Forest productivity, feedstock removals, and implications for nutrient flux and sustainability

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Productivity tasks

- Task SM-SP-4.2. Estimate nutrient and carbon removals and retention under various levels of biomass harvesting

- Task SM-SP-4.3. Determine sustainable levels of bioenergy feedstock under range of silvicultural intensities

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Productivity tasks

- Estimate nutrient and carbon removals and retention under various levels of biomass harvesting
  - Biomass equations & nutrient concentrations
  - Retention and removals during felling and yarding
  - Implications for nutrient retention and removal
- Determine sustainable levels of bioenergy feedstock under range of silvicultural intensities
  - Variation in biomass distribution by silvicultural regime
  - Variation in biomass and nutrient removals by regime and logging systems

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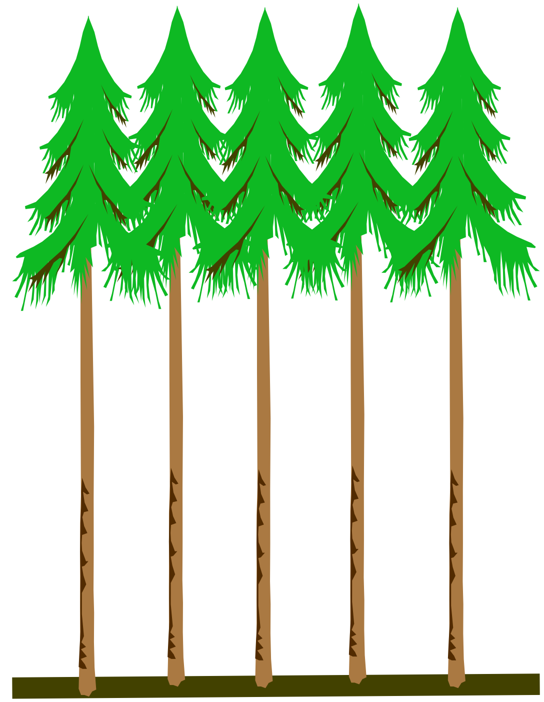
Biomass Sampling

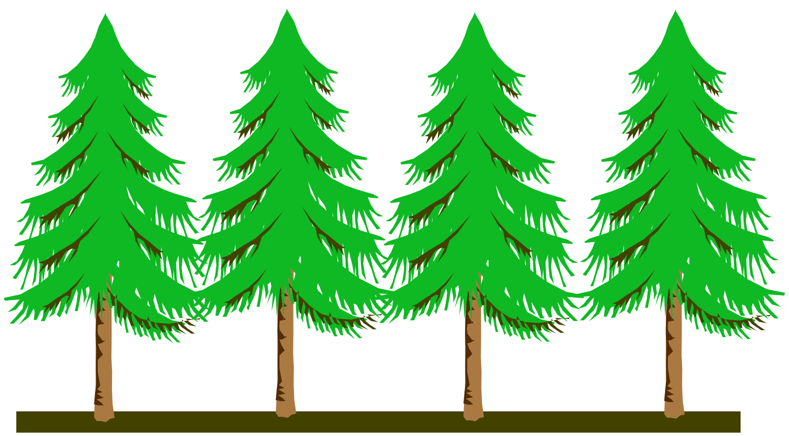
$BIOMASS = \beta_1 DBH^{\beta_2}$?

Not consistent across differing management regimes.

