OSU College of Forestry

Scholarship & stewardship working together for a sustainable future

Role of silvicultural research in providing solutions and support for intensive management of planted forests: Global and regional perspectives

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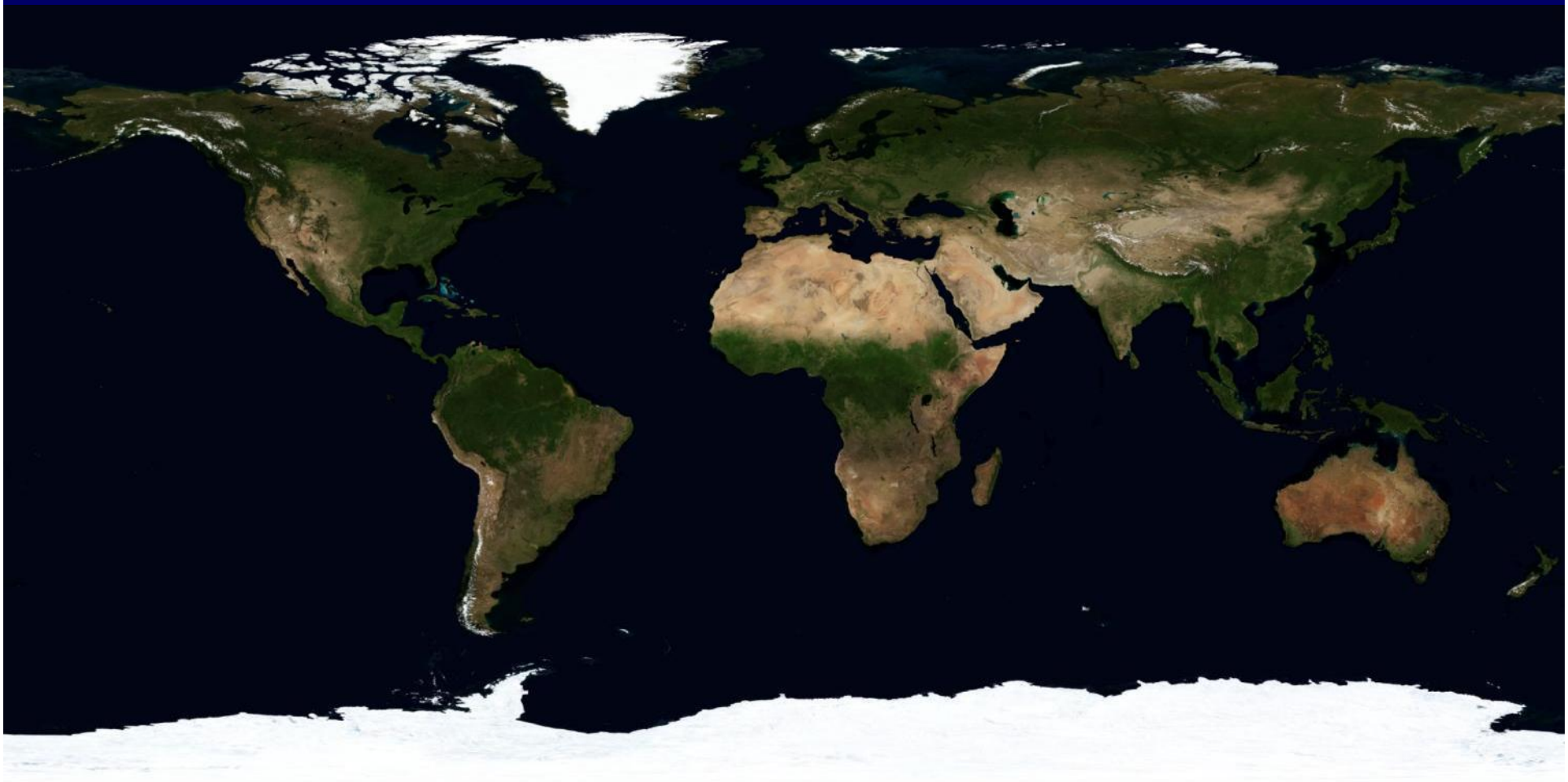
CIPS

Role of silvicultural research

- Regional and global perspective
- Current activities and issues in intensive silviculture with a Douglas-fir bias (Knowledge base whose application John Gordon gave a C-grade)
- Economic returns (the biological growth that yields 50% of investment growth ï Stephen Levesque)
- Environmental performance

Role of silvicultural research

What is the global context?



PNW Douglas-fir Productivity

Estimates of PNW Douglas-fir productivity	Potential MAI
Bulletin 201 (1930, 1961. Normal yield tables for Douglas-fir)	210 ft^3/ac/yr
Staebler (1955) adjustment for capture of mortality (gross increment)	270 ft^3/ac/yr
Current field trials	300 ft^3/ac/yr

Global Douglas-fir Productivity in Context

Species, location	Potential MAI	
Douglas-fir, PNW	21 m^3/ha/yr	300 ft^3/ac/yr
Douglas-fir, New Zealand	30 m^3/ha/yr	428 ft^3/ac/yr
Eucalypts, Brazil	56 mm^3/ha/yr	800 ft^3/ac/yr

- *For Douglas-fir, resource availability is driver not genetics*
- *Current and future products from different species: engineered wood products, composites, pulp & paper, . . .)*

Role of silvicultural research in: *Eucalyptus* clonal plantations in Brazil

Brazil: 4-fold increase in *Eucalyptus* productivity over last 4 decades:

