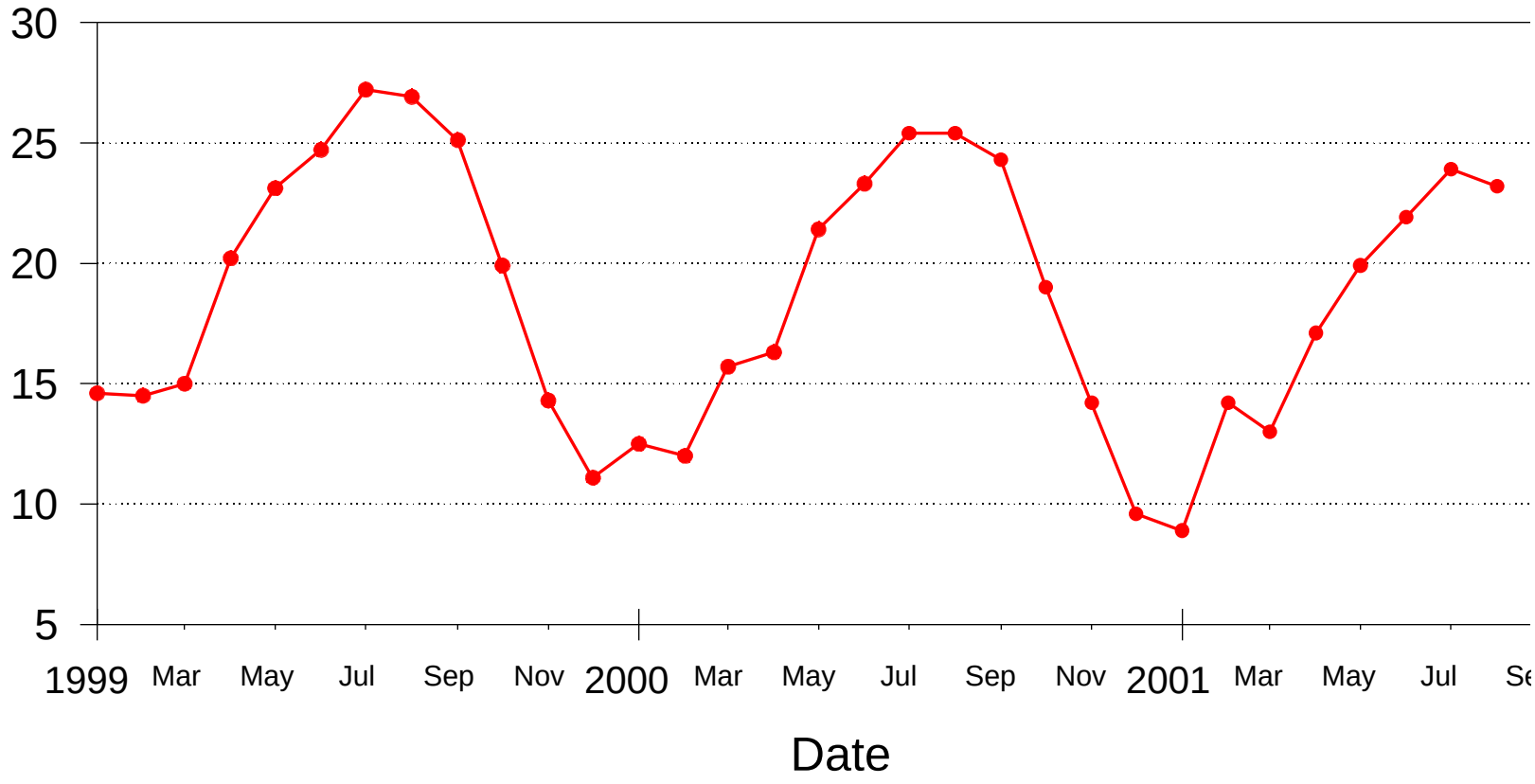


Sampson et al. 2001