Close spacing



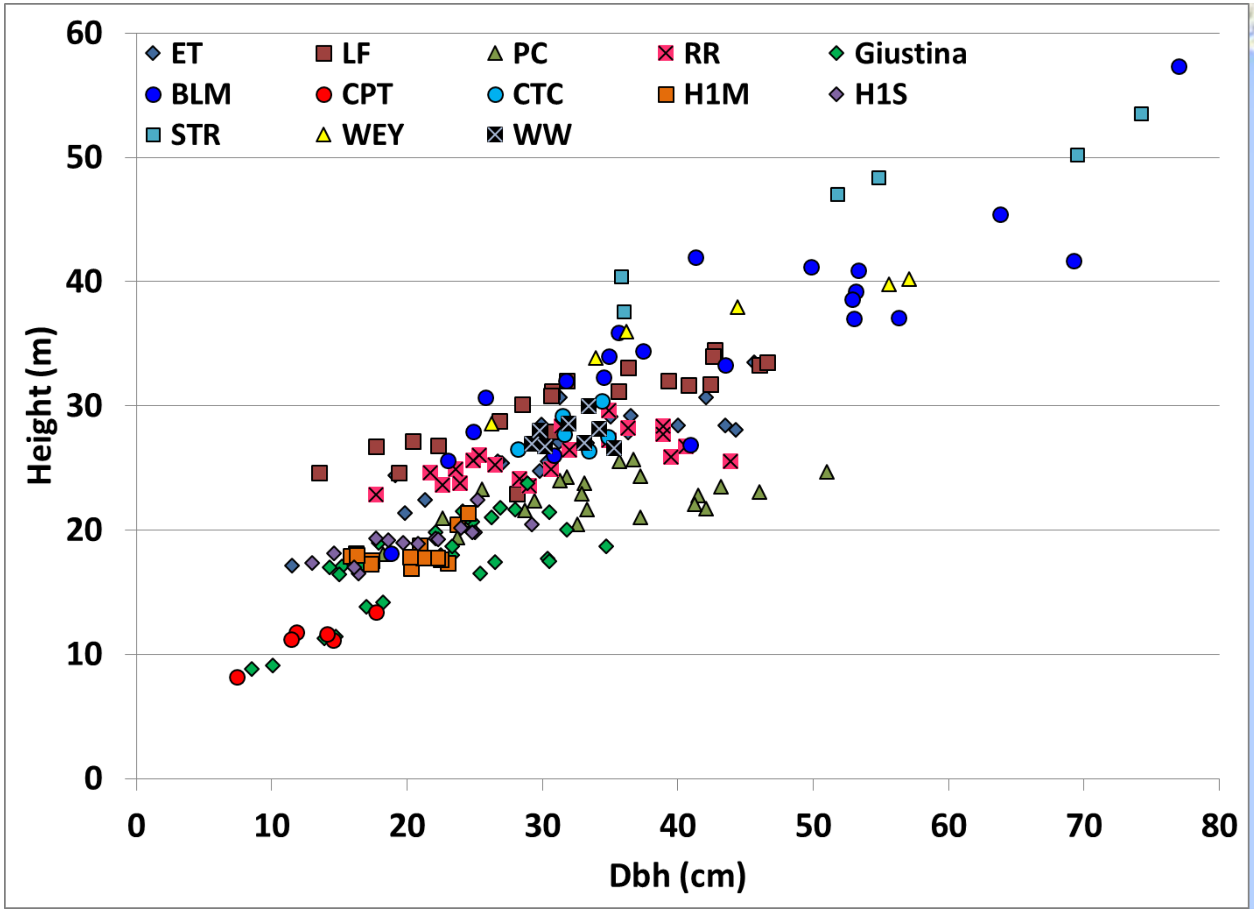
Wide spacing

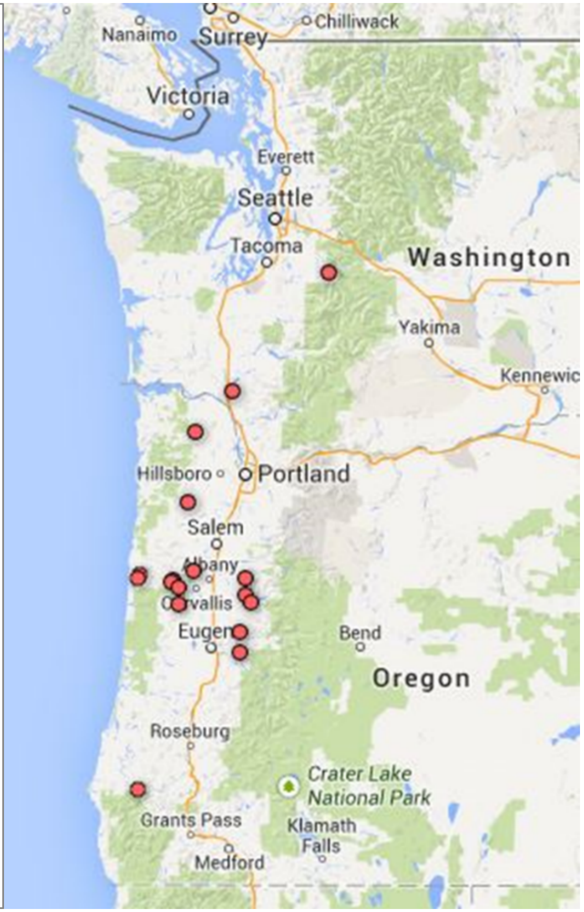


Same diameter but very different stem and crown biomass of individual trees: Have to account for diameter AND height.

Biomass Sampling

Bivariate range in diameter and height!!





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Biomass Sampling

- Sampled stands and trees
  - Westside Douglas-fir stands, Oregon and Washington
  - Total of 200 trees from 23 sites
  - Age ranged from 12-90 years
  - Included planted and natural stands
  - Included stands subject to intensive competing vegetation control, stand density manipulations, and nitrogen fertilization

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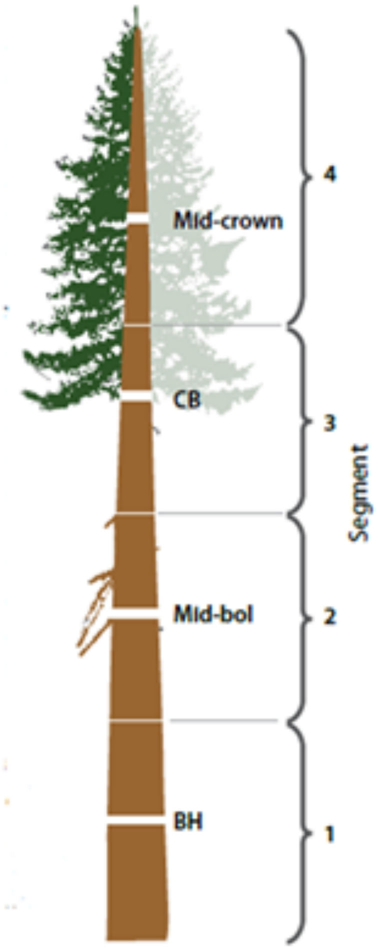
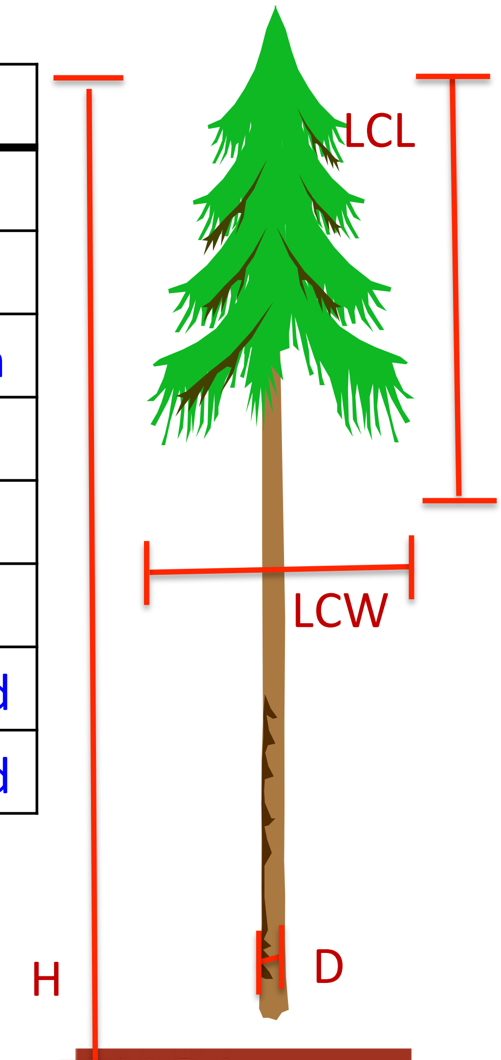
Biomass Sampling

- Biomass components
  - Foliage (1, 2, 3+ yr old)
  - Live branchwood (wood + bark)
  - Dead branchwood (wood + bark)
  - Stem bark
  - Sapwood
  - Heartwood



Biomass equations

Biomass component	Predictors
Foliage	Live crown length and width
Live branches	Live crown width and % foliage
Dead branches	Diameter, height, clear bole length
Bark	Diameter, height, live crown ratio
Heartwood + sapwood	Diameter, height, live crown ratio
% sapwood	Diameter, height, live crown ratio
Sapwood	% sapwood, sapwood + heartwood
Heartwood	% sapwood, sapwood + heartwood



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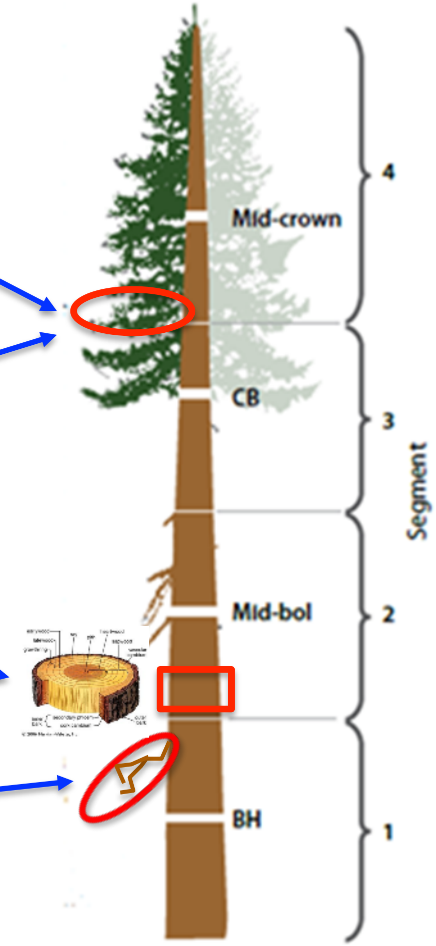
Tissues sampled for aboveground *nutrient content*

- **Foliage** (1, 2, 3 yr old, from mid-crown primary branch of each 10th and 90th percentile tree)
- **Live branch** (largest mid-crown branch of each tree)
- **Heartwood**, **Sapwood**, **Bark** (from mid-bole disk of each tree)
- **Dead branch** (1 small, 1 large branch from each 90th percentile tree)



