Broad-scale patterns of ecosystem N stocks and soil N availability in post-fire lodgepole pine ecosystems

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Outline

- Patterns of total ecosystem N stocks and soil N availability with stand age and density along a replicated chronosequence in GYE
- Implications for understanding nutrient limitations and wildfire-N interactions in lodgepole pine forests

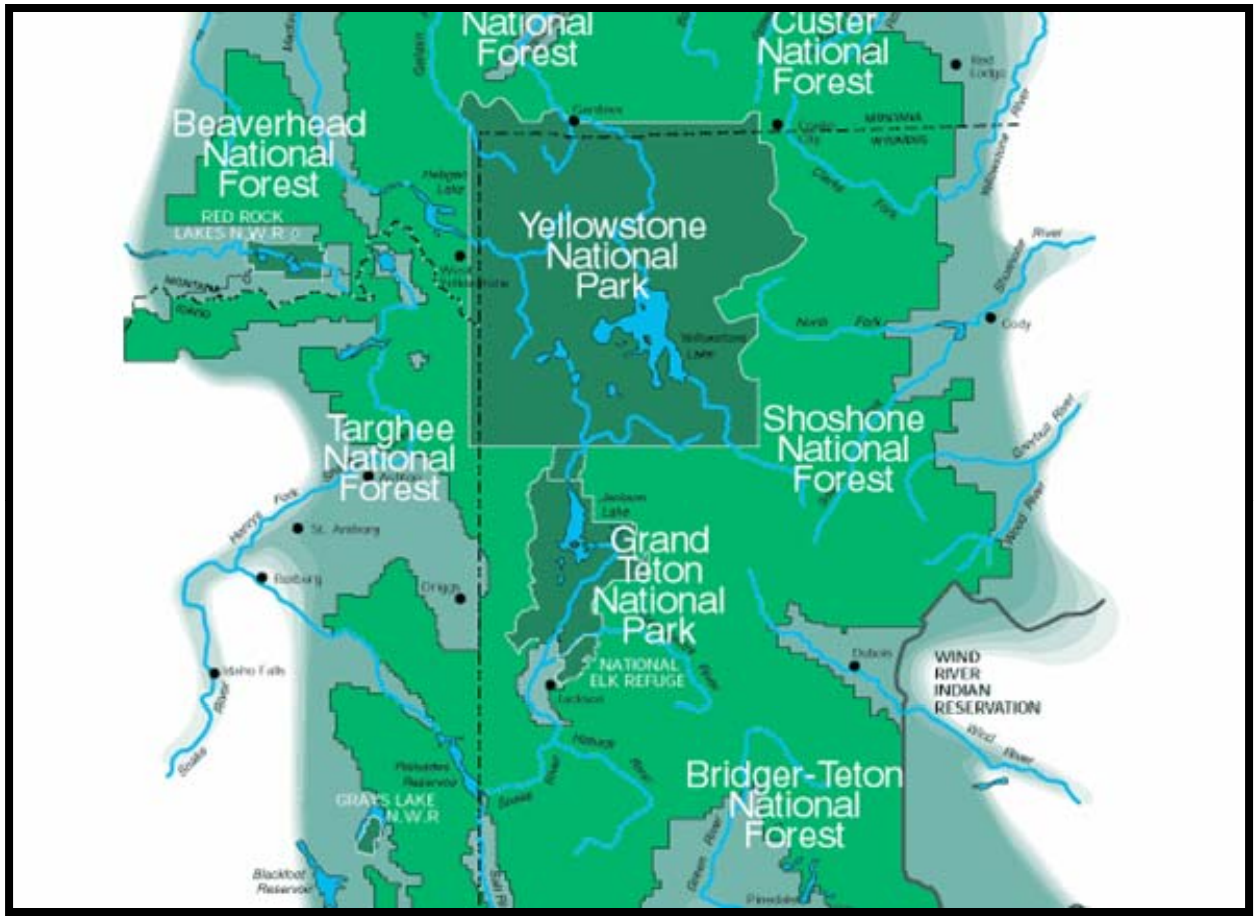
Min temp =

-17.8 °C (Jan) to 3.9°C (Jul)

Max temp =

-2.0 °C (Jan) to 23.6 °C (Jul)

Precip = 61.9 cm



Greater Yellowstone Ecosystem

~80%
Lodgepole pine
(Pinus contorta var. *latifolia)*

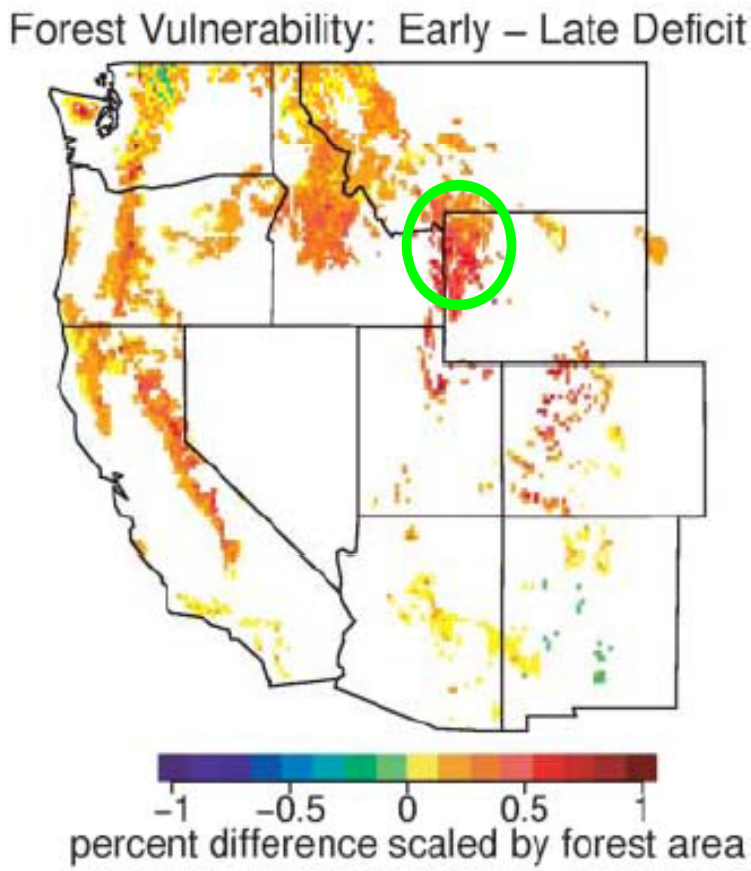
Serotinous

N-limited

Lodgepole pine ecosystems

Fire in Western U.S.

Mid-elevation forests in the Western US are expected to be vulnerable to more severe fires under climate change



Westerling et al., Science 2006

Mean fire return intervals =

192 ± 90 yrs at low elevations (<2300m)

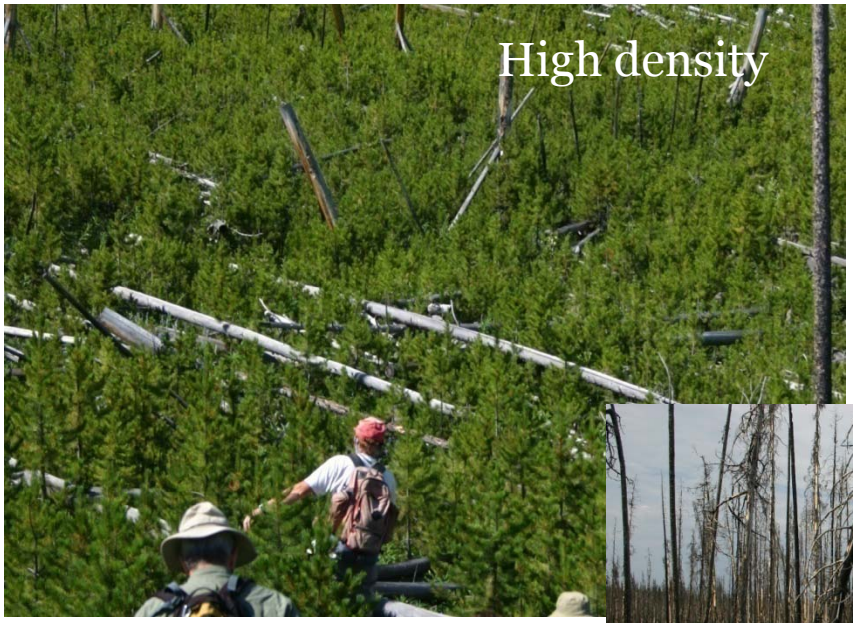
276 ± 87 yrs at high elevations (>2300m)

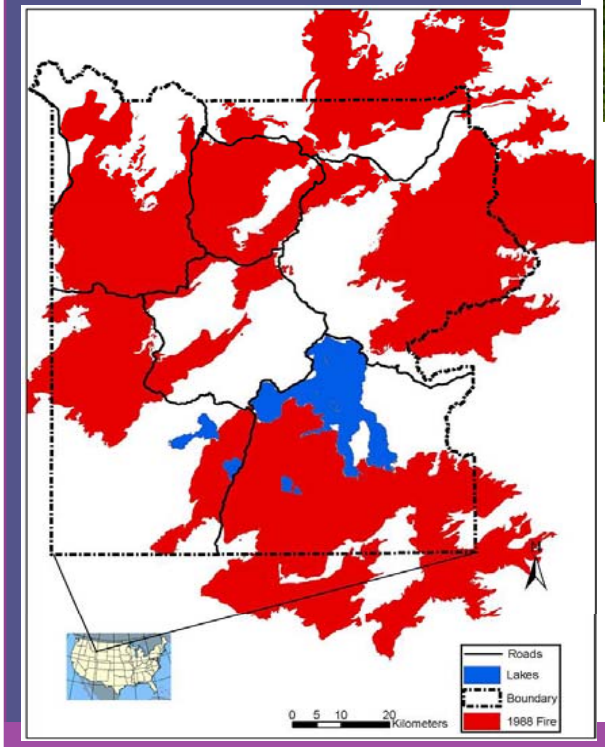
(Schoennagel et al. 2003, Ecology)

Severe canopy fire, Yellowstone NP

Picture from www.nps.gov

1988 Yellowstone Fires





Variation in post-fire stand density

Turner et al. 1994, 1997, 2003;
Kashian et al. 2004

Question 1

- (1) How do total ecosystem N stocks vary with stand age?
  - Hypothesis: Ecosystem N stocks would converge among stands of varying post-fire density by ~100 yrs
    - Models show a limited period following fire in which post-fire density affects C and N storage (Smithwick et al., available online, Global Change Biology; Kashian et al., 2006, Bioscience).