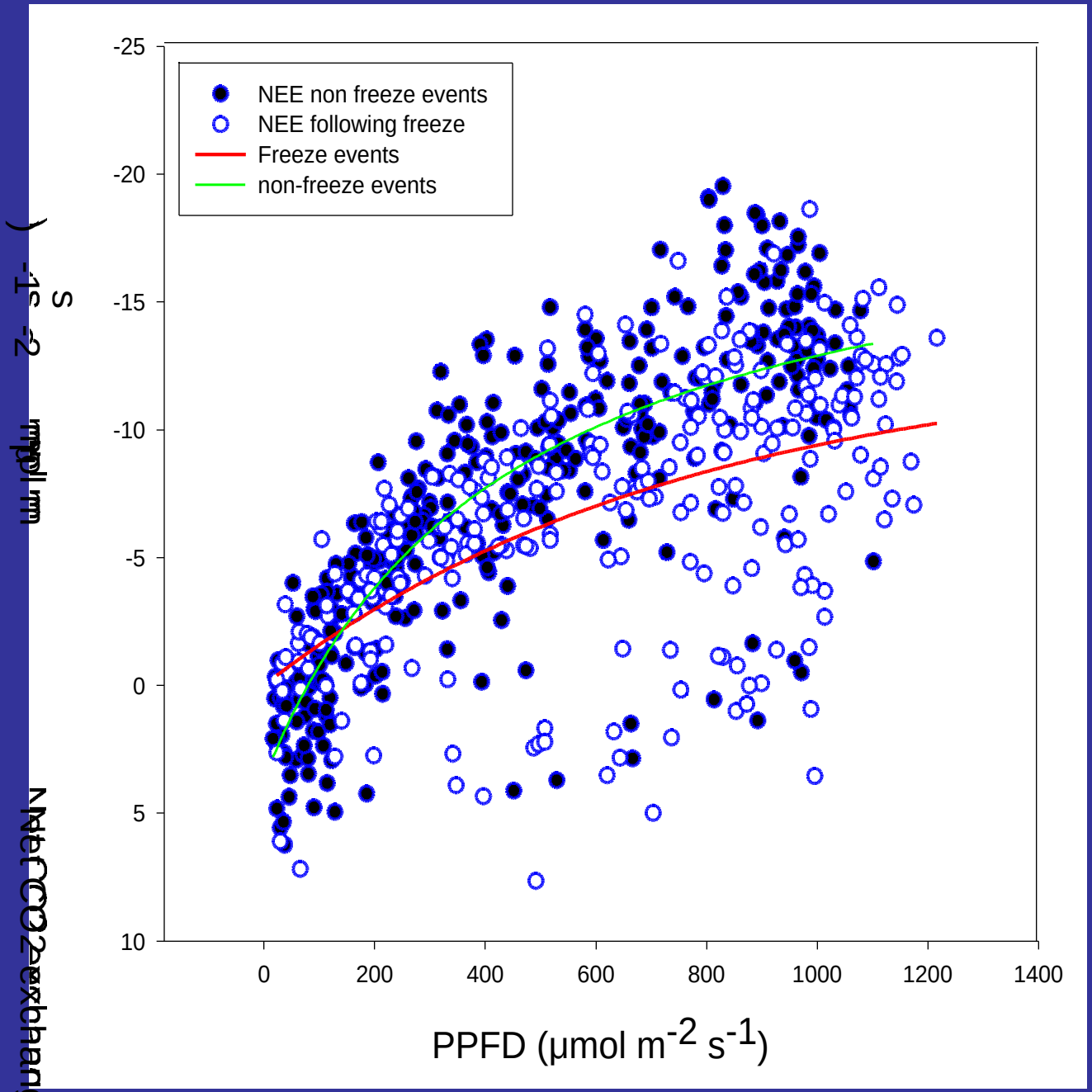
TRANSPIRATION (mm)