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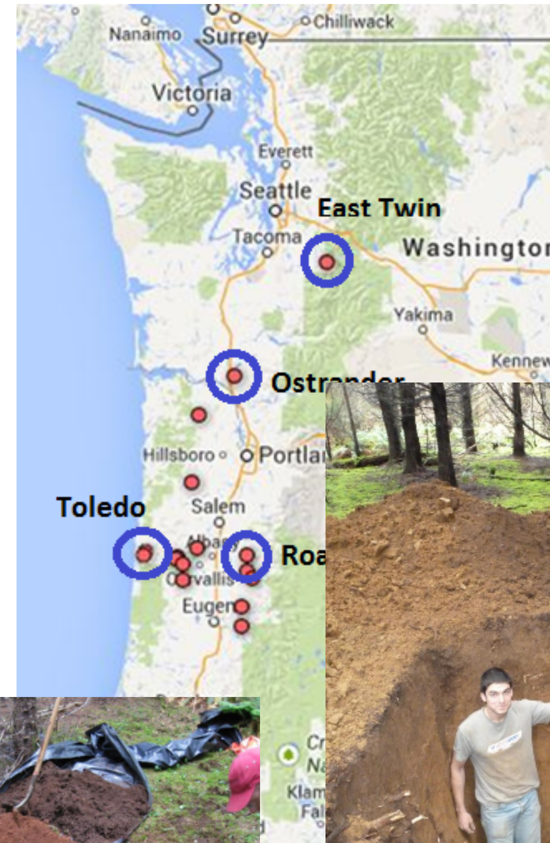
Soil sampling
(Paul Footen/Rob Harrison, UW)

- Sampled at four SMC Type I installations
- Sampled to a depth of 1 m

  5-6 horizons per site, with:
  - pH, CEC
  - Bulk density
  - Macronutrient content

    (N, P, K, Ca, Mg)



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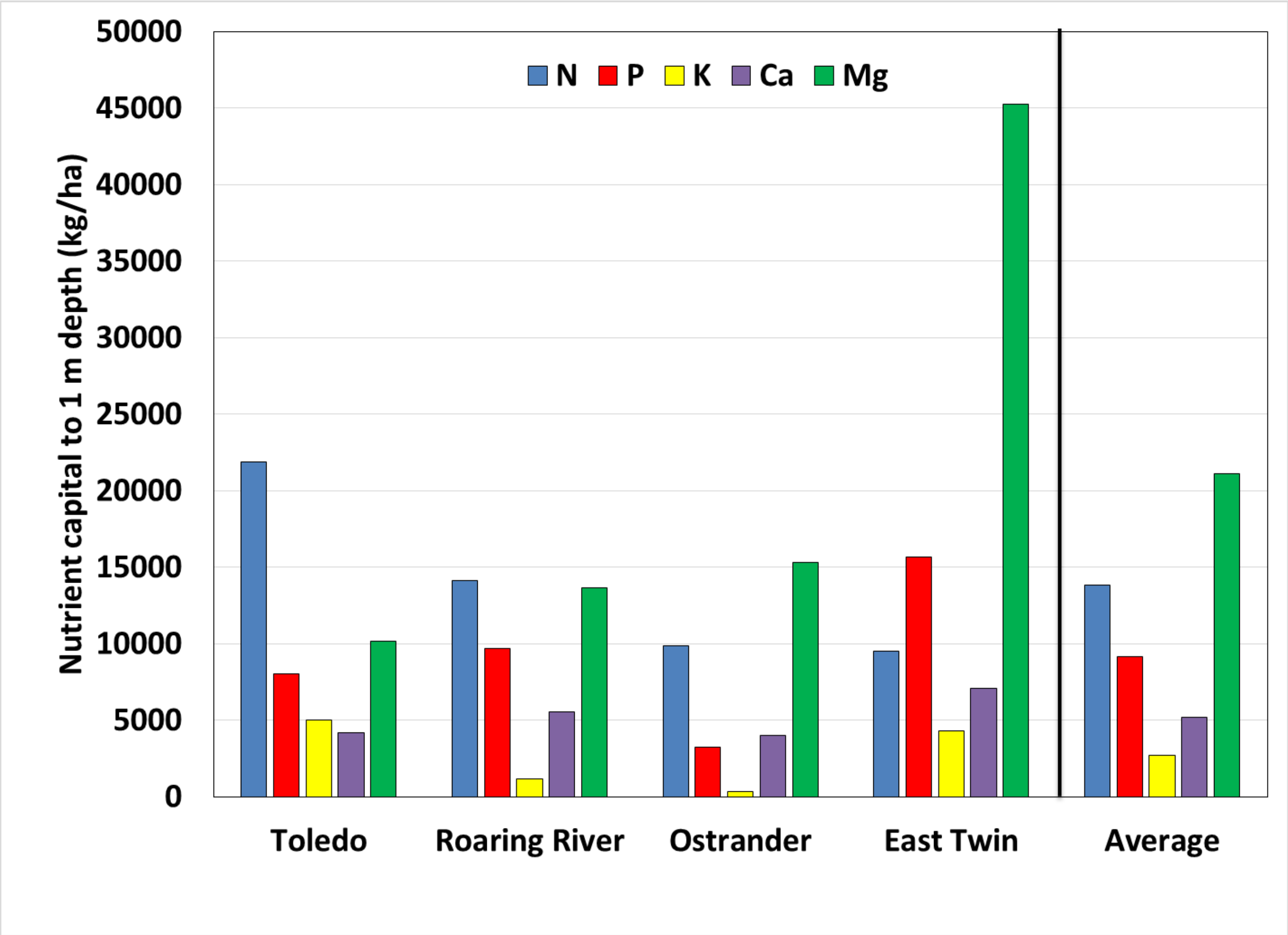
Soil nutrient capital
(e.g., N pool ranged from 10 to 22 Mg/ha)