Question 2

- (2) How does inorganic soil N availability vary with stand age and density?
  - Hypothesis:
    - Age: ***increase*** with stand age (increases in forest floor stocks, Yermakov and Rothstein; or N fixation (Perez et al.) or ***decrease*** with stand age (increased N availability following fire, Turner et al. 2007)
    - Density: decrease with increasing density (Levitt 2006)

Study Design

- 5 age-classes
  - <25 yrs
  - 40-70 yrs
  - 80-130 yrs
  - 170-230 yrs
  - >250 yrs

- 5 density classes

<170 yrs	>170 yrs
o Low	oHistorical (70s-80s) beetle kill
o Moderate	o No historical beetle kill
o High	→ small variation in stand density

Total stands = 77
3 plots (10 x 50 m), separated by ~50 m
Total area = 6500 m^2 per stand

Methods

In situ resin bags

- Index of N availability
- 20 g cation/anion in nylon bags
- 58 new stands + data from 12 others

(Litton et al. 2004)

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EFFECTS OF TREE DENSITY AND STAND AGE ON CARBON ALLOCATION PATTERNS IN POSTFIRE LODGEPOLE PINE

Creighton M. Litton,[1,3] Michael G. Ryan,[2] and Dennis H. Knight[1]

Methods

Live Pools (n=77 stands)

- Live Pools =
  - Aboveground tree
    - bole + branch + foliage
  - Saplings
  - Coarse roots
  - Live fine roots
    - 0-15 and 15-30cm
- New allometrics (M.S. thesis, R. Arcano)
- Biomass reported in Kashian et al., in prep

Methods

Detrital and soil pools

- Detrital pools
  - Downed and standing
  - Stumps
  - Forest floor
  - Dead fine roots
    - 0-15cm and 15-30cm
  - Litterfall
- Soil
    - 0-15 and 15-30cm

Methods

Nitrogen concentrations

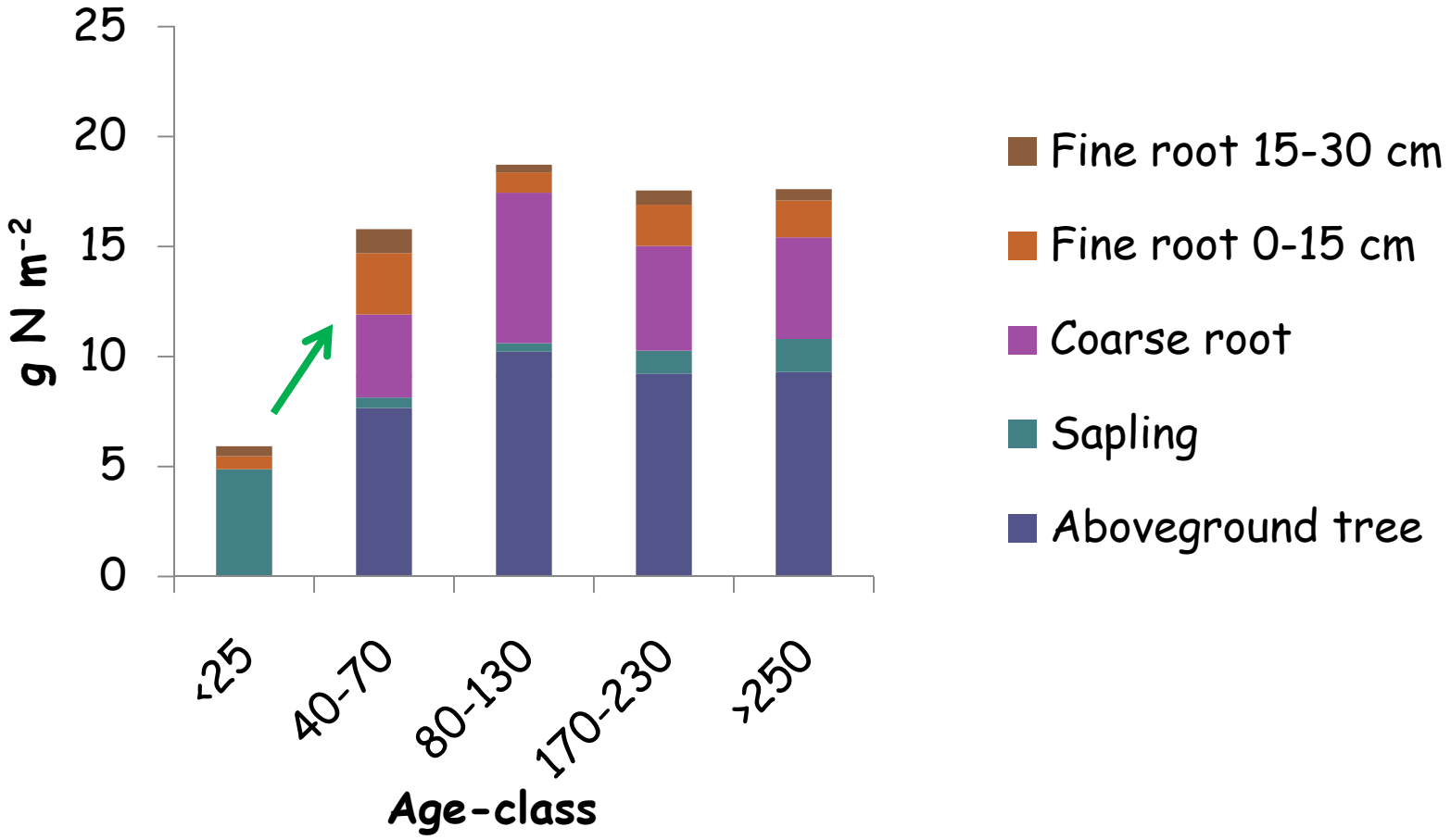
- Literature [N]
  - Downed wood class 1-2, standing wood (Fahey 1983)
  - Aboveground bole (Pearson et al. 1987)

- Measured [N]
  - Foliage composites (Kashian and Ryan, in prep)
  - Forest floor
  - Soil N
  - Downed wood class 3-5

RESULTS

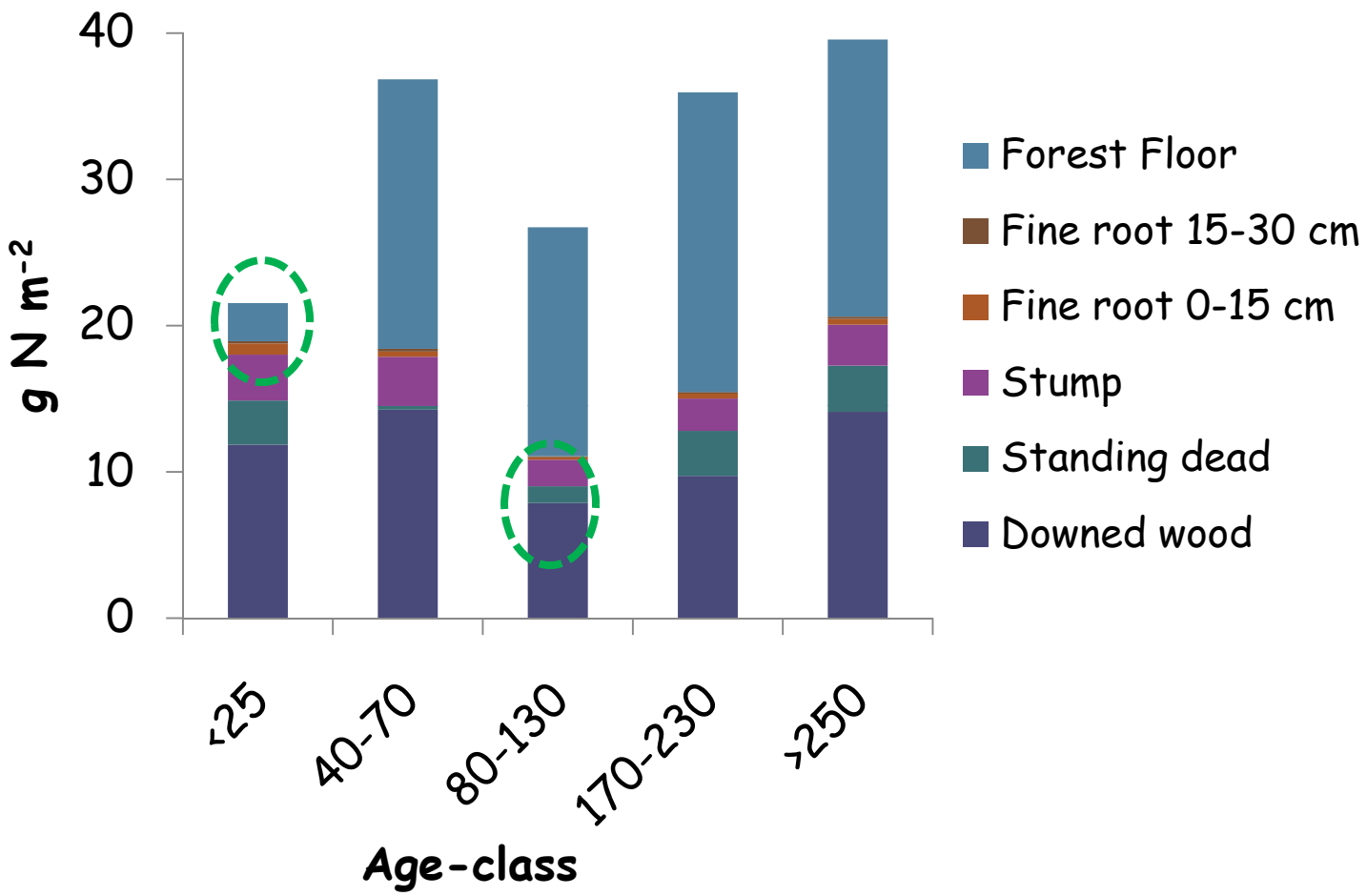
(1) HOW DO TOTAL ECOSYSTEM N STOCKS VARY WITH STAND AGE?