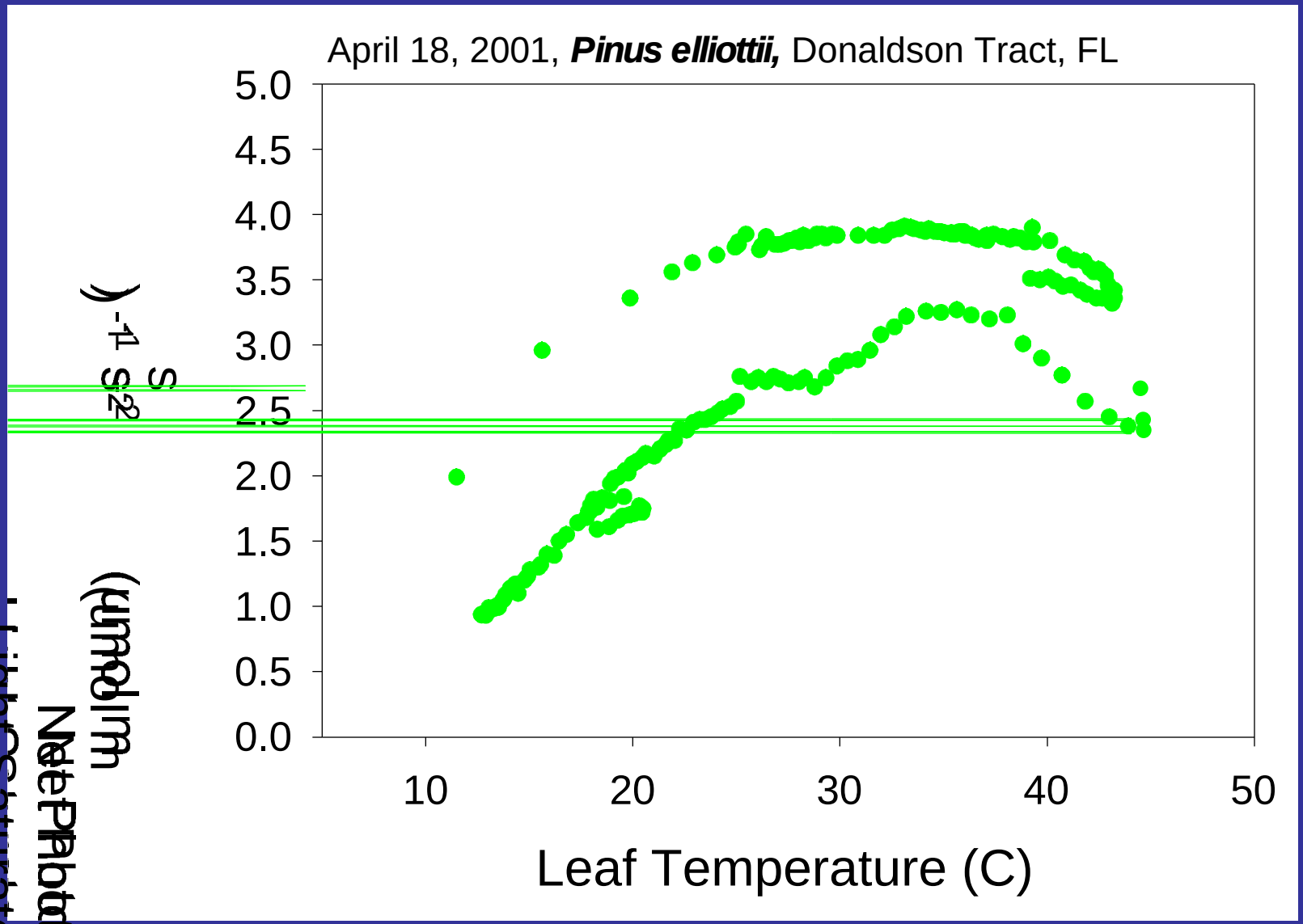
Martin 2000