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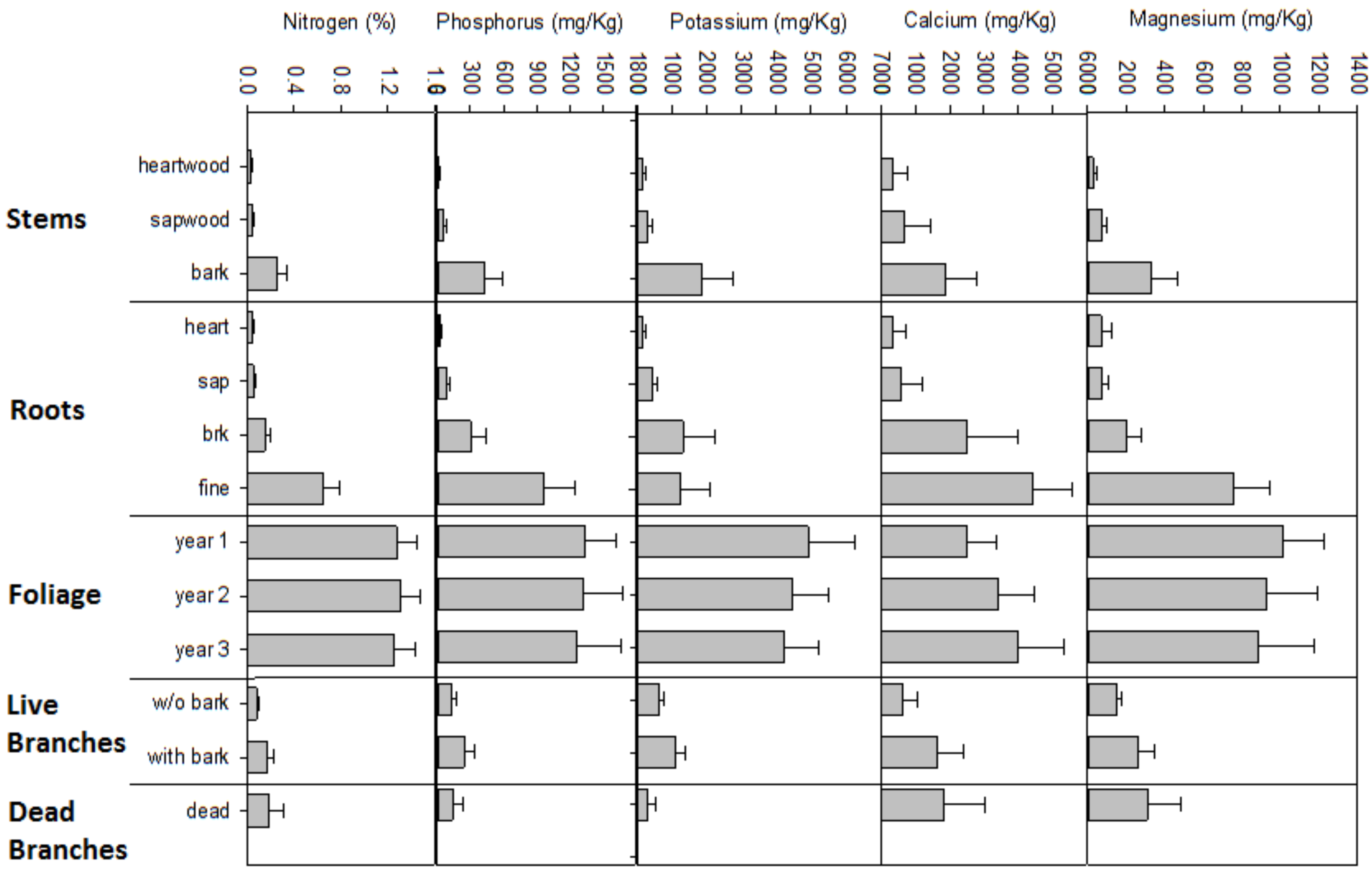
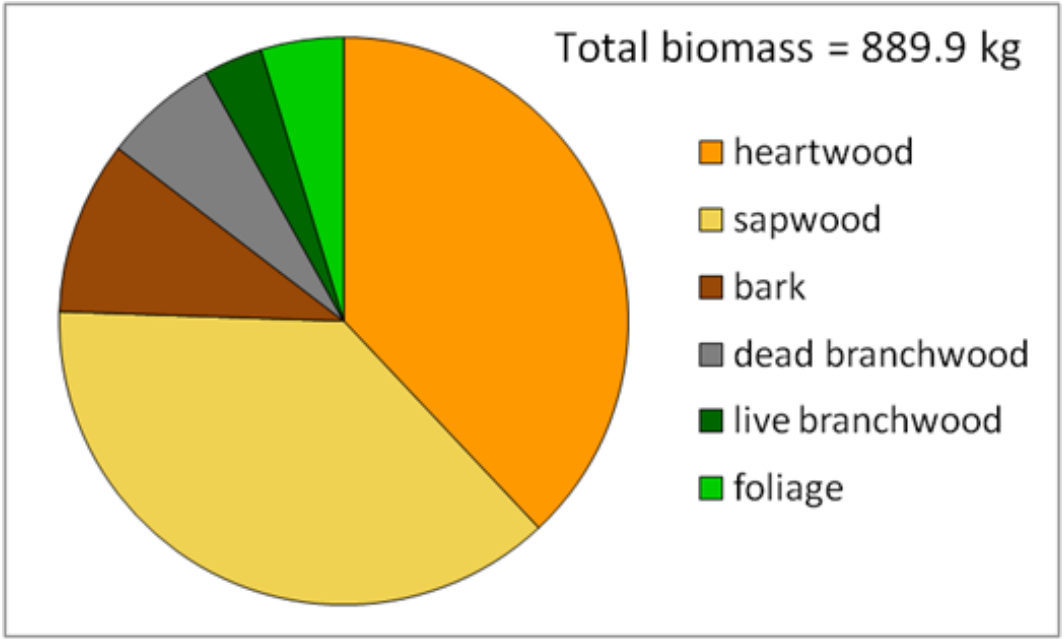
Macro-nutrient concentrations in biomass

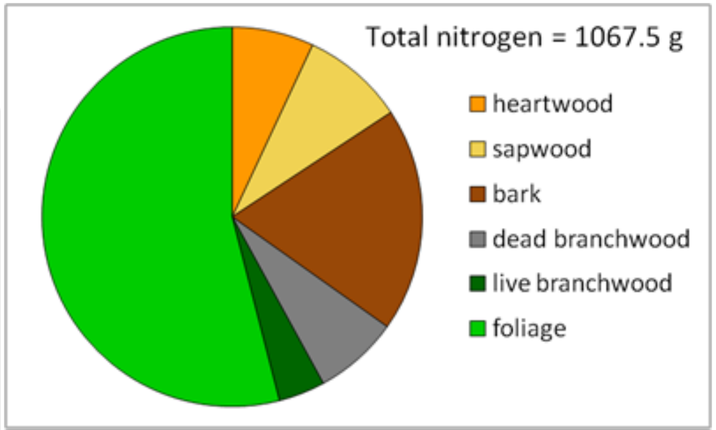


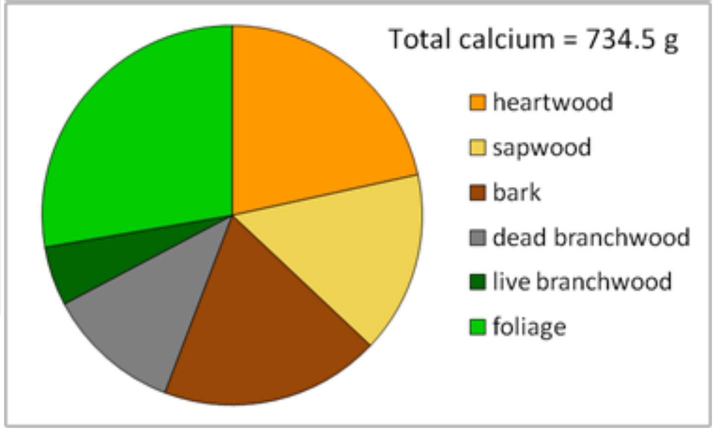
Total aboveground nutrients

Douglas-fir tree, 38 yrs old

dbh=45.6, height =33.5, crown length =19.9







Balance between harvest removals, replenishment rates, and initial pools

- Project tree lists to harvest age (40 years) with growth model
- Estimate:
  - Standing biomass
  - Biomass removed for utilization
  - Nutrient losses
- (Compare losses to initial nutrient pools -> Evans stability ratio)
- (Alternatively) Simulate fluxes:
  - Organic decomposition (=retained biomass)
  - Parent material weathering rate
  - Atmospheric deposition
  - Leaching loss
  - Biological fixation rate (nitrogen)
- Simulate uptake by forest re-growth, potential limitations to production