Live N stocks



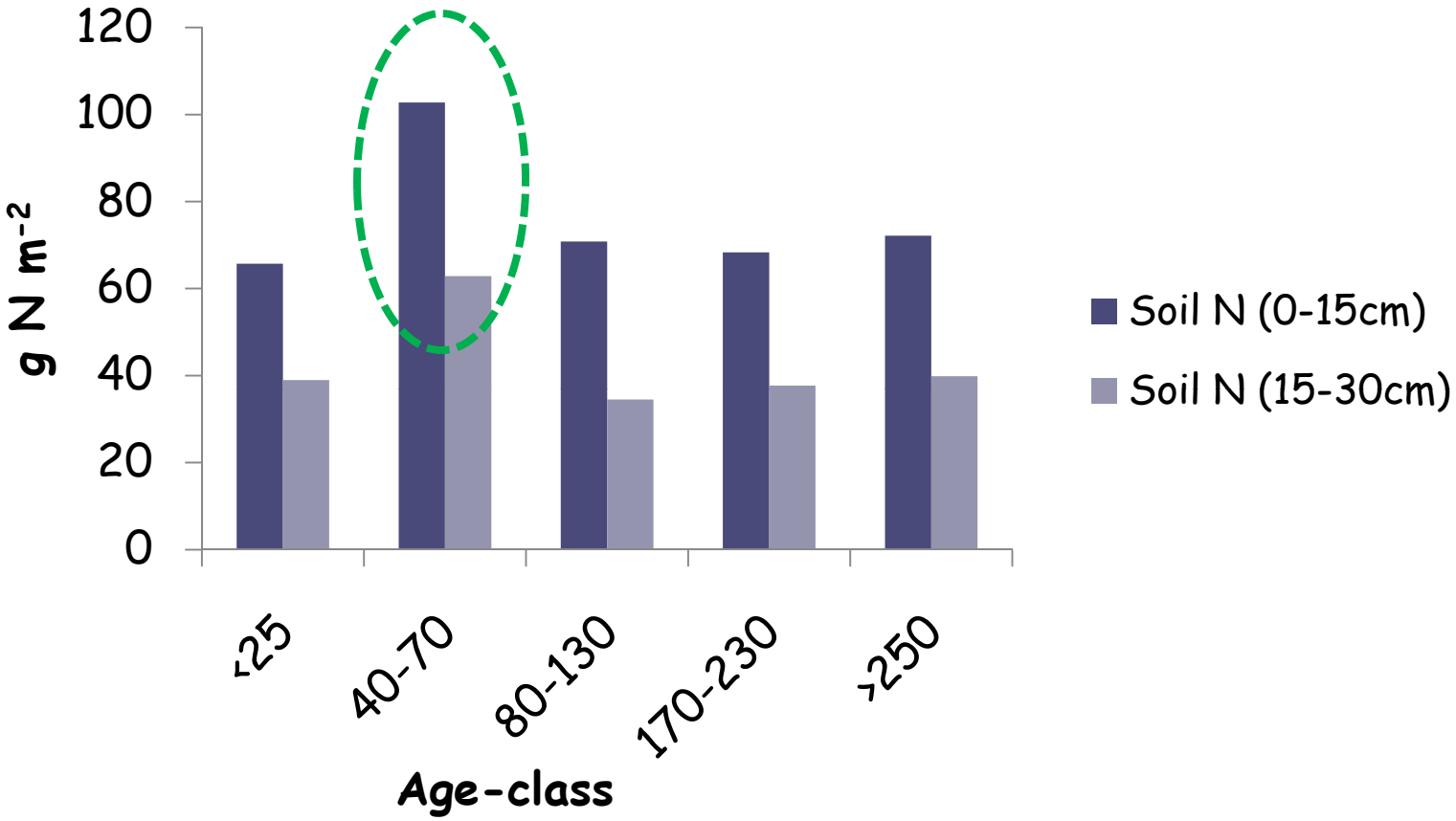
- Live N increased between <25 and 40-70 yr age-class
- Small % of total ecosystem N:
  Tree + saplings (5 -10%) **Coarse Roots** (3 – 7%) **FR** =(<3%)

Dead N



- Coarse wood N (stump+standing+downed) least in 80-130 yr class
- Forest floor N least in <25 yr age-class

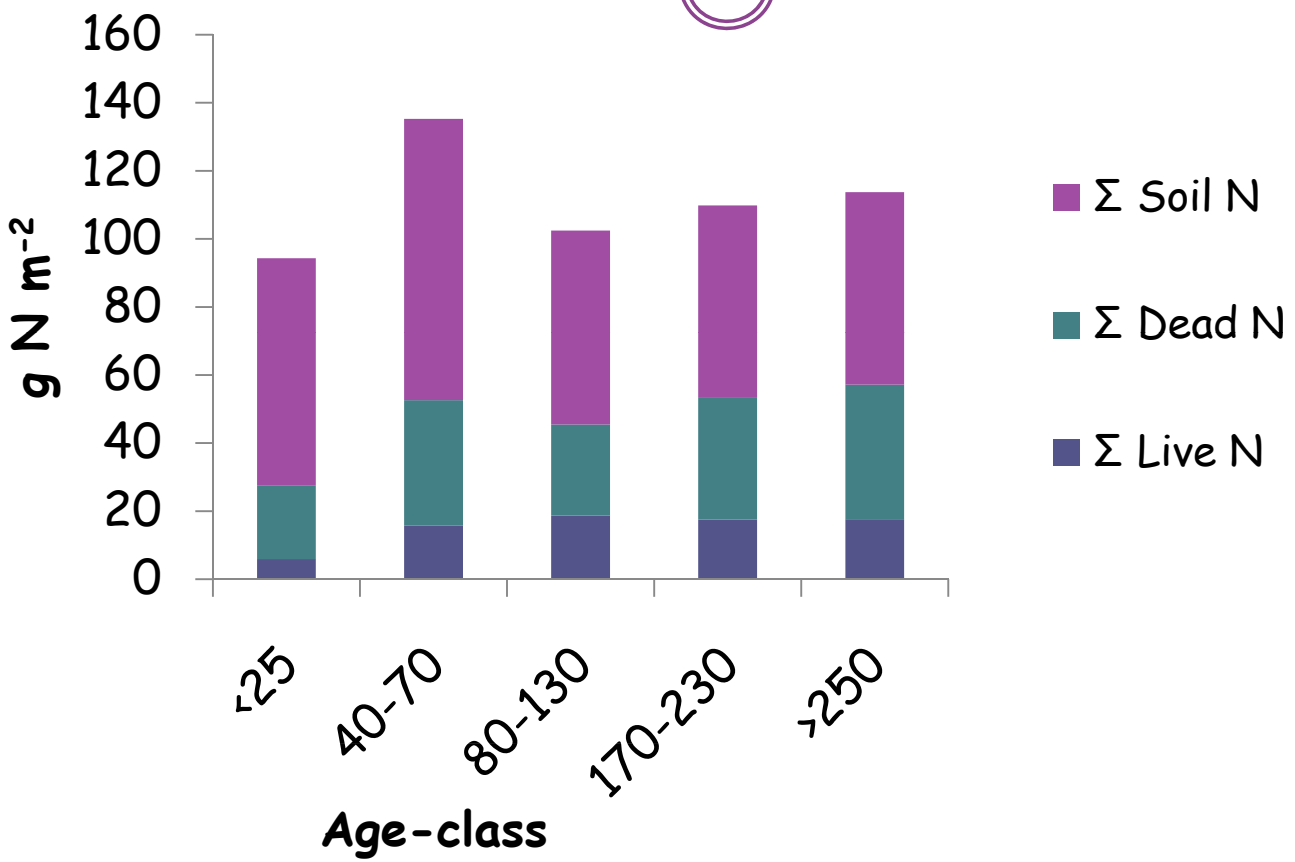
Soil N stocks



Average soil N (0-30) :

- As % of total ecosystem N: Soil N (50-71%)
- highest in 40-70 yr age-class

Total Ecosystem N



- Total stocks were similar with increasing stand age
- Soil N (50-71%) Dead N (23-35%) Live N (6-18%)

Result summary
(N stocks & stand age)

- Hypothesis: Ecosystem N stocks would converge among stands by ~100 yrs

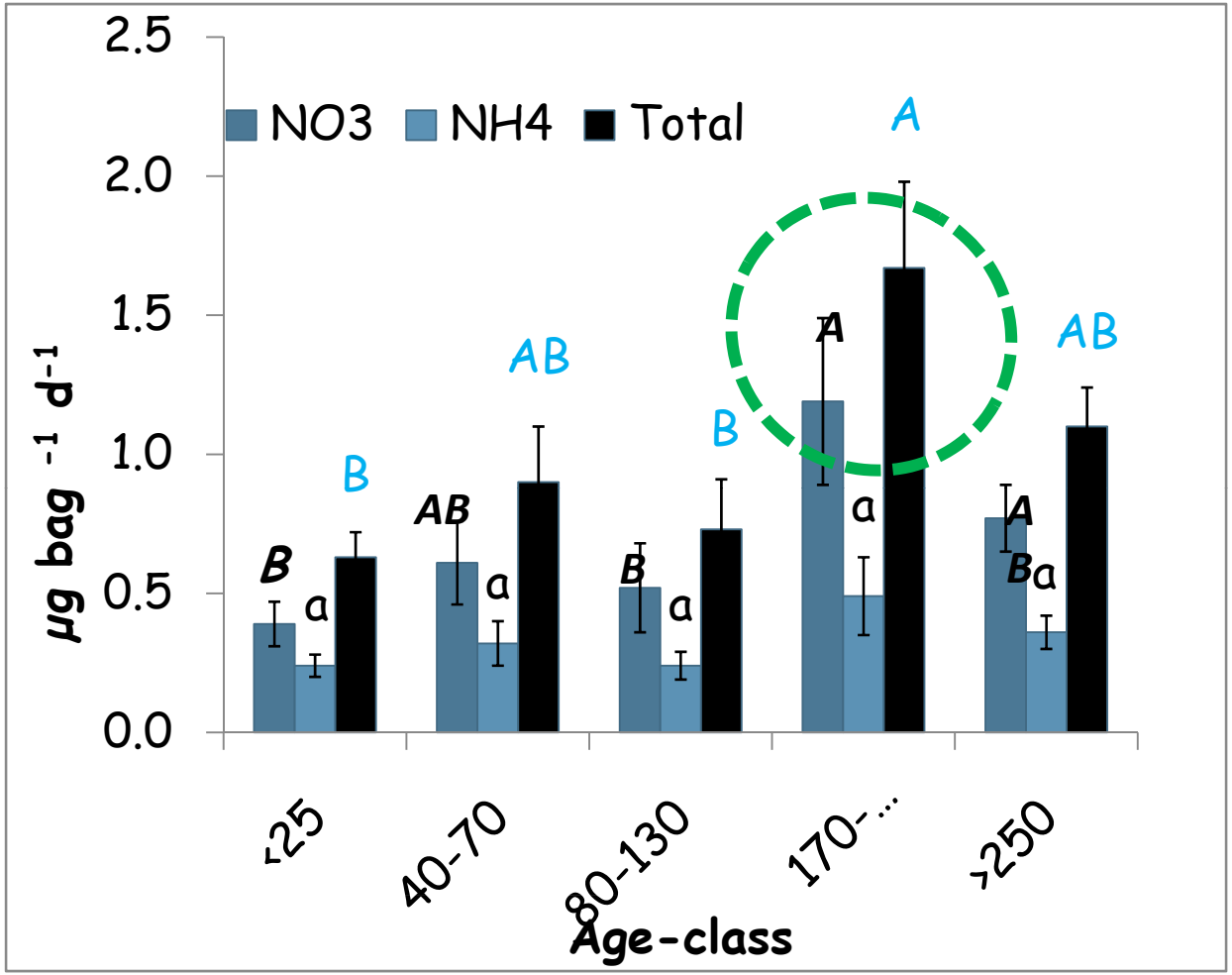
No – N stocks converged earlier, by 25-40 yrs

Results

(2) HOW DOES INORGANIC SOIL N AVAILABILITY VARY WITH STAND AGE AND DENSITY?