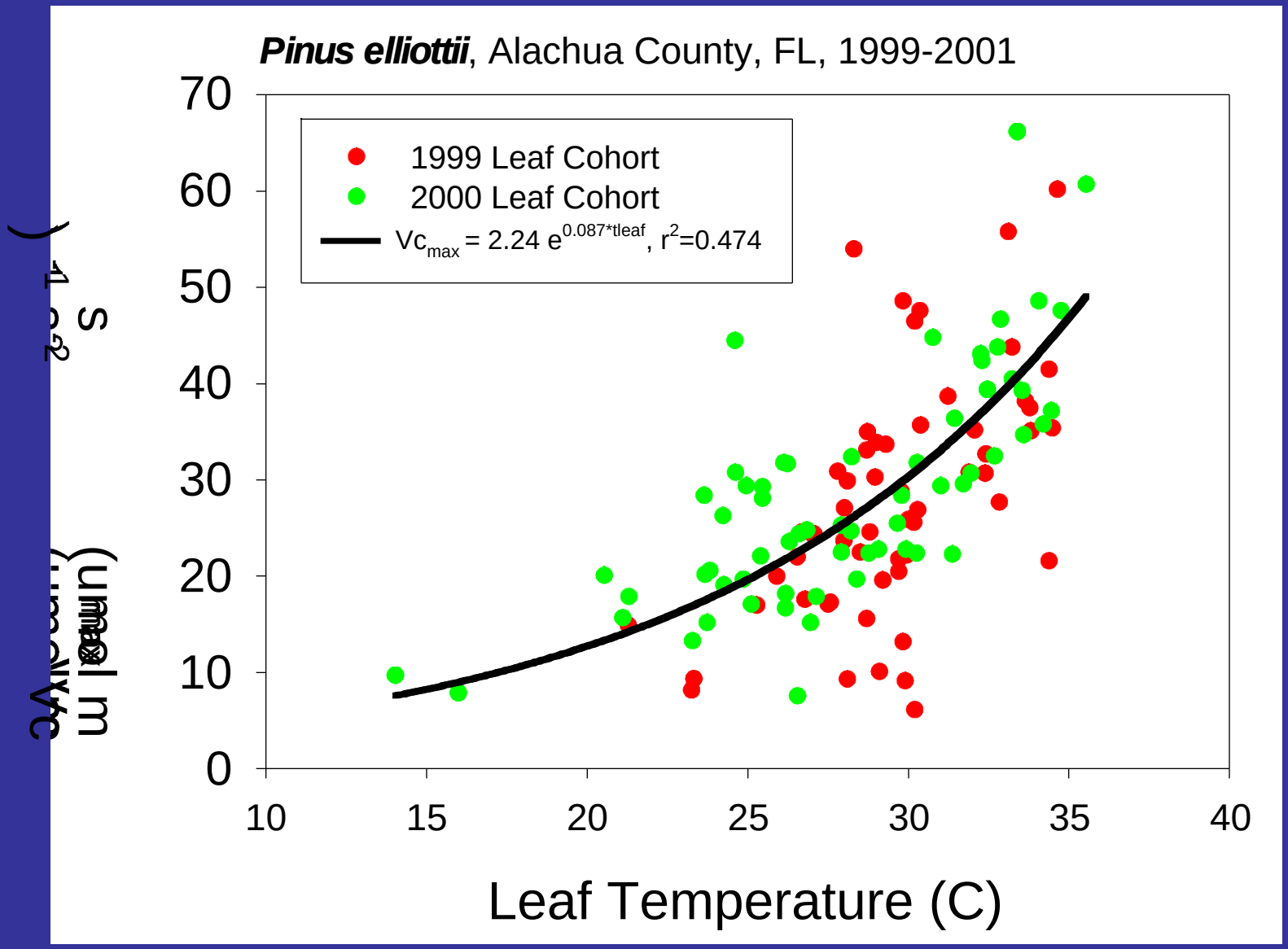