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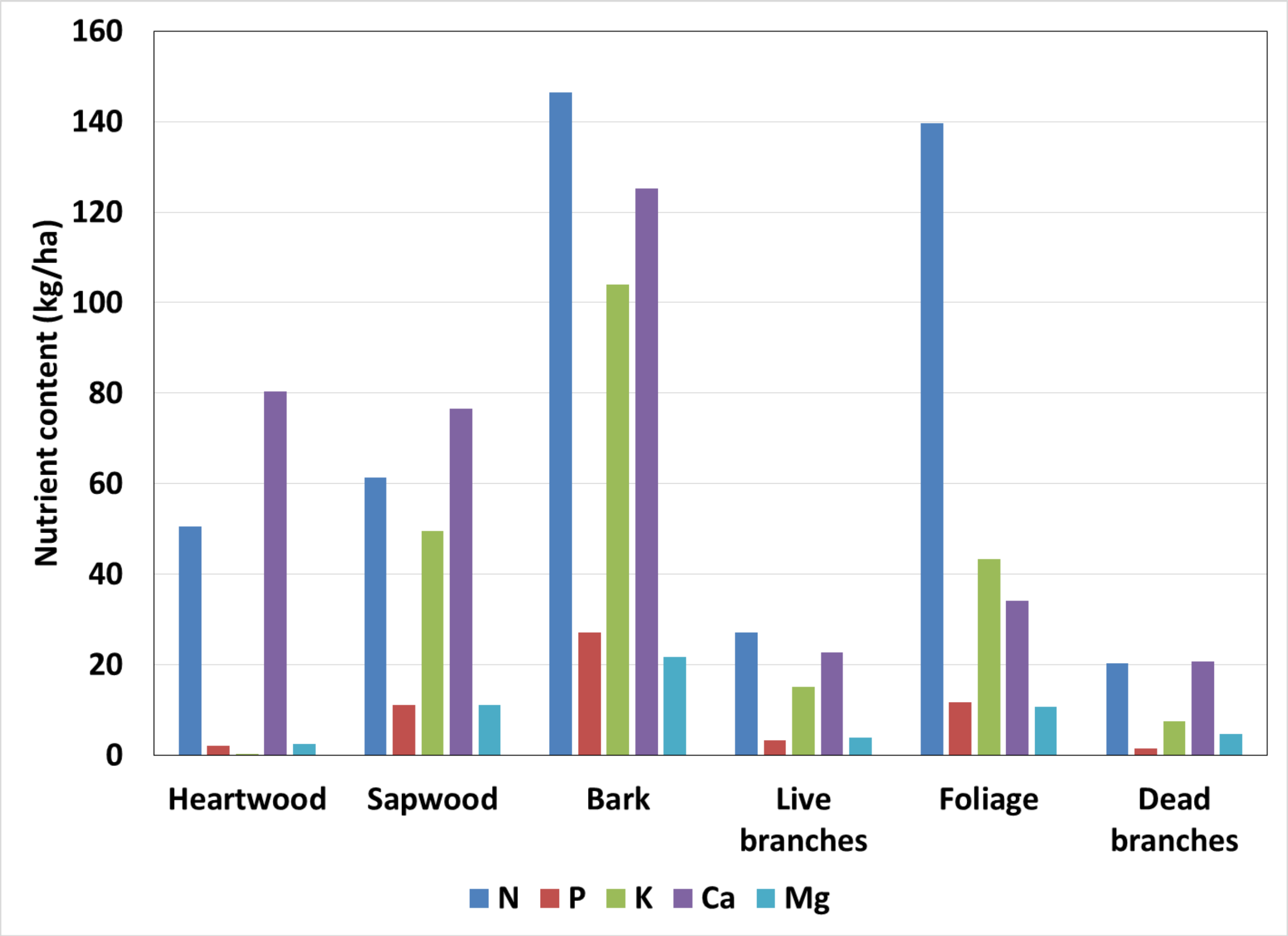
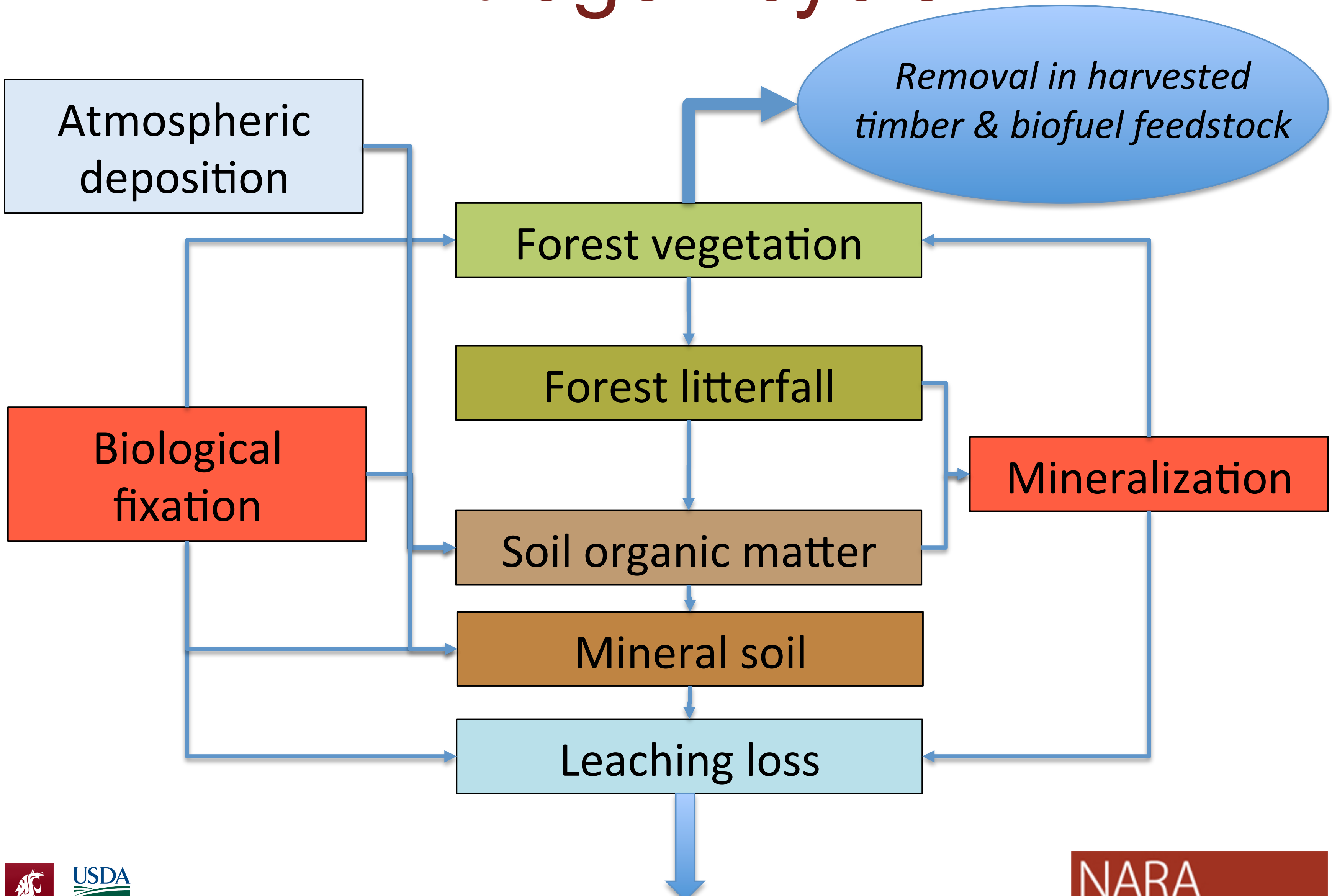
Total aboveground nutrients @ 40 yrs
SMC Type I – Roaring River (SI 46.5m @ 50 yrs)