Total (NO_3^- +NH_4^+) and NO_3^- highest in 170-230 yr age-class – remained high

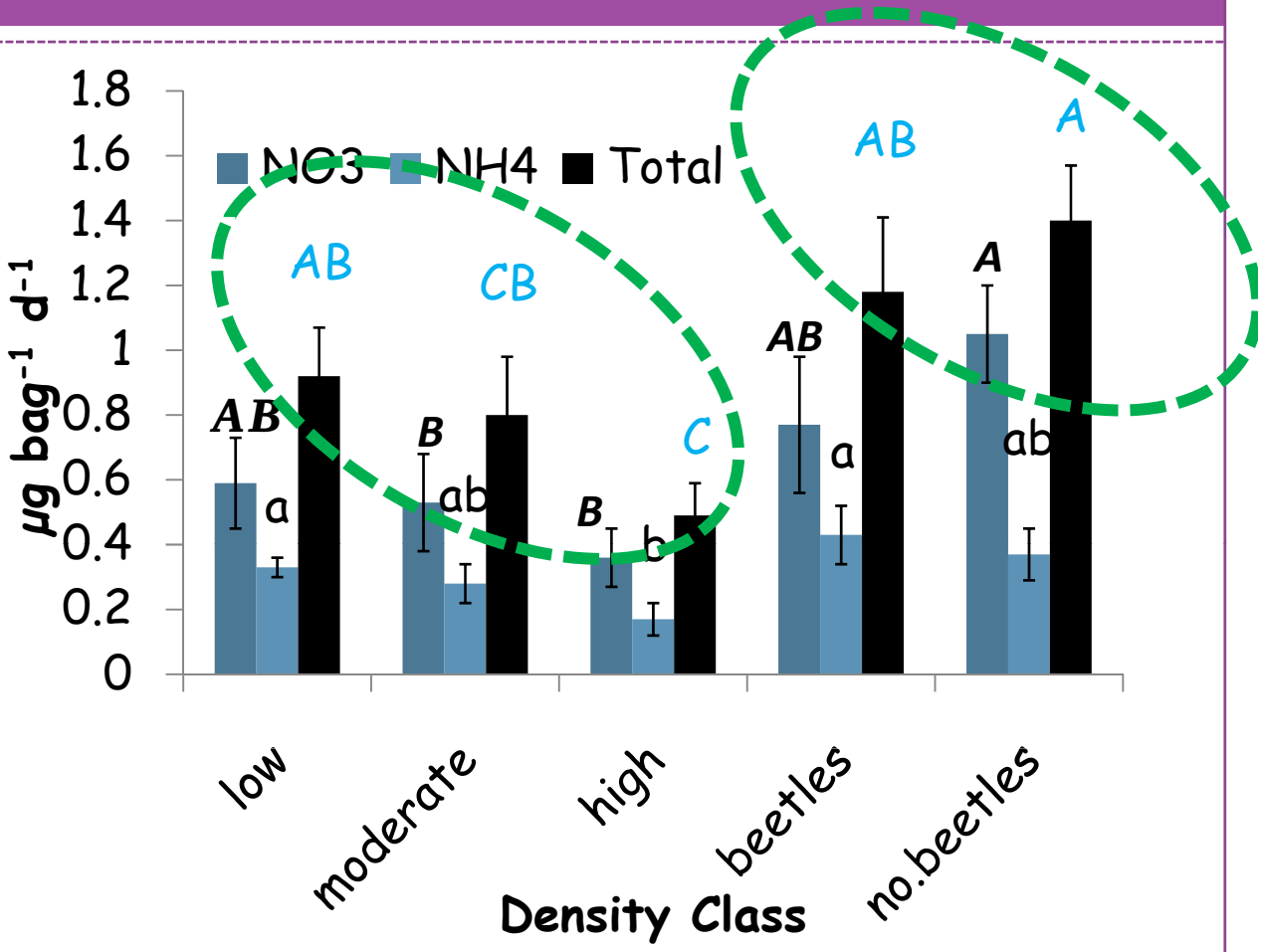
NH_4^+ did not vary with stand age



Resin N vs. Age-class

Resin N decreased with increased stand density

Not different for stands that varied in density due to historical beetle-kill



Resin N vs. Density class

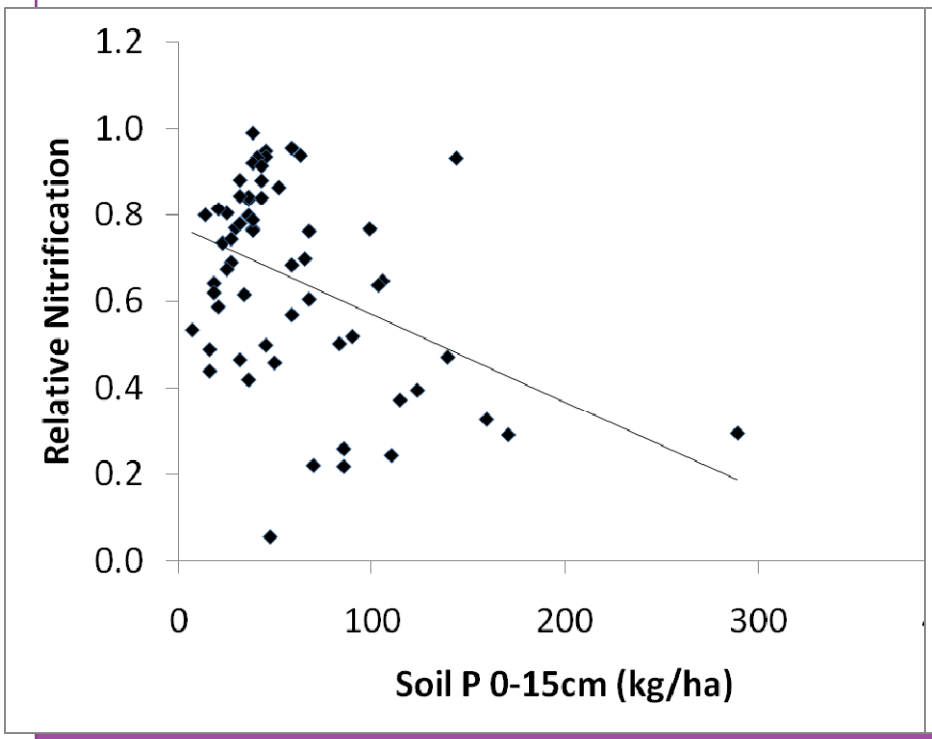
Model selection (AICc) to predict resin N

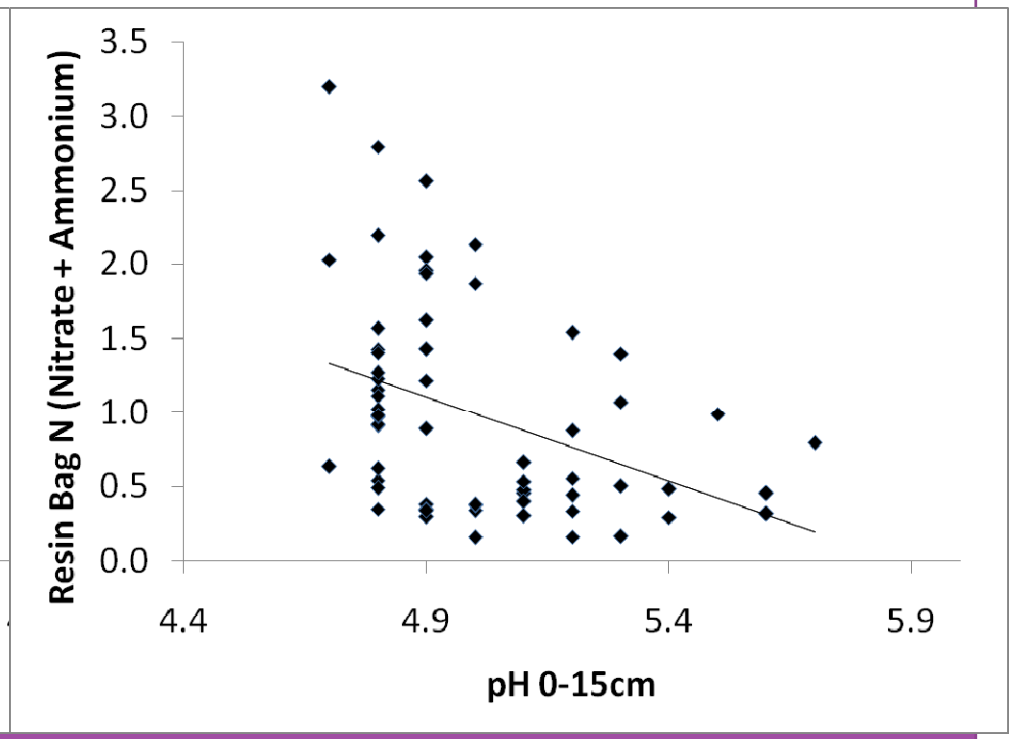
	K	Adj R^2	R^2	Variables	Δ_i	w_i
				All age-classes		
NH_4^+	5	0.17	0.22	**pH_{0-15}, pH_{15-30}**, bulk density	0	0.18
	4	0.13	0.16	**P_{0-15}**, bulk density	1.15	0.10
	5	0.14	0.19	Aboveground tree N, CoarseRoot N, bulk density	1.64	0.08
NO_3^-	5	0.35	0.39	Aboveground sapling N , **pH_{0-15}, P_{0-15}**	0	0.19
	5	0.34	0.38	Dead $FineRoot_{0-15}$, **pH_{0-15}, P_{0-15}**	0.60	0.14
	5	0.34	0.38	Litterfall N , **pH_{0-15}, P_{0-15}**	0.72	0.13
$NH_4^+ + NO_3^-$	5	0.35	0.39	Aboveground sapling N , Litterfall N , **pH_{0-15}**	0	0.27
Relative	5	0.36	0.40	**pH_{0-15}, pH_{15-30}, P_{0-15}**	0	0.14
NO_3^-	5	0.36	0.39	Forest floor N, **pH_{15-30}, P_{0-15}**	0.48	0.11
	5	0.35	0.39	**pH_{15-30}, P_{0-15}**, bulk density	0.67	0.10

Two-variable models (PROC GLM) explained between 10 and 23%

Relative nitrification negatively correlated with soil P $_{(0\text{-}15cm)}$ but not pH

Total resin N negatively correlated with soil pH $_{(0\text{-}15cm)}$ but not P





Results Summary
N availability with age & density

Hypothesis:

Age: ***increase*** with stand age (e.g., increases in forest floor stocks (Yermakov and Rothstein 2006) or N fixation (Perez et al.2004)) or ***decrease*** with stand age (increased N availability following fire, Turner et al. 2007)

Stand N availability did not decrease with stand age; in fact, was highest in 170-230 yr age-class

Density: decrease with increasing density (Levitt 2006; Litton et al. 2004)

Yes – N availability was lower among stands of higher tree density (<170 yrs) but there were few differences among small variations in stand density represented in older stands

Implications for understanding N limitations

EVIDENCE OF INCREASED N LIMITATIONS THROUGH STAND DEVELOPMENT?

LANDSCAPE CONTEXT?