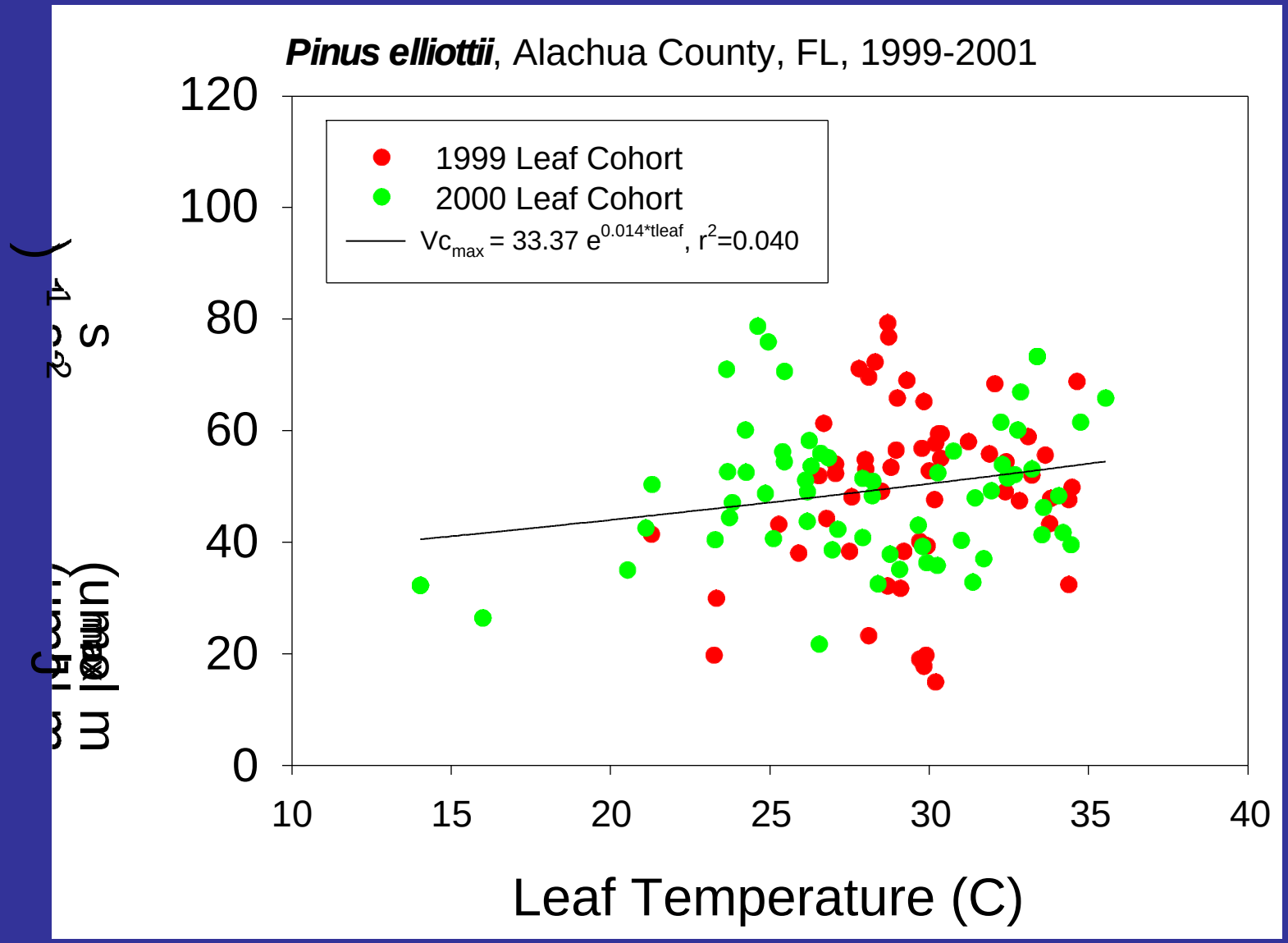
Air Temperature (C)