Nitrogen cycle



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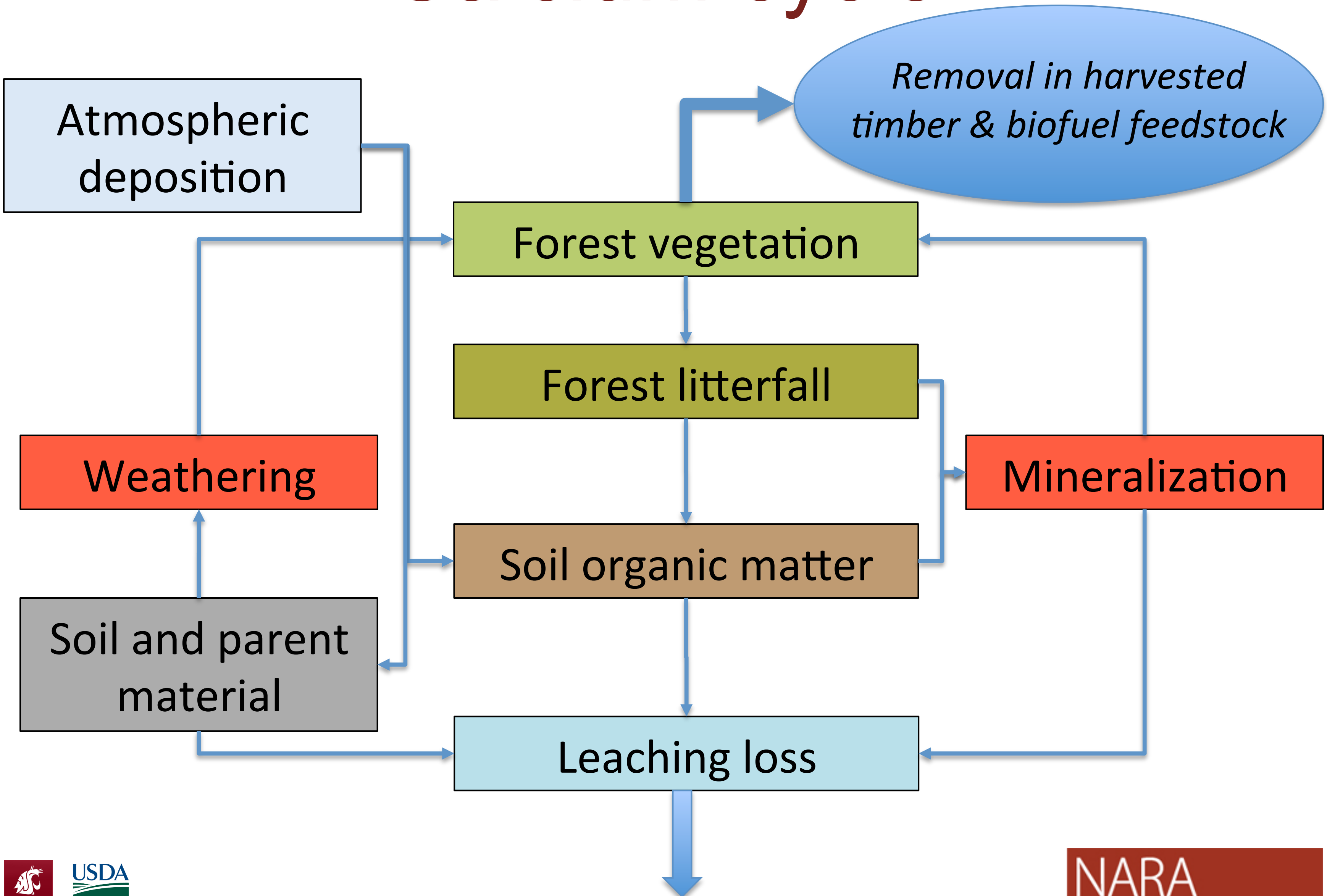
Calcium cycle



Determination of harvest removals

- Tree list projected to 40-yr rotation with SMC-ORGANON
- Apply tree-level biomass equations to tree list
- Nutrient content = biomass · average nutrient concentration
- Partial harvest of top of stem and percentage of crown

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Harvest intensity, residual material

- Whole tree—nothing left in woods
- Bole only—entire crown left in woods
- Merchantable—everything above 5” diameter + vertical half of crown below 5” diameter left in woods
- NARA—whole tree; 67.2% of crown residuals are recoverable (average from Kevin Boston’s work)

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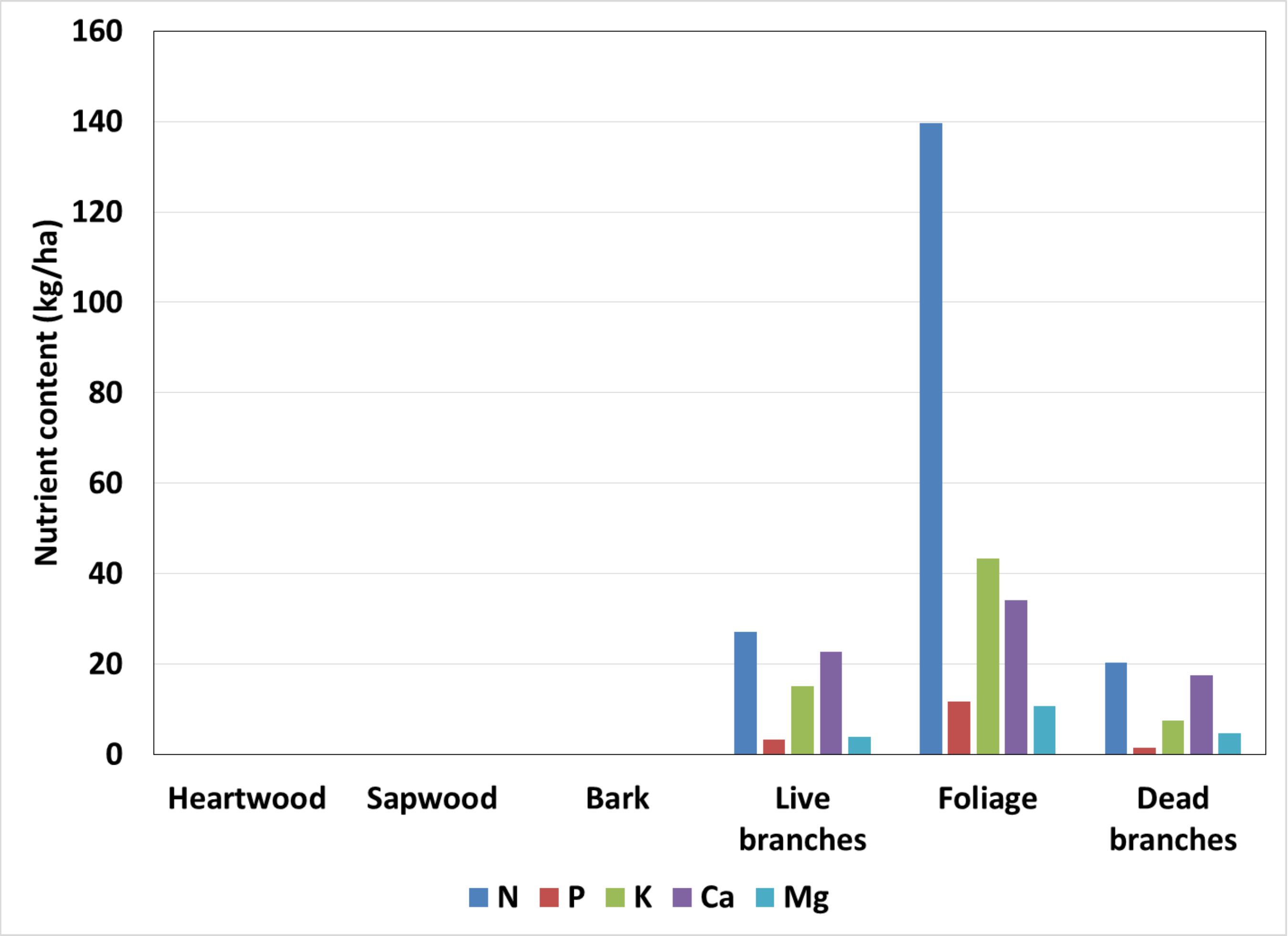
Nutrient retention, removing bole only