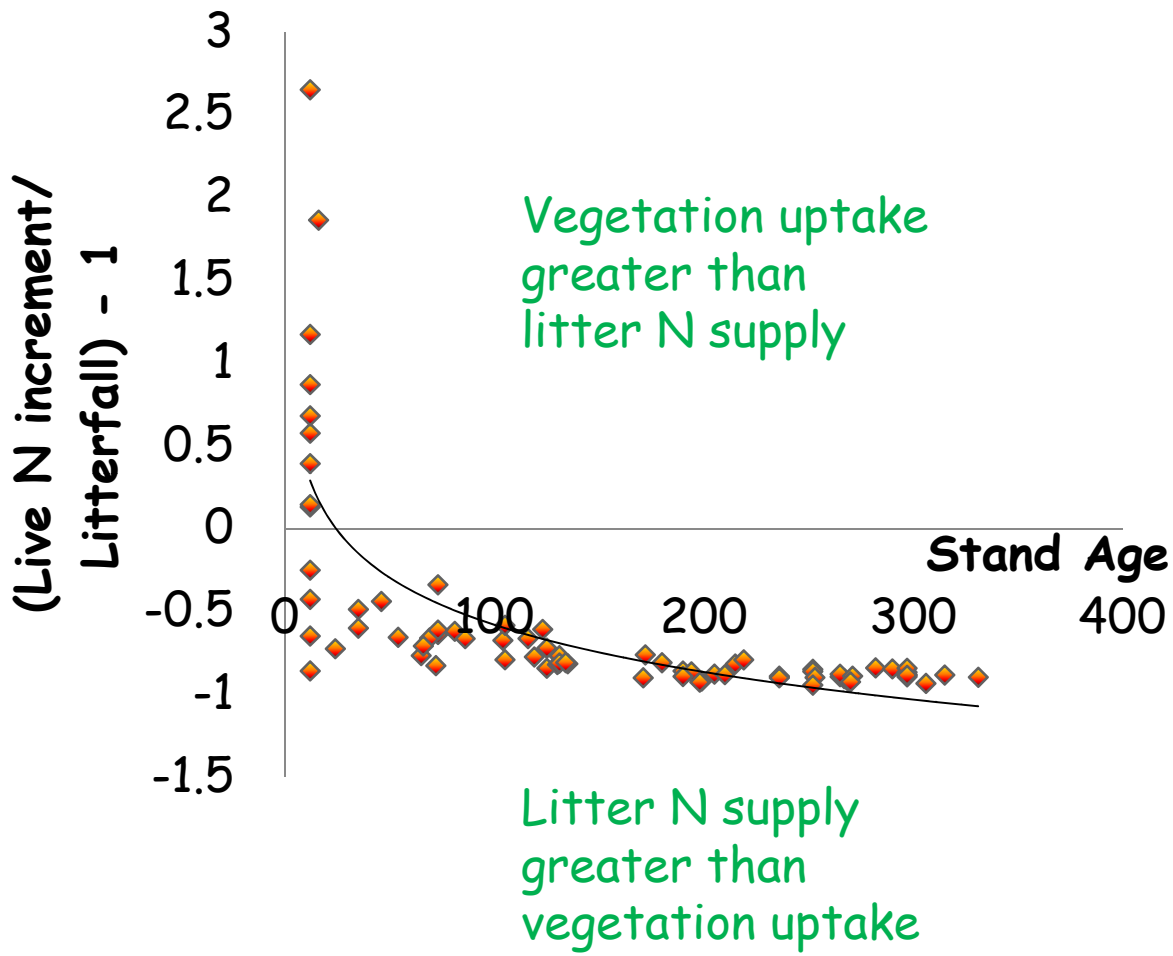
In young stands:

"mining" of soil N to meet demands?

great variability due to stand density

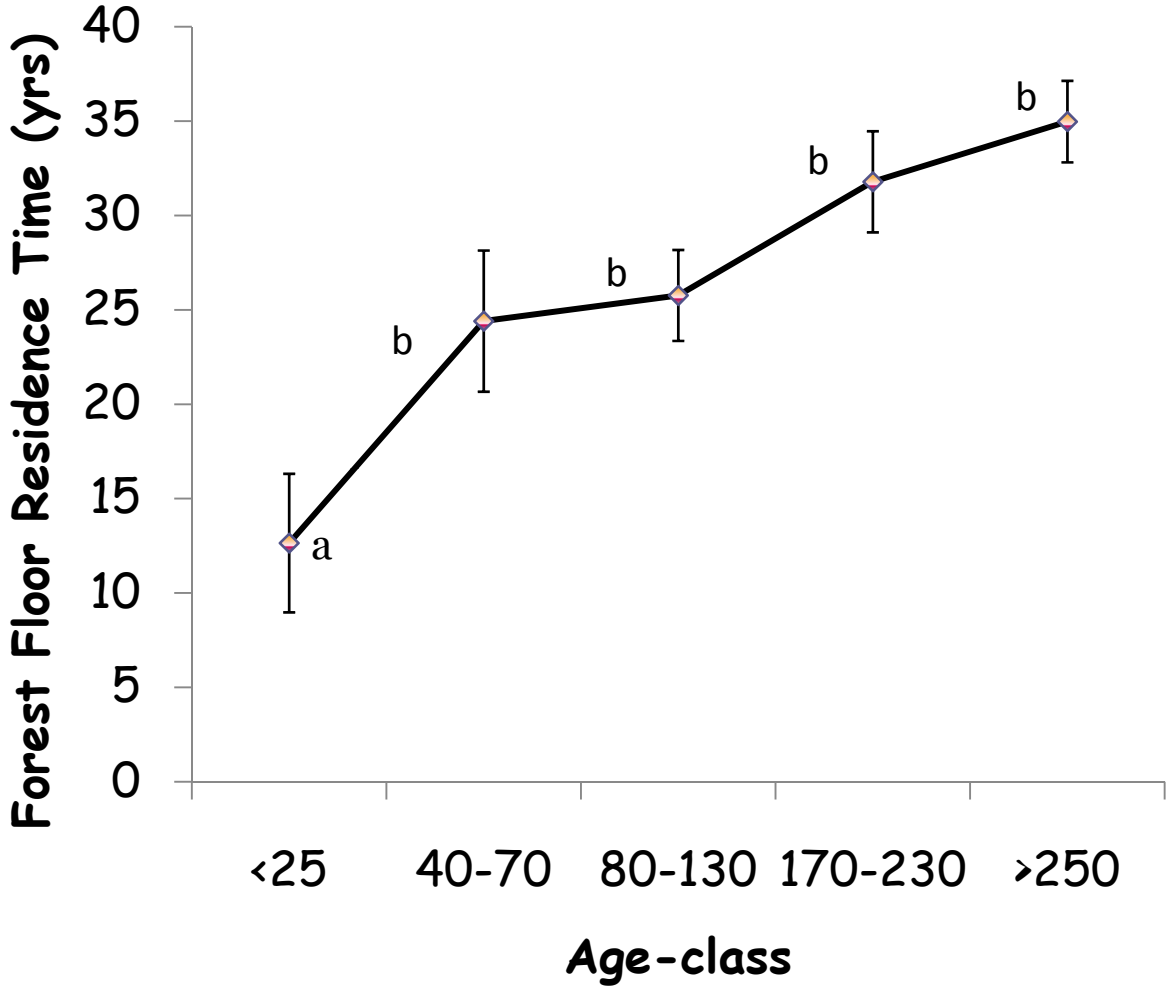
In old stands:

increased internal N cycling?



Live N increment = ∑live pools/stand age

Lower forest floor residence time in young stands



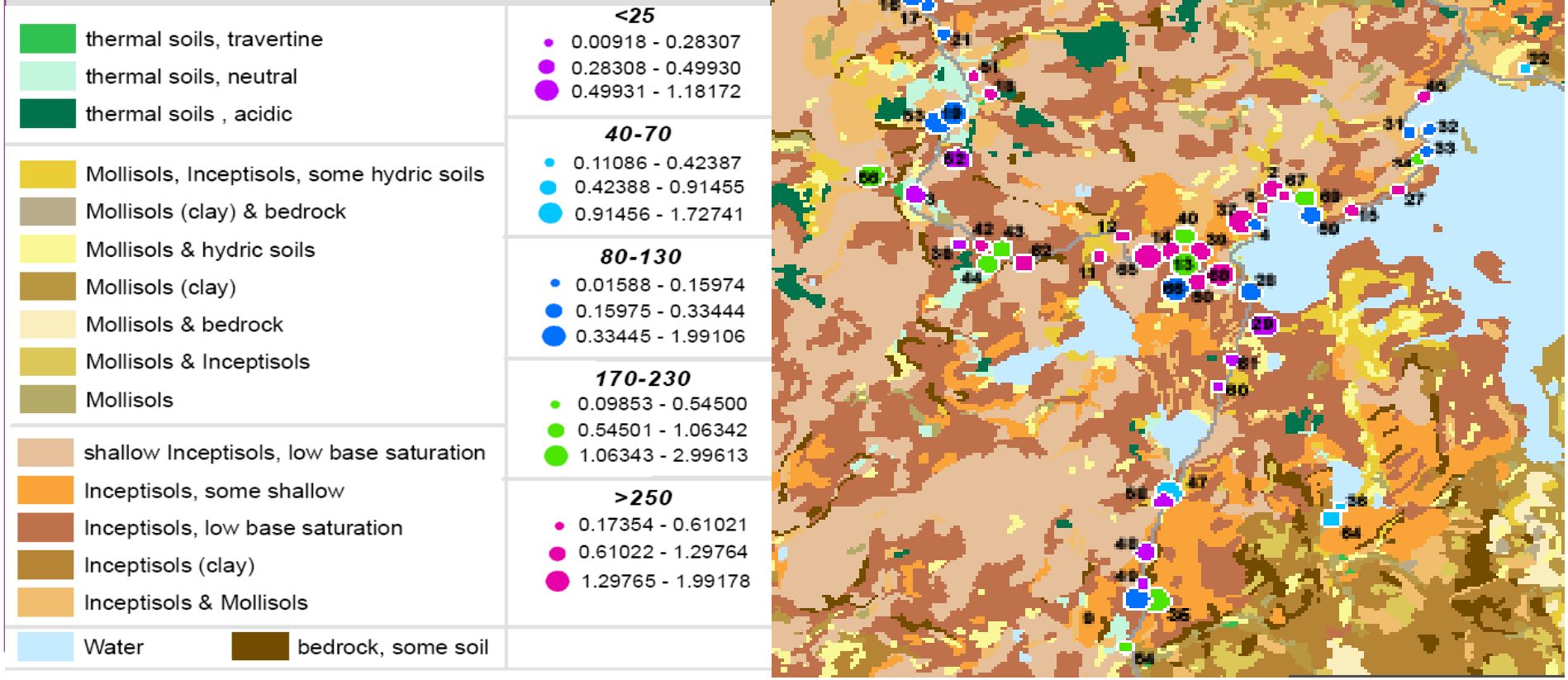
Forest floor N mass/Litterfall mass

Stand development & N limitations

- If N is increasing limited with stand age, inorganic N supply (resin bags) may not be good index
  - May not capture spatial variation in N supply
  - May not represent true tree N source (e.g., organic N)