12 → 48 $m^3ha^{-1}yr^{-1}$

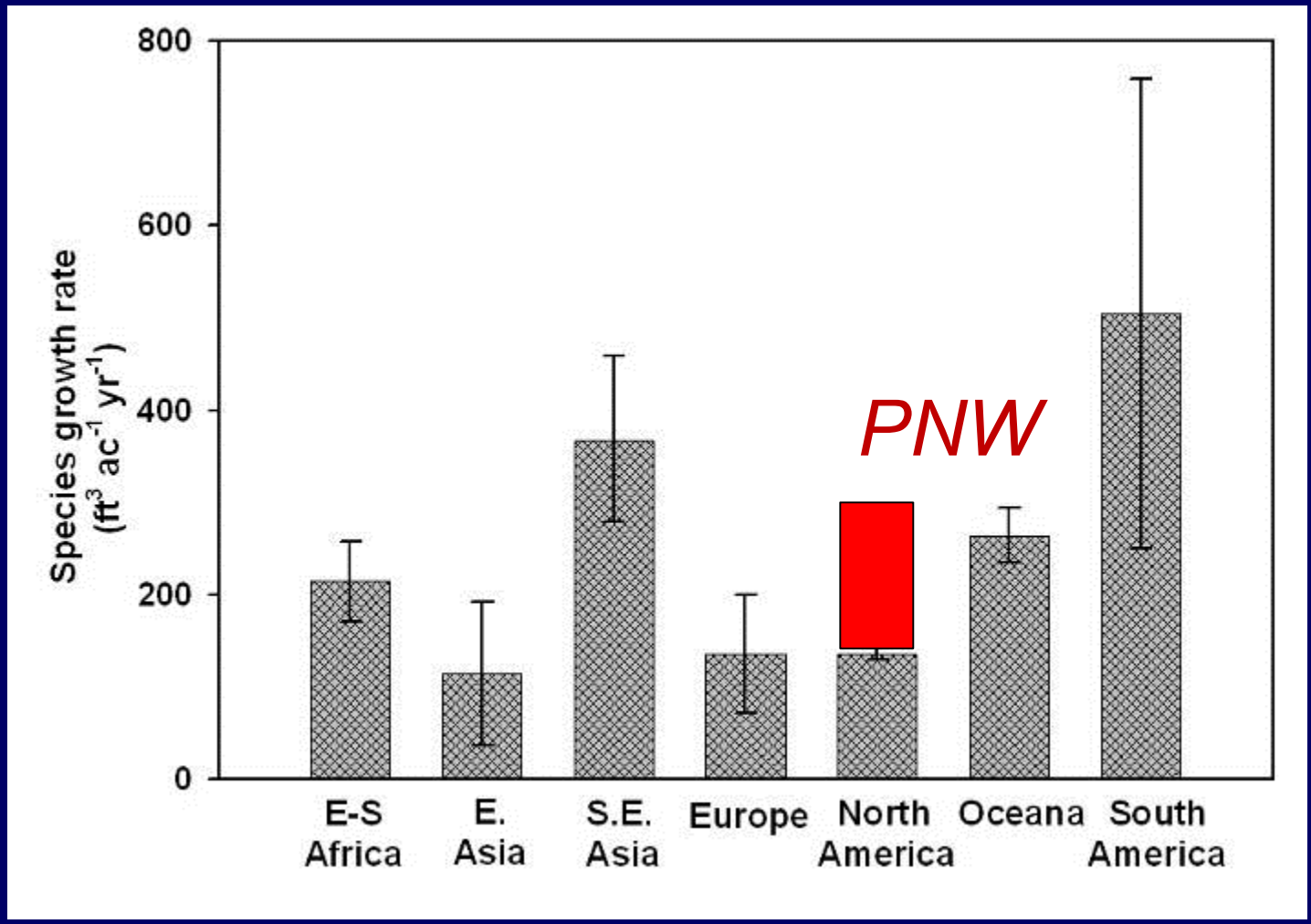
Genetics (species-provenance-hybrids-clones)

Silviculture (site prep, fertilization, pest control, . . .)

Veracel average and target mean annual increment

	$m^3ha^{-1}yr^{-1}$	$ft^3ac^{-1}yr^{-1}$	bf $ac^{-1}yr^{-1}$
2004	51	729	3,645
2008	56	800	4,000
target	63	900	4,500

National and Global Context



Role of silvicultural research

- What questions arise when producing wood from plantations?
  - What are the opportunities for genetic manipulation?
  - How aggressively should sites be prepared?
  - What is achieved by varying levels of competing vegetation control?
  - When, where, and how should we fertilize?
  - What is the optimal stand density regime?

** *What is the combined effect of complex treatment regimes?*

Role of silvicultural research

- Approaches to genetic manipulation
  - Seed from superior parents in the "wild"
  - Seed from rogued orchards, based on information from progeny tests
    - Open-pollinated half-sibs
    - Controlled crosses
  - Clones
  - GMOs (genetically modified organisms)

Role of silvicultural research

- What type of genetic information is available for current decision-making in Douglas-fir?
  - Heritable portion of height and diameter growth (-> Improved seed from orchards; superior seedlings)
  - Bounds on wood quality: frequency of ramicorn branches; wood density; stiffness; branchiness
- What are the potential gains?
  - Peter Gould (Gould et al. 2008. Forest Science): Douglas-fir height growth gains of 14-20% at year 10; diameter growth gains of 30%
  - Keith Jayawickrama (2006. NWTIC Annual Report): volume gains of 50% at year 15