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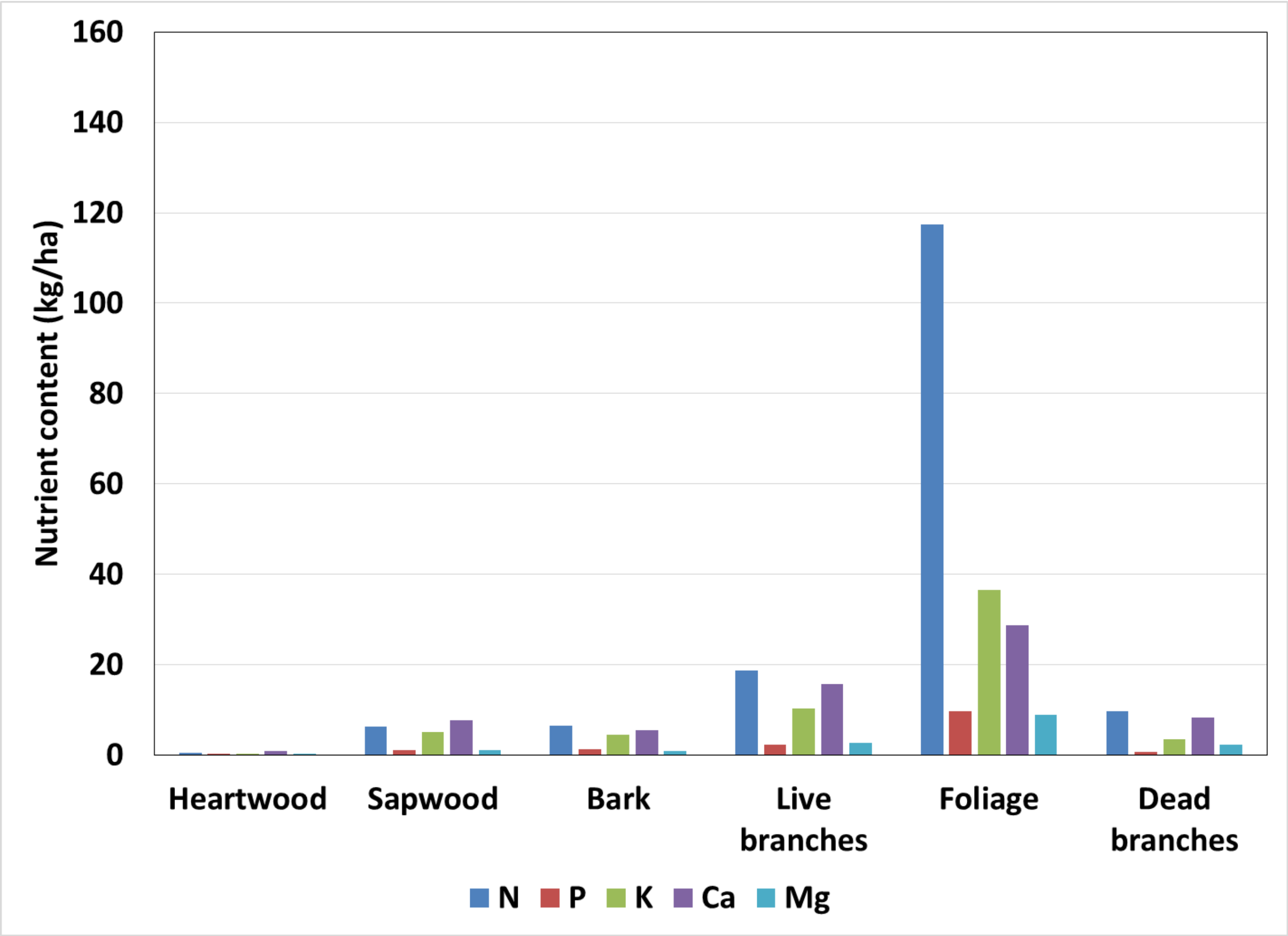
Nutrient retention, removing bole + crown material



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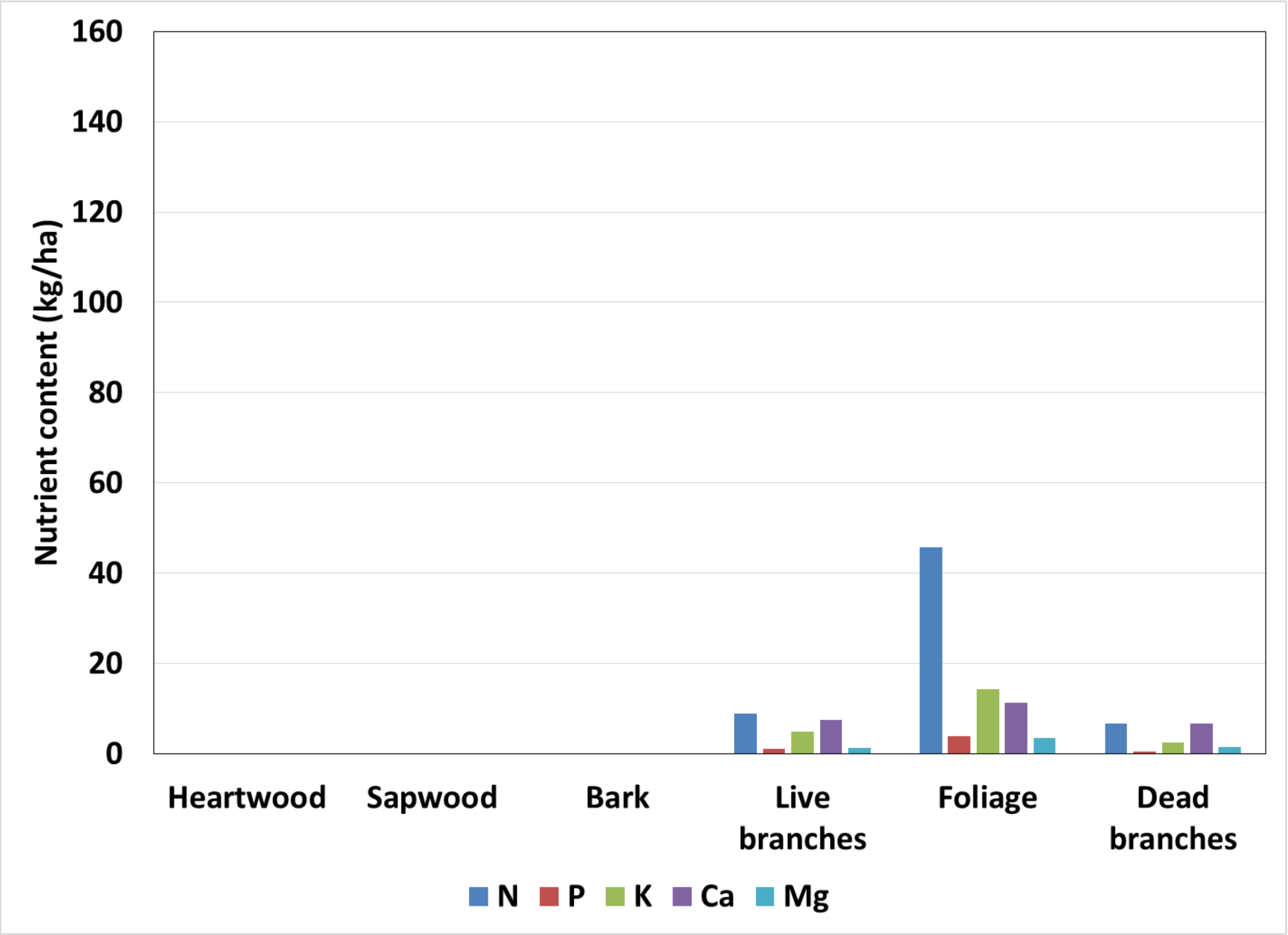
Nutrient retention, removing 67% of crown material during stem extraction