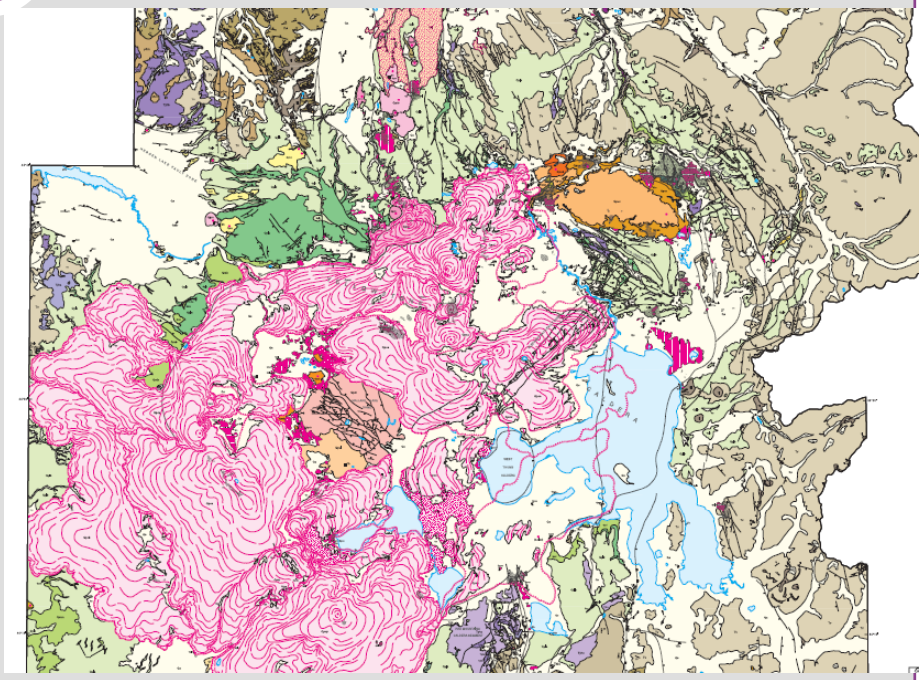
Landscape Context & N limitations

- Soils
  - pH and P consistently showed up in model selection results

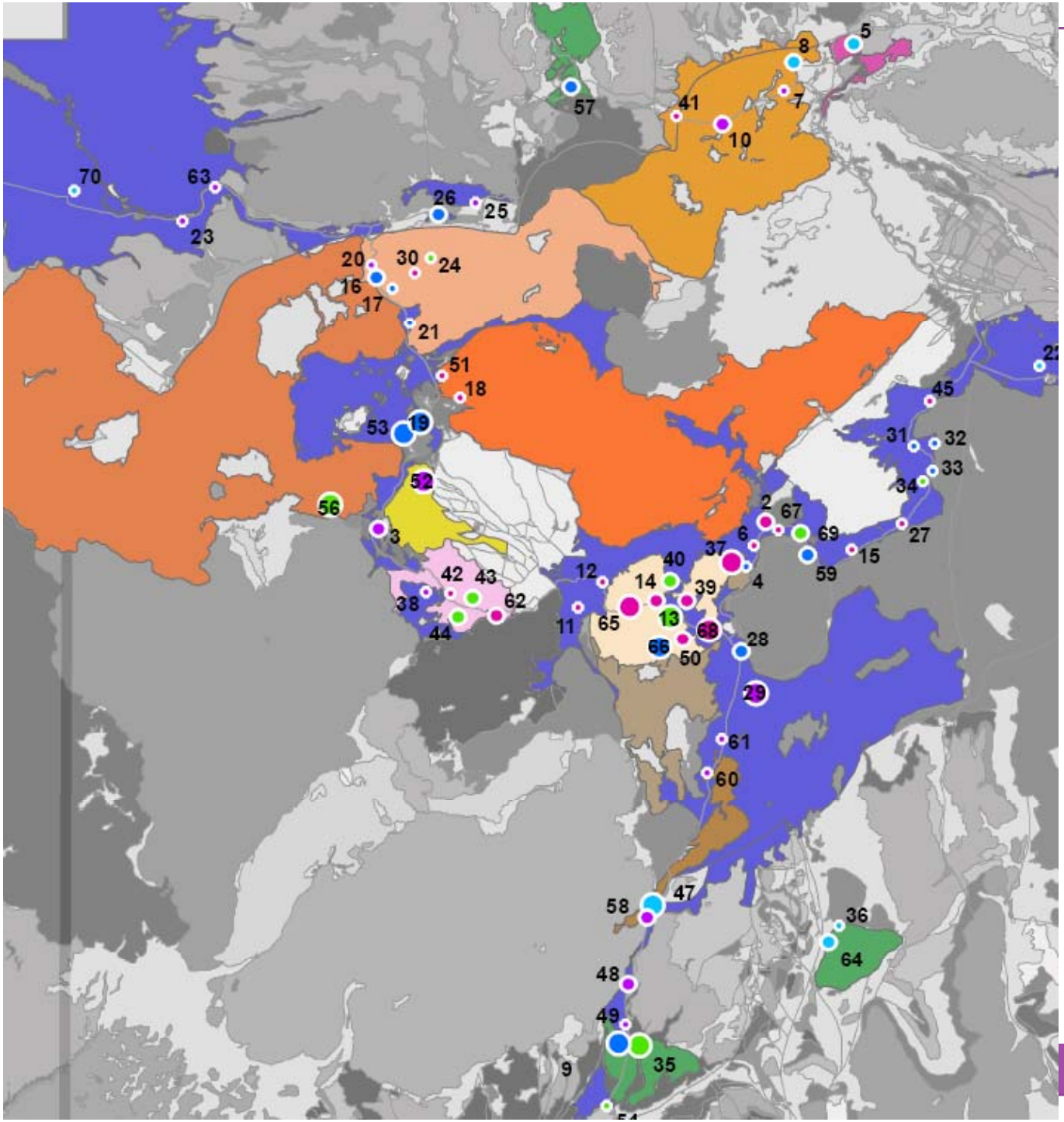


Landscape Context & N limitations

- Geology
  - N availability should increase during ecosystem development until ~20,000 yrs
  - P is present in mineral forms early, labile forms 20,000-150,000 yrs, and in more recalcitrant forms later



3rd stage of volcanic activity (1.2 Million to 0.1 Million ybp; youngest flows 71,000)



Geology: P Containing Site Points

- Qpca
- Qpcd
- Qpce
- Qpcf
- Qpcl
- Qpcn
- Qpcy
- Qpuc
- Qpul
- Qpm
- Qs
- Qylb

<25

- 0.00918 - 0.28307
- 0.28308 - 0.49930
- 0.49931 - 1.18172

40-70

- 0.11086 - 0.42387
- 0.42388 - 0.91455
- 0.91456 - 1.72741

80-130

- 0.01588 - 0.15974
- 0.15975 - 0.33444
- 0.33445 - 1.99106

170-230

- 0.09853 - 0.54500
- 0.54501 - 1.06342
- 1.06343 - 2.99613

>250

- 0.17354 - 0.61021
- 0.61022 - 1.29764
- 1.29765 - 1.99178

Implications for wildfire- N interactions

- Recovery of N combusted from severe stand-replacing fire is quickly recovered (within 25 yrs)

- Changes to fire frequency would thus need to be dramatic to have significant affect on long term N storage

	Expected mean fire return interval (Schoennagel et al. 2004)	Need to increase fire frequency… to see long term change in N
Low elevation	135-185	=5 to 7 times
High elevation	280-310	=11 to 12 times

Acknowledgements

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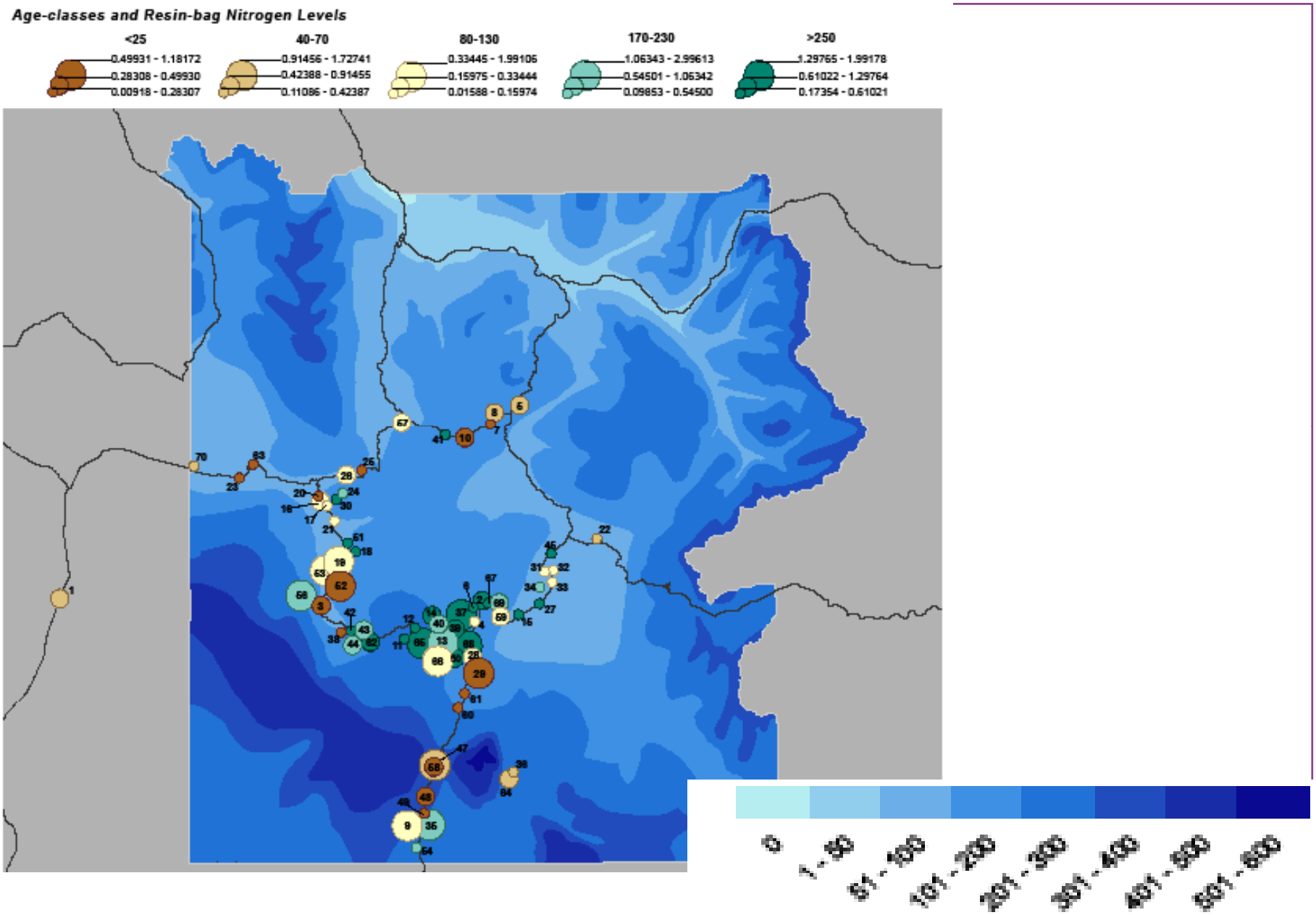
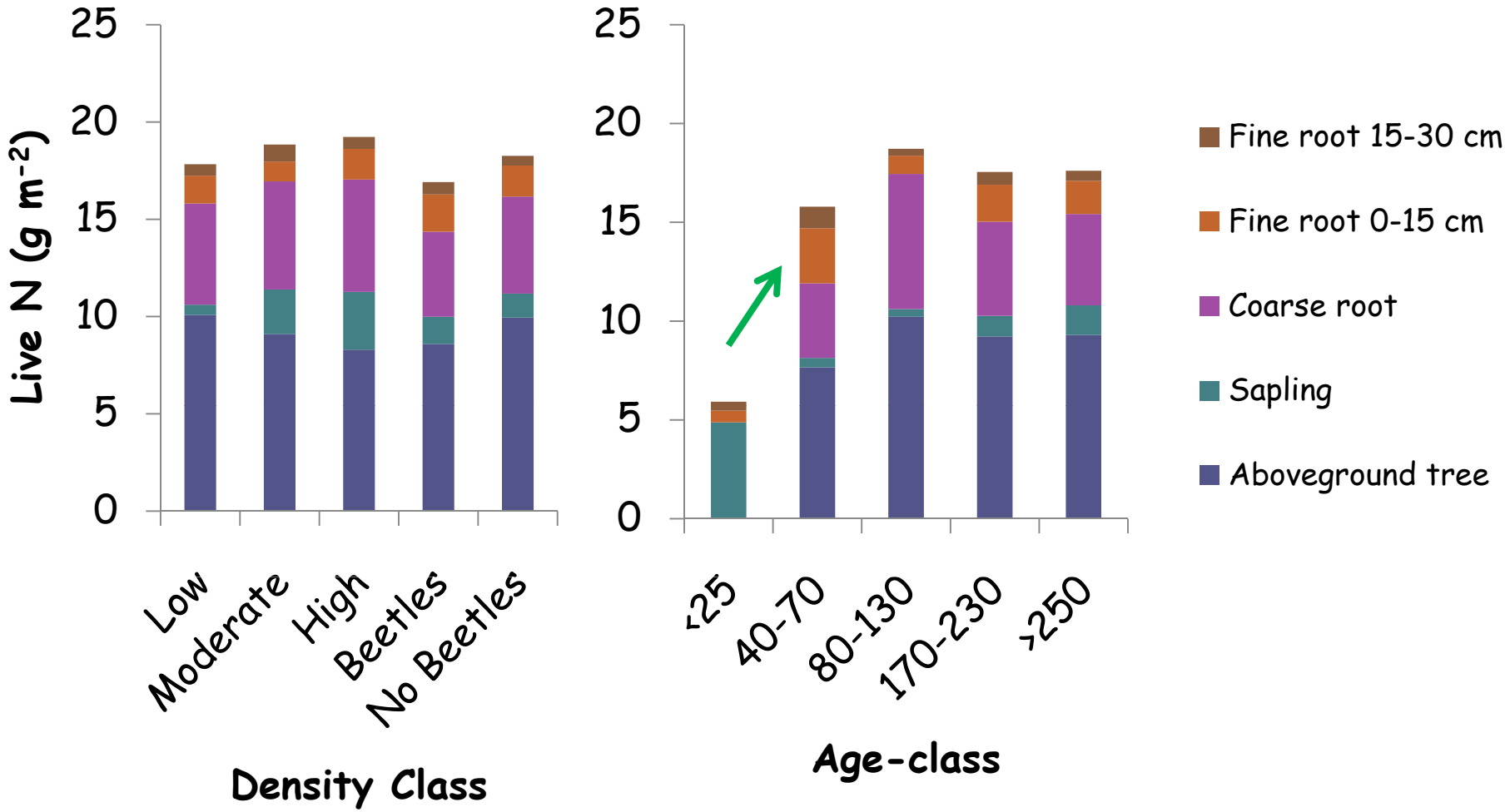