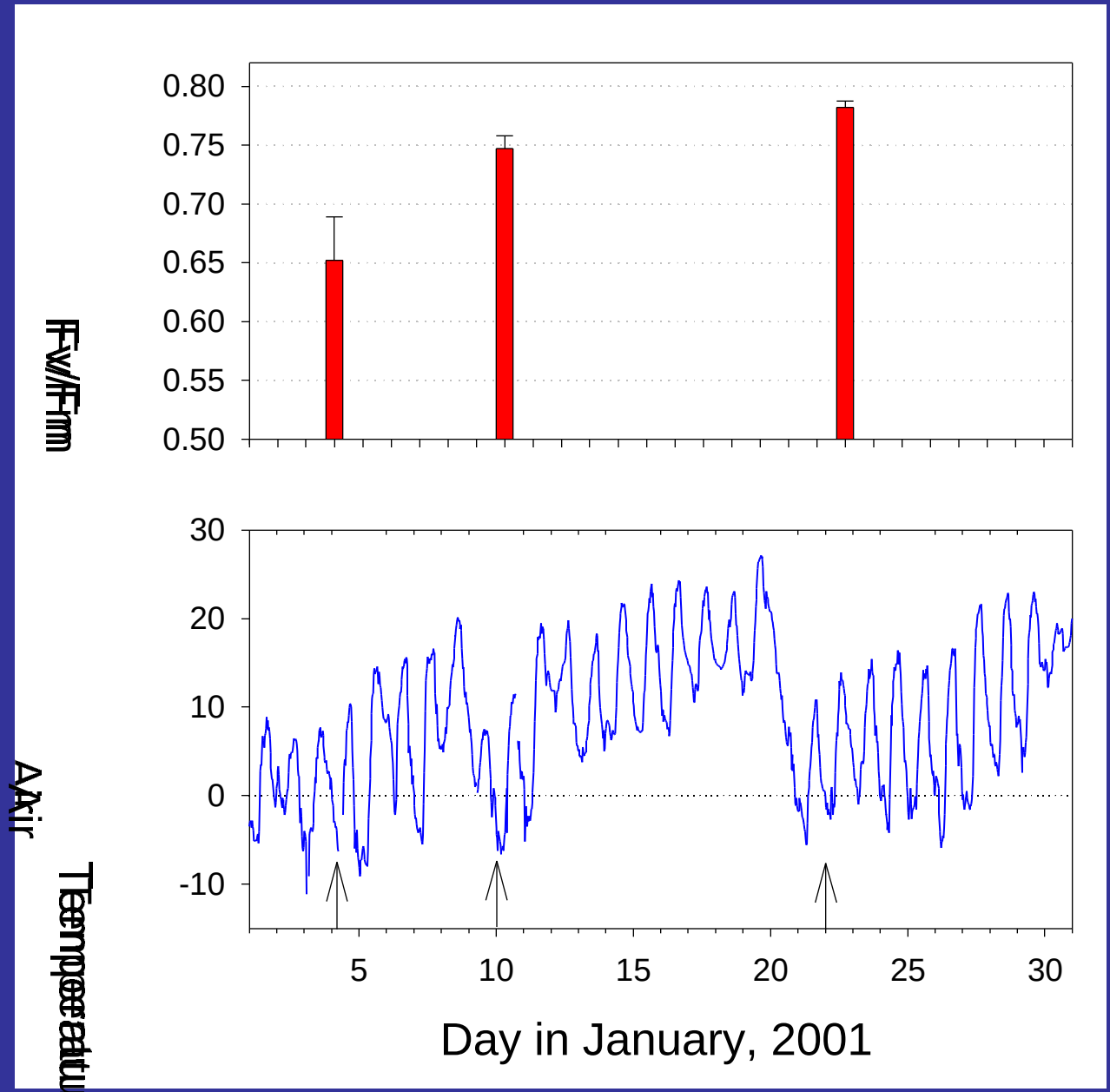
Monthly Mean

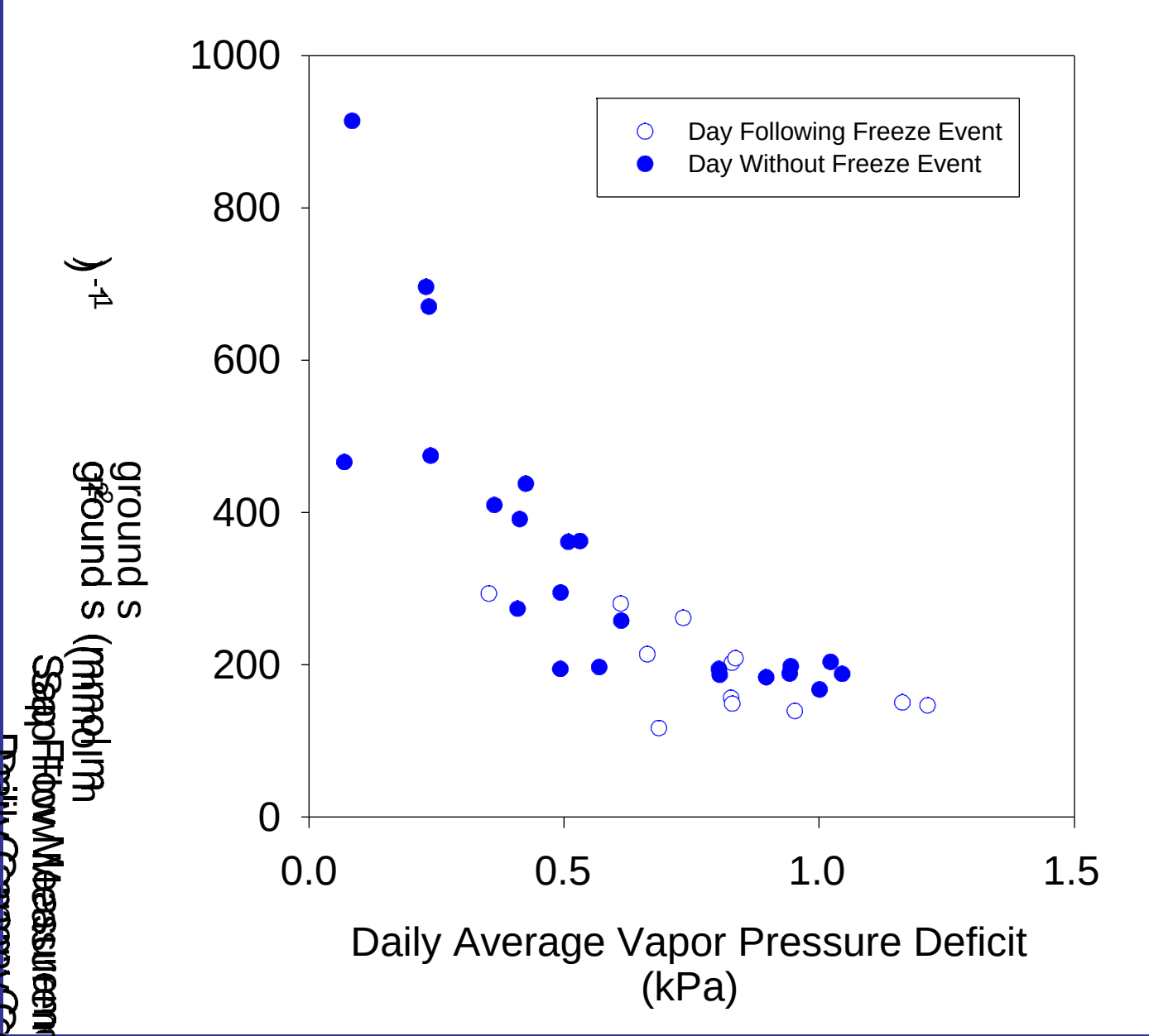

NEE non freeze events
NEE following freeze
Freeze events
non-freeze events
-25
-20
-15
-10
-5
0
5
10
0
200
400
600
800
1000
1200
1400
PPFD (µmol m-2 s-1)
Net CO2 exchange (µmol m-2 s-1)