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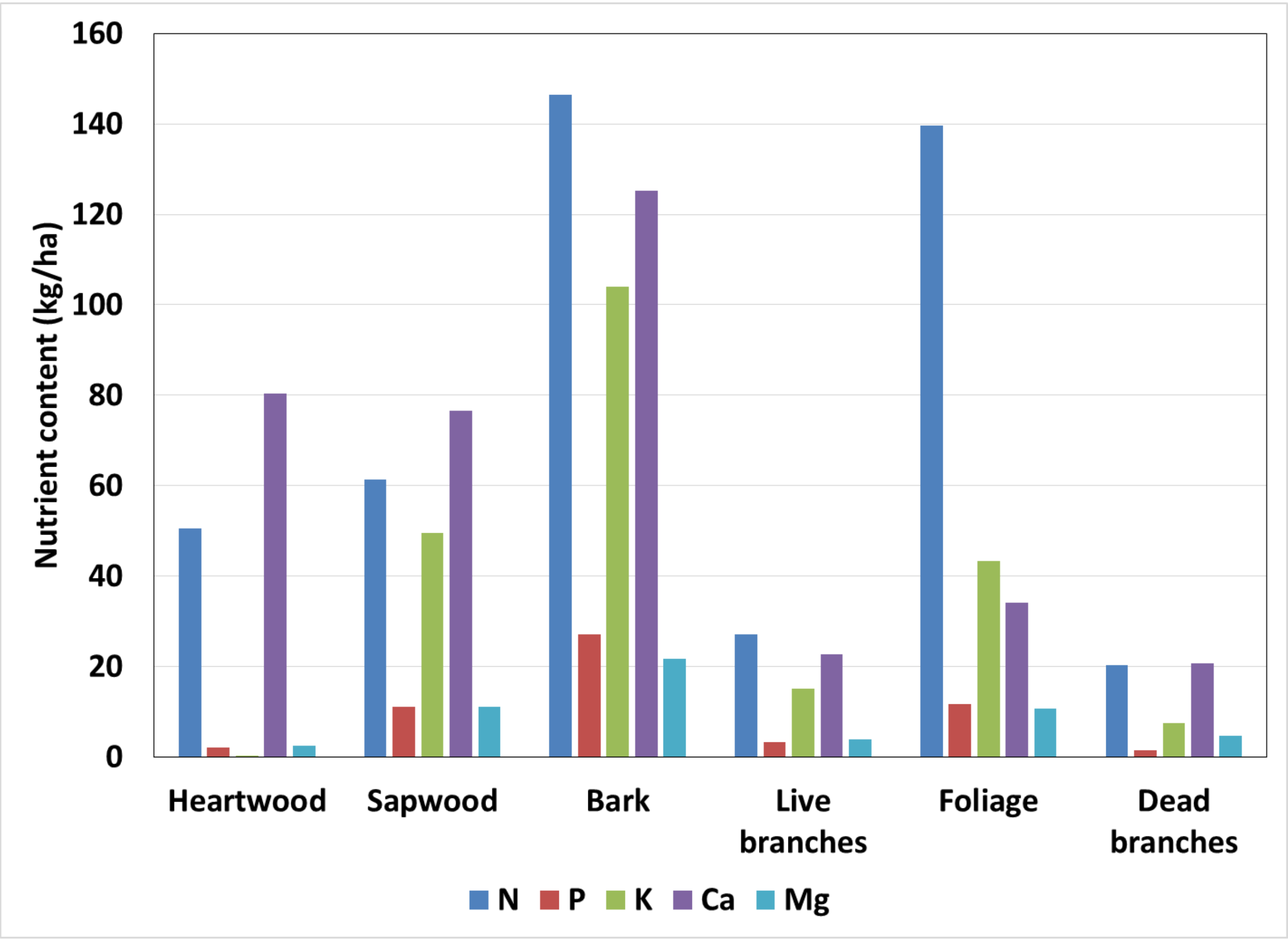
Total aboveground nutrients @ 40 yrs
SMC Type I – Roaring River (SI 46.5m @ 50 yrs)



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Nutrient flux

- Flux based on base cation model:
  - Additions
    - Weathering + atmospheric deposition
    - (Biological fixation from atmosphere for N)
  - Subtractions
    - Leaching + harvest removals

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Published nutrient fluxes in DF forests

- Published values are typically focused on only a few locations
- Values for specific locations are based on balancing inputs and outputs
- Subset of values included for this analysis were those from studies which included balanced data

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Average of published nutrient fluxes in Douglas-fir forests

		kg/ha/yr				
Flux type		**N**	**P**	**K**	**Ca**	**Mg**
Deposition		1.43	0.27	0.38	0.73	0.89
Weathering			0.20	9.95	68.70	7.20
Leaching	***Cascades***	1.05	0.41	5.30	63.75	9.00
	Coastal	5.94	0.02	6.43	8.24	7.83

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Evans Stability Ratio

- Ratio of removed nutrients to initial site nutrient capital (expressed as %)
- Used as index of sustainability
- <10% : little risk to productivity
- >10% and <30% : moderate risk to productivity
- >30% : significant risk to productivity

Evans Stability Ratio

Roaring River

Harvest removals as % of initial soil and forest floor pool					
	N	**P**	**K**	**Ca**	**Mg**
WT	-3	-0.53	-16.1	-6.33	-0.4
BO	-1.88	-0.4	-12.03	-5.05	-0.3
Merch	-2.05	-0.41	-12.36	-5.22	-0.31
NARA	-2.63	-0.49	-14.76	-5.91	-0.37

Medium risk
10-30%

Low risk
<10%

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Nutrient flux (kg/ha), Cascades
40-year rotation at Roaring River SMC installation

40 year % change in nutrient capital					
	N	**P**	**K**	**Ca**	**Mg**
WT	-2.89	-0.51	0.22	-2.38	-0.67
BO	-0.66	-0.25	8.36	0.17	-0.45
Merch	-1.00	-0.27	7.70	-0.17	-0.48
NARA	-2.16	-0.42	2.89	-1.54	-0.60

- **Net flux of -2.89% for N under WT harvest implies depletion after 34 40-yr rotations (if fluxes accurate and conditions remain stable)**
- **Potassium increases (=>high weathering rate)**
- **Relatively low risk to long term site productivity, regardless of harvest intensity**

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Nutrient flux (kg/ha), Coast Range sedimentary
40-year rotation at Toledo SMC Type I

40 year % change in nutrient capital

	N	P	K	Ca	Mg
WT	-2.56	-0.36	-0.51	-14.03	-0.40
BO	-0.55	0.08	2.29	-9.29	0.01
Merch	-1.17	-0.04	1.48	-10.85	-0.11
NARA	-1.90	-0.21	0.41	-12.48	-0.26

- **Calcium source in coastal soils mostly atmospheric (assumption of no weathering)**
- **% removed highly dependent on leaching**
- **Calcium flux of -14.03% under WT implies only 7 40-yr rotations before potential calcium limitations, although unclear whether the decline would be gradual or sudden**

Thanks for your attention!

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