Role of silvicultural research

- In short, opportunity for genetic manipulation involves selection for:
  - Growth rate directly (progeny tests under NWTIC, Northwest Tree Improvement Cooperative)
  - Traits that are desirable from product point of view (wood density, branchiness, etc.)
  - Traits that confer growth rate or wood quality
  - Insect/disease resistance or traits that confer resistance

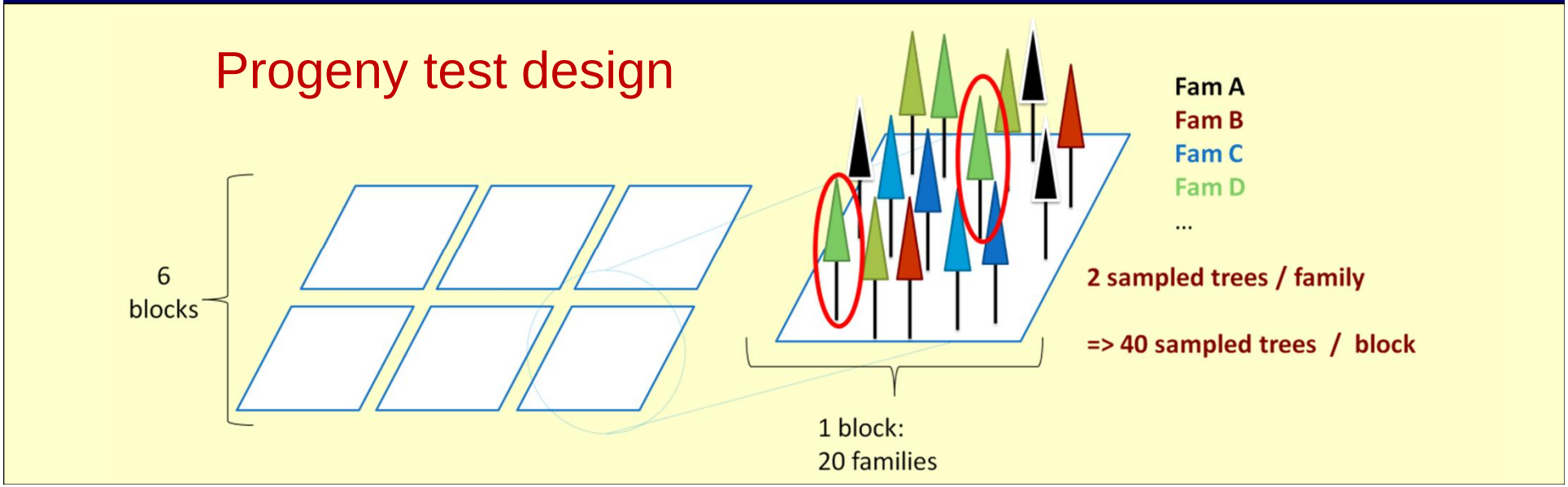
Role of silvicultural research

Deployment of improved seedlings

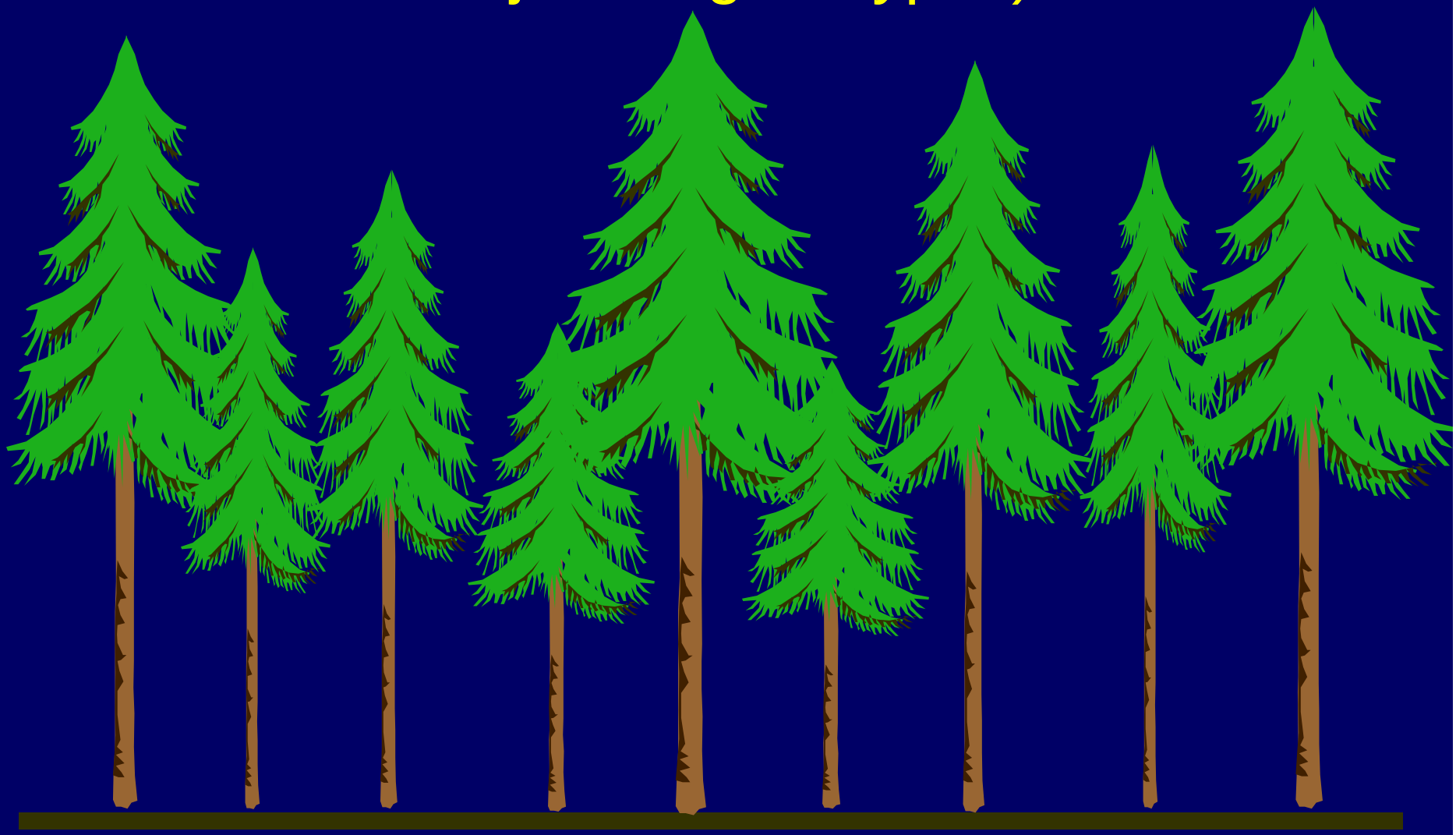
- Vexing questions remaining for research
  - Individual tree performance from progeny tests vs. stand-level growth of operationally deployed mixes of families
  - Realized gain trials (St. Clair et al. 2004. WJAF)
  - Design carried over to Stand Management Cooperative Type IV installations (Jayawickrama 2006)