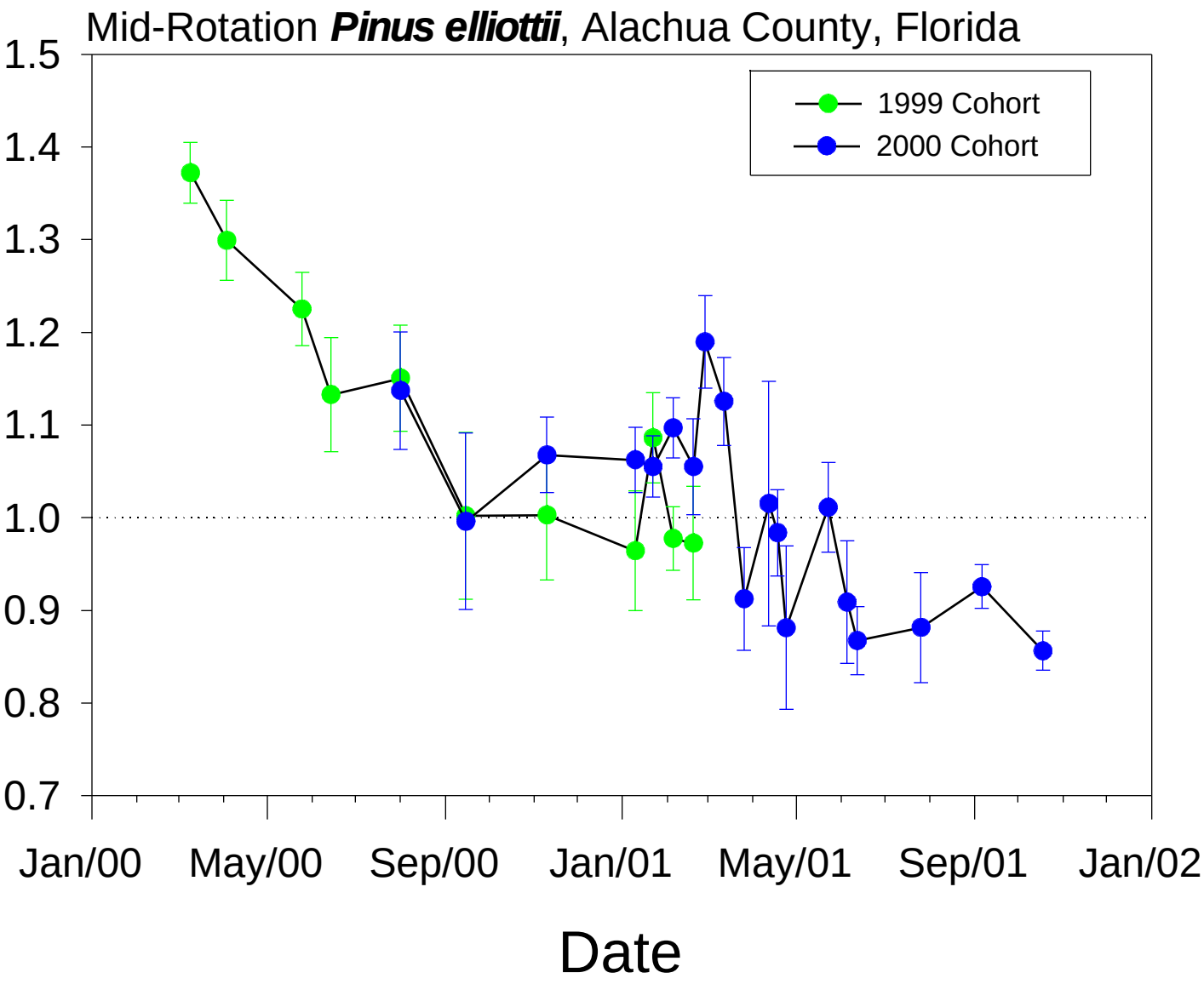

April 18, 2001, ***Pinus elliottii,*** Donaldson Tract, FL
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10
20
30
40
50
Leaf Temperature (C)
Net Photosynthesis (umol m-2 s-1)
Light-Saturated


Pinus elliottii, Alachua County, FL, 1999-2001
1999 Leaf Cohort
2000 Leaf Cohort
$Vc_{max} = 2.24\ e^{0.087*tleaf}$, r^2=0.474
Vcmax (umol m-2 s-1)
Leaf Temperature (C)
0
10
20
30
40
50
60
70
10
15
20
25
30
35
40


Pinus elliottii, Alachua County, FL, 1999-2001
1999 Leaf Cohort
2000 Leaf Cohort
$Vc_{max} = 33.37\ e^{0.014*tleaf}$, r^2=0.040
120
100
80
60
40
20
0
10
15
20
25
30
35
40
Leaf Temperature (C)


0.80
0.75
0.70
0.65
0.60
0.55
0.50
30
20
10
0
-10
5
10
15
20
25
30
Day in January, 2001


1000
800
600
400
200
0
0.0
0.5
1.0
1.5
Day Following Freeze Event
Day Without Freeze Event
Daily Average Vapor Pressure Deficit
(kPa)



Foliage Nitrogen Concentration (%)

- Drought strongly impacted C exchange
  - stomatal limitations dominant
  - longer term impacts of LAI and foliar [N]?
  - role of stand development?
- Freeze and cold temperatures strongly impacted C exchange
  - direct effects on Vcmax
  - damage to PSII
  - stomatal response to VPD
- Nutrient limitations may be important
  - interaction of management, stand development, climate

Further Questions

- To what extent does LAI influence drought responses?
  - Within-stand, temporal variation
  - Between-stand, ontogenetic variation
- Prevalence of soil drought
  - water table dependent?
- Interactions among temperature, water, nutrients?

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