Age-classes and Resin-bag Nitrogen Levels
<25
0.49931 - 1.18172
0.28308 - 0.49930
0.00918 - 0.28307
40-70
0.91456 - 1.72741
0.42388 - 0.91455
0.11086 - 0.42387
80-130
0.33445 - 1.99106
0.15975 - 0.33444
0.01588 - 0.15974
170-230
1.06343 - 2.99613
0.54501 - 1.06342
0.09853 - 0.54500
>250
1.29765 - 1.99178
0.61022 - 1.29764
0.17354 - 0.61021
0
1 - 50
51 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600

		Partial R^2	Model R^2	p
NH_4^+	**-pH_{0-15}**	**0.08, p=0.028**	0.10	0.05
	-P_{0-15}	0.02, p=0.270		
NO_3^-	**-pH_{0-15}**	**0.11, p =0.006**	0.23	0.0005
	-P_{0-15}	**0.12, p =0.003**		
NH_4^++ NO_3^-	**-pH_{0-15}**	**0.16, p =0.001**	0.19	0.0018
	-P_{0-15}	0.04, p= 0.114		
Relative NO_3^-	-pH_{0-15}	0.001, p =0.750	0.21	0.0008
	-P_{0-15}	**0.21, p=0.0002**		

Pool		<25	40-70	80-130	170-230	>250
Live N	Aboveground tree	na	7.66 (0.68)a	10.22 (5.64)a	9.22 (0.92)a	9.30 (0.79)a
	Sapling	4.88 (1.14)a	0.48 (0.14)b	0.39 (0.10)b	1.05 (0.16)b	1.50 (0.29)b
	Coarse root	na	3.77 (0.45)b	6.84 (0.34)a	4.76 (0.34)b	4.62 (0.37)b
	Fine root $_{0\text{-}15\ cm}$	0.59 (0.30)d	2.79 (0.34)a	0.92 (0.14)cd	1.87 (0.19)b	1.68 (0.14)bc
	Fine root $_{15\text{-}30\ cm}$	0.45 (0.16)ab	1.09 (0.25)a	0.35 (0.06)b	0.65 (0.07)ab	0.51 (0.05)ab
	ΣLive N	**5.9**	**15.8**	**18.7**	**17.6**	**17.6**
Dead N	Downed wood	11.87 (0.99)a	14.25 (4.03)a	7.87 (1.51)a	9.73 (0.97)a	14.11 (1.29)a
	Standing dead	3.01 (0.89)a	0.26 (0.08)b	1.15 (0.19)ab	3.08 (0.52)a	3.16 (0.47)a
	Stump	3.14 (0.32)ab	3.36 (0.68)a	1.81 (0.31)b	2.21 (0.28)ab	2.79 (0.23)ab
	Fine root $_{0\text{-}15\ cm}$	0.76 (0.41)a	0.36 (0.07)b	0.17 (0.05)b	0.33 (0.07)b	0.40 (0.07)ab
	Fine root $_{15\text{-}30\ cm}$	0.16 (0.04)a	0.18 (0.04)a	0.07 (0.02)a	0.11 (0.02)a	0.16 (0.03)a
	Forest Floor	2.60 (0.96)b	18.43 (2.36)a	15.66 (0.80)a	20.49 (1.76)a	18.94 (1.30)a
	ΣDead N	**21.5**	**36.8**	**26.73**	**35.95**	**39.56**
Soil N	**Soil N (0-30 cm)**	**66.84 (3.31)b**	**82.66 (7.89)a**	**57.02 (4.20)b**	**56.33 (4.19)b**	**56.58 (3.39)b**
	Σ Ecosystem	**94.3**	**135.3**	**102.5**	**109.8**	**113.8**
Litterfall N		0.26 (0.05)c	0.87 (0.11)a	0.66 (0.04)ab	0.66 (0.04)ab	0.61 (0.05)b
Forest Floor Residence Time (yrs)		12.65 (3.67)b	24.41 (3.74)a	25.77 (2.41)a	31.79(2.68)a	34.98(2.16)a

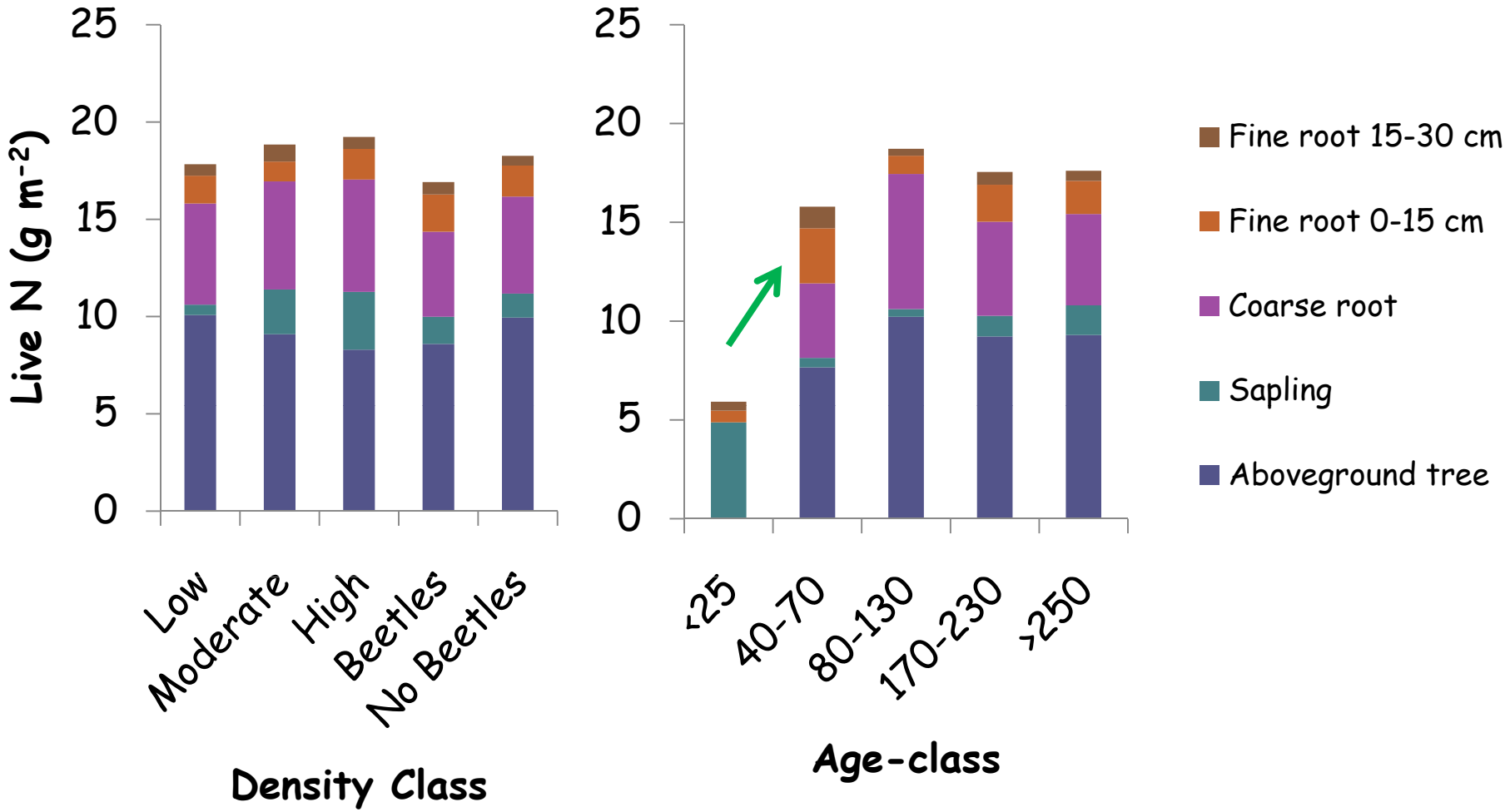
Pool		Low	Moderate	High	Beetles	No Beetles
Live N	Aboveground tree	10.08 (1.30)a	9.09 (0.55)a	8.30 (0.86)a	8.59 (0.87)a	9.95 (0.79)a
	Sapling	0.53 (0.11)c	2.30 (1.00)ab	2.97 (1.02)a	1.40 (0.21)bc	1.23 (0.31)bc
	Coarse root	5.20 (0.72)a	5.56 (0.62)a	5.77 (0.80)a	4.37 (0.36)a	4.99 (0.35)a
	Fine root $_{0\text{-}15\ cm}$	1.43 (0.43)ab	1.02 (0.26)b	1.58 (0.39)ab	1.92 (0.16)a	1.59 (0.15)ab
	Fine root $_{15\text{-}30\ cm}$	0.59 (0.17)a	0.87 (0.35)a	0.61 (0.13)a	0.63 (0.06)a	0.50 (0.06)a
	ΣLive N	**17.8**	**18.8**	**19.2**	**16.9**	**18.26**
Dead N	Downed wood	11.38 (1.64)a	13.13 (2.86)a	8.35 (1.8)a	13.75 (1.58)a	10.86 (0.89)a
	Standing dead	1.37 (0.51)b	2.11 (0.80)ab	1.09 (0.38)b	2.75 (0.46)ab	3.50 (0.51)a
	Stump	2.64 (0.347)a	2.75 (0.38)a	2.73 (0.63)a	2.73 (0.24)a	2.38 (0.28)a
	Fine root $_{0\text{-}15\ cm}$	1.43 (0.43)a	0.41 (0.16)a	0.35 (0.09)a	0.40 (0.07)a	0.33 (0.08)a
	Fine root $_{15\text{-}30\ cm}$	0.59 (0.17)a	0.13 (0.04)a	0.11 (0.03)a	0.15 (0.03)a	0.13 (0.02)a
	Forest Floor	11.56 (3.16)c	12.37 (2.08)bc	11.60 (1.69)c	21.38 (1.43)a	17.78 (1.43)ab
	ΣDead N	**29.0**	**30.9**	**24.2**	**41.2**	**35.0**
Soil N	**ΣSoil N**	**76.99 (7.30)**a	64.17 (3.18)ab	63.31 (6.03)ab	60.51 (3.50)ab	52.45 (3.67)b
	ΣEcosystem	**123.8**	**113.9**	**106.8**	**118.6**	**105.7**