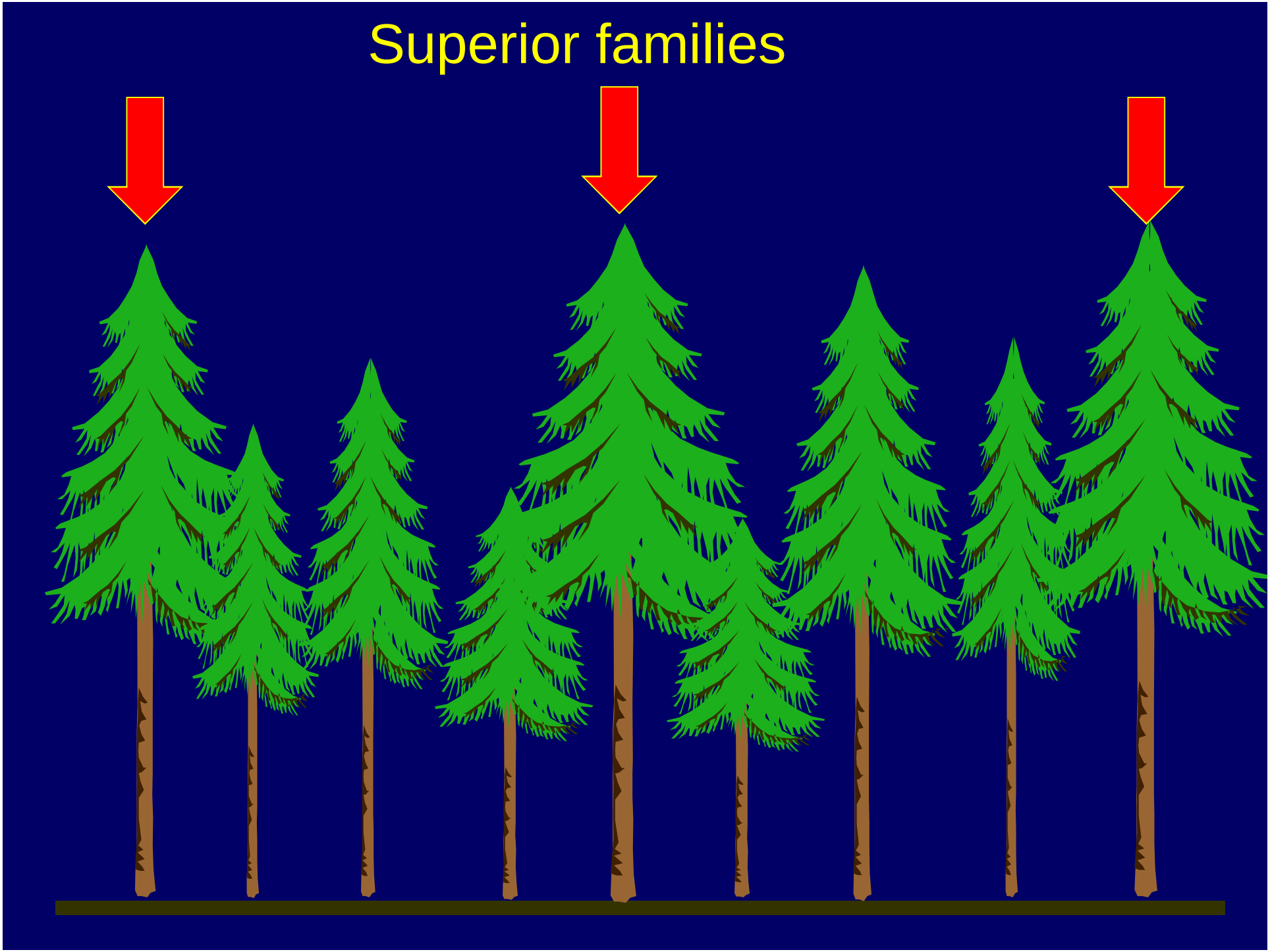
Role of silvicultural research

- Issue of mix and spatial arrangement of genotypes
  - Influence on relative growth rates and stand differentiation
  - Influence on stand-level productivity
  - Progeny test performance after crown closure depends on growth rate of adjacent trees

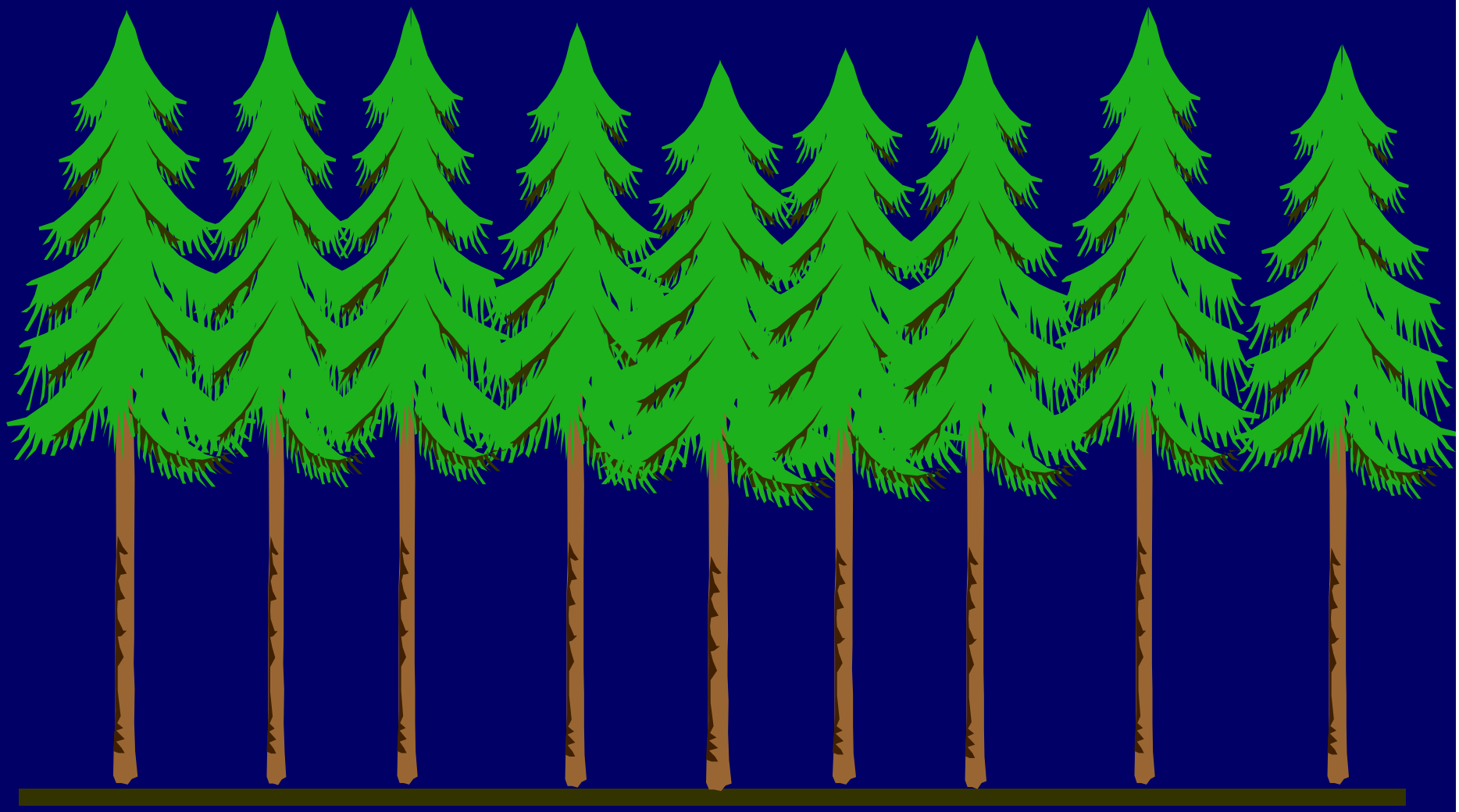


Growth dependent on genotype and local competitive environment (relative growth rates of adjacent genotypes)

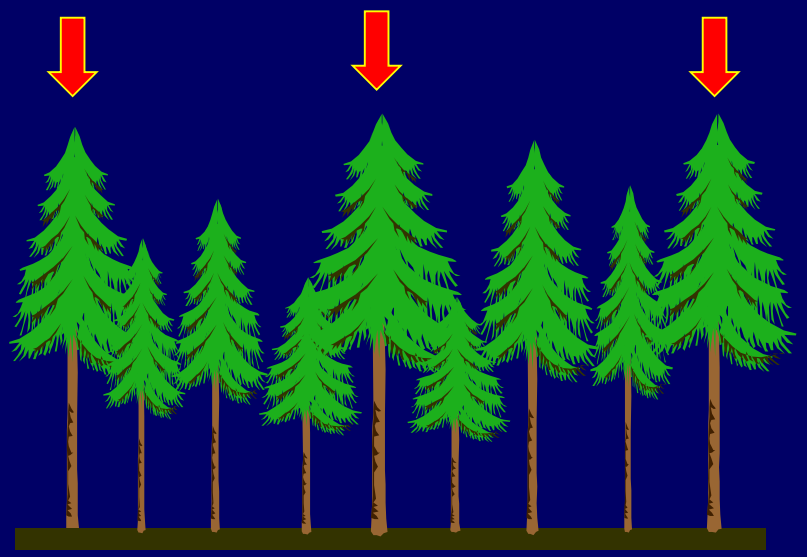



Superior families

Same growth gains if adjacent to SAME family or genotype?



Role of silvicultural research



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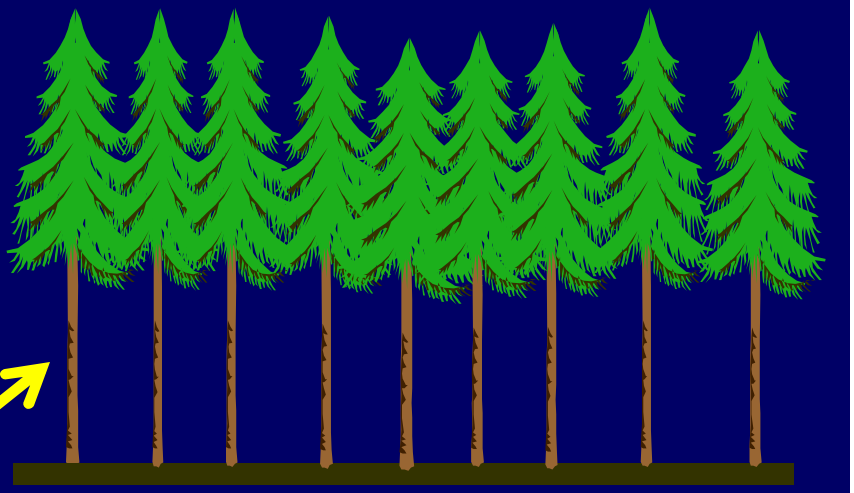
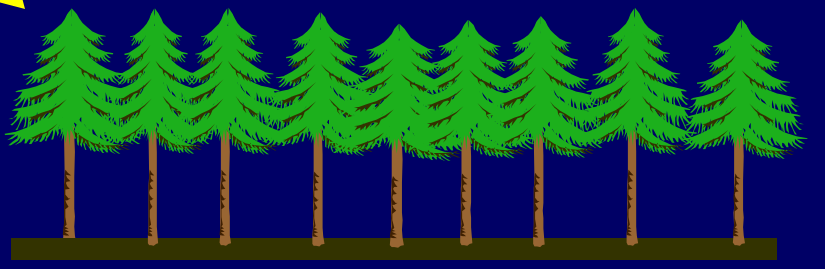


consistent performance



poorer performance

Role of silvicultural research

Å Realized gain trials (St. Clair et al. 2004)

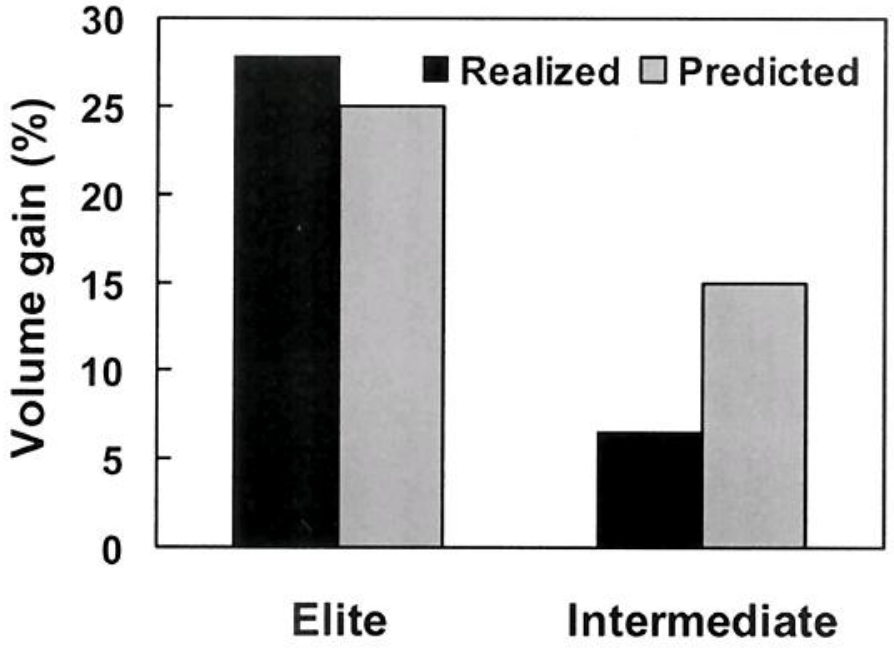
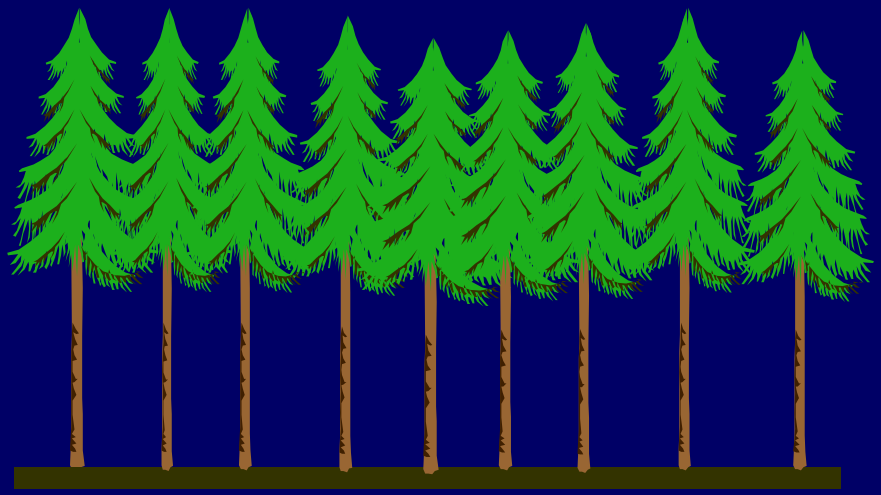


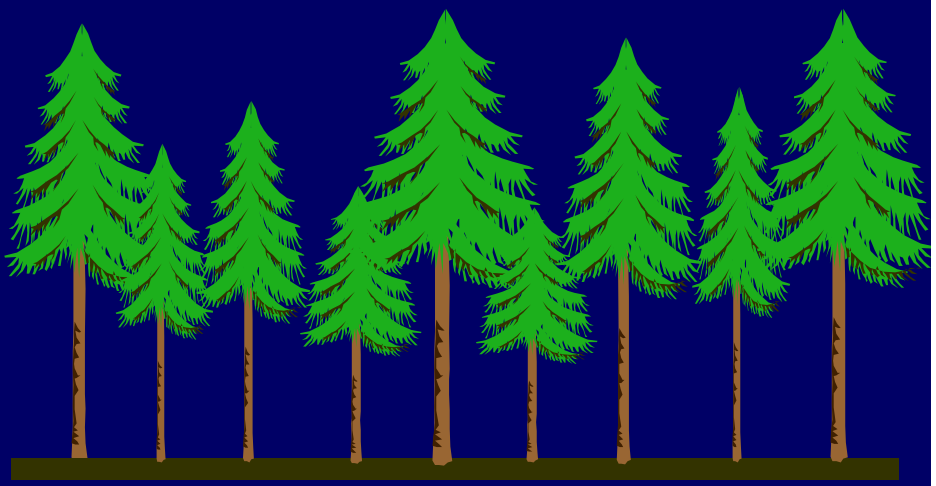
Figure 1. Realized and predicted genetic gains (percentage) for height, diameter, and stem volume for two genetically improved populations of coastal Douglas-fir 5 years after planting in the northern Oregon Cascades.

Role of silvicultural research

- Two potentially important implications:
  - Binkleyôs dominance hypothesis
    - Dominant/codominant trees are most efficient
    - Non-dominant trees are less efficient
    - Inefficient trees in stands with uneven size distribution bring stand-level productivity down



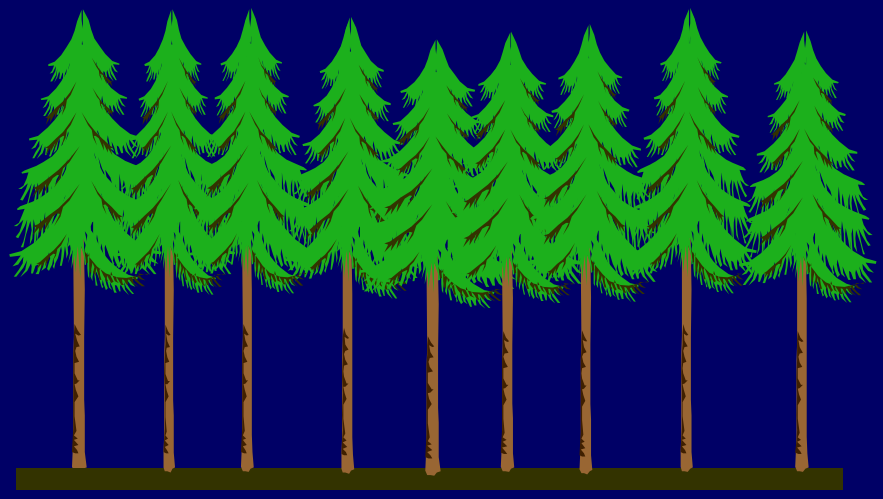
Higher productivity



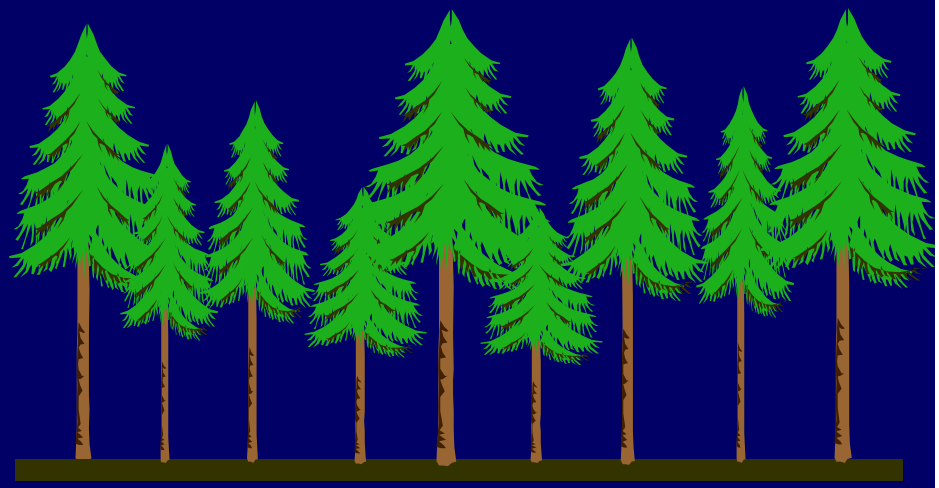
Lower productivity

Role of silvicultural research

- Two potentially important implications (contôd):
  - Product uniformity
    - Uniformity minimizes sorting; gives uniform target product
    - Lack of uniformity demands sorting and more effort into value recovery (20%; Glen Murphy)
    - Douglas-fir plantations exhibit greater within-stand variability than between stand variability (Briggs/SMC)



Higher uniformity



Lower uniformity

Role of silvicultural research

- What questions arise when producing wood from plantations?
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  - What is achieved by varying levels of competing vegetation control?
  - When, where, and how should we fertilize?
  - What is the optimal stand density regime?

** *What is the combined effect of complex treatment regimes?*

Role of silvicultural research

- Site preparation
  - Mechanical
  - Chemical
- Opportunity on "bare ground"
  - Aeration
  - Improve structure
  - Incorporate organic matter
  - Accelerate decomposition
- Or, better to go with "no-till forestry"
  - Soil microfauna/microflora
  - Maintenance of organic matter, carbon

Role of silvicultural research

PNW

ÅPiled and burned
ÅSprayed

Role of silvicultural research

- Site preparation (continued)
  - Issues
    - Delay chemical site prep for green-up and better chemical control
    - Potential damage to seedlings? (probably not)
  - Great results continue to come in from
    - Vegetation Management Research Cooperative
    - Fall River and other affiliated Long-term Site Productivity installations
  - Challenge of separating site preparation effects from effects of competing vegetation on research trials (CIPS)

Role of silvicultural research

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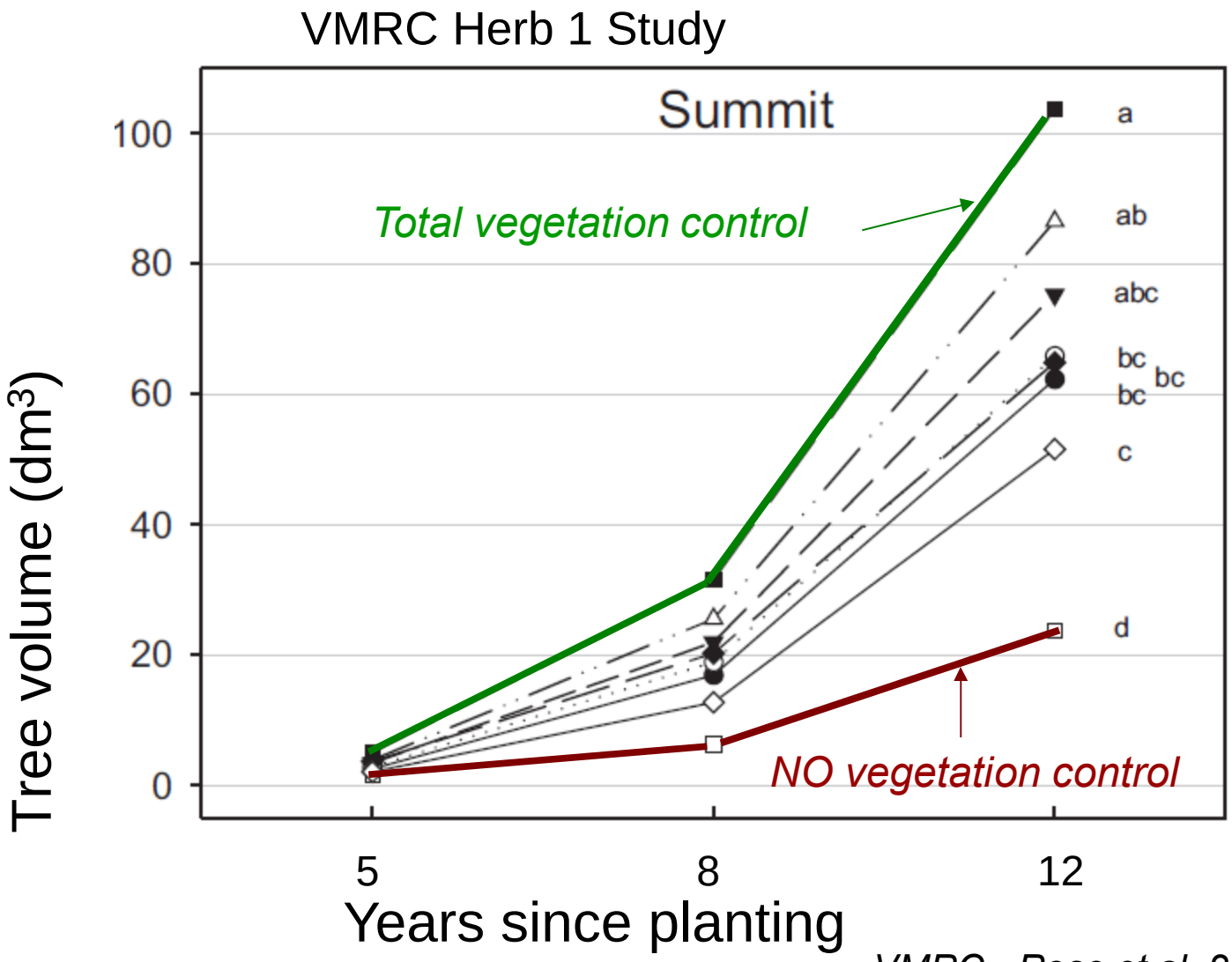
Role of silvicultural research