Live N stocks



- Live N increased between <25 and 40-70 age-class
- As % of total ecosystem N: **Tree + saplings** (5.2 -10.4%)
  Coarse Roots (2.8 – 6.7)
  FR =(<3%)

Live N stocks

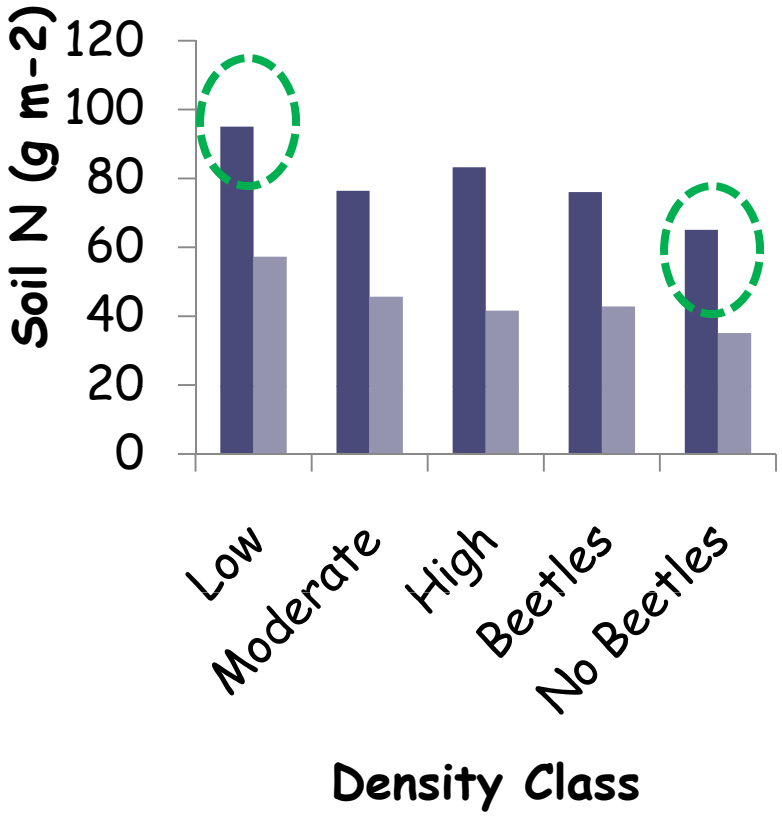


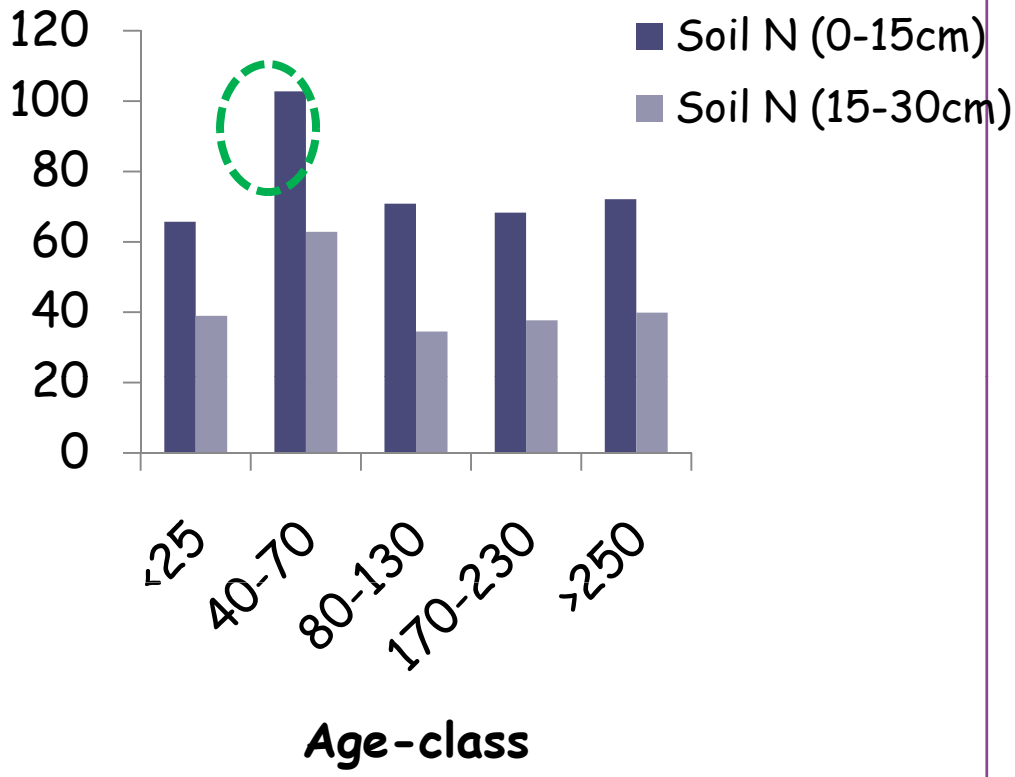
- Live N increased between <25 and 40-70 age-class
- As % of total ecosystem N: **Tree + saplings** (5.2 -10.4%)
  Coarse Roots (2.8 – 6.7)
  FR =(<3%)

Dead N

- Decreased with increasing stand density
- Coarse wood N (stump+standing+downed) least in intermediate class
- Forest floor N least in <25 yr age-class

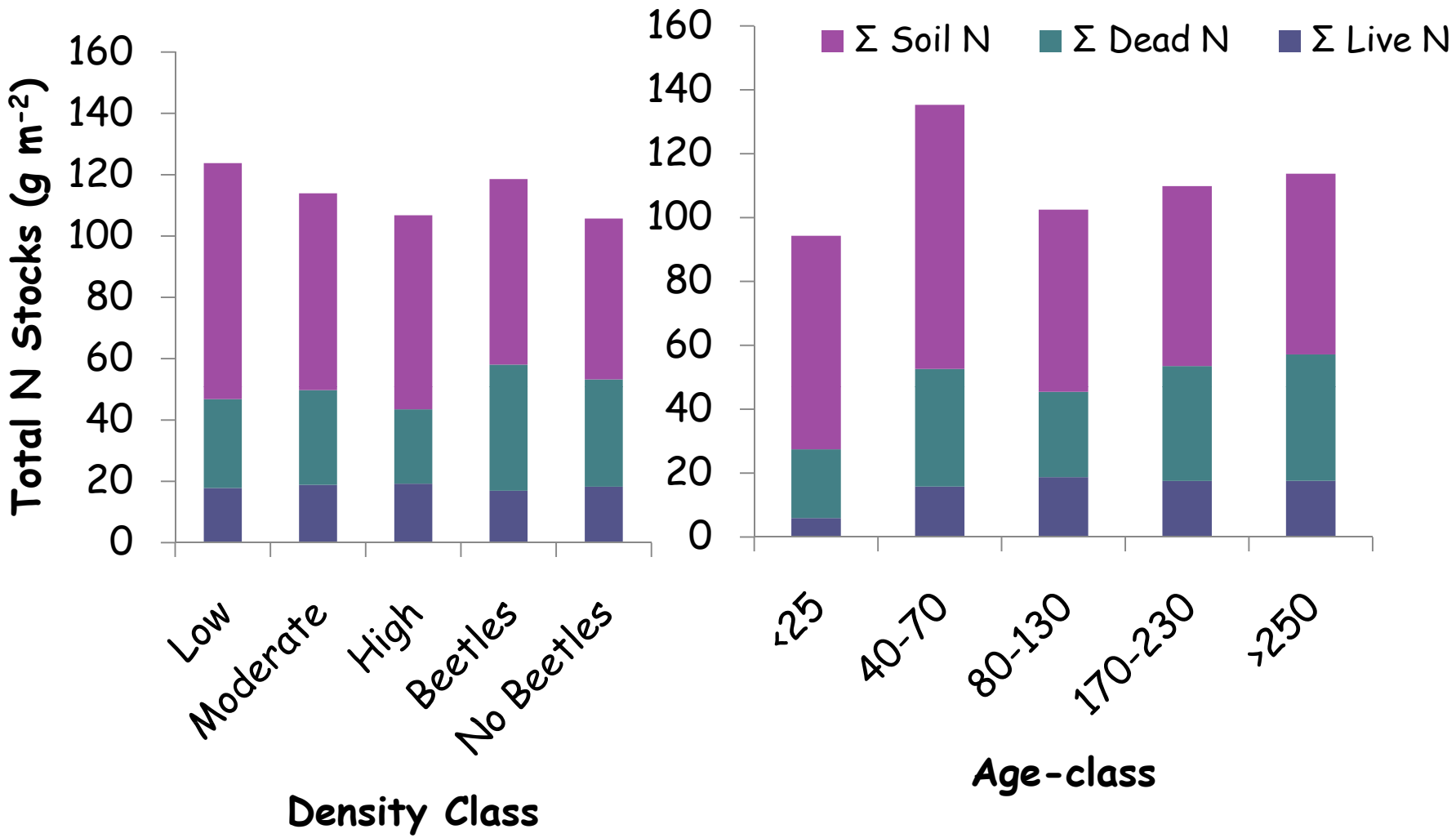
Soil N stocks





Average soil N (0-30) :

- Soil N (50-71%)
- higher in low vs. no.beetles
- highest in 40-70 yr age-class



- Total stocks were not different among age or density classes
  - Soil N (50-71%) Dead N (23-35%) Live N (6-18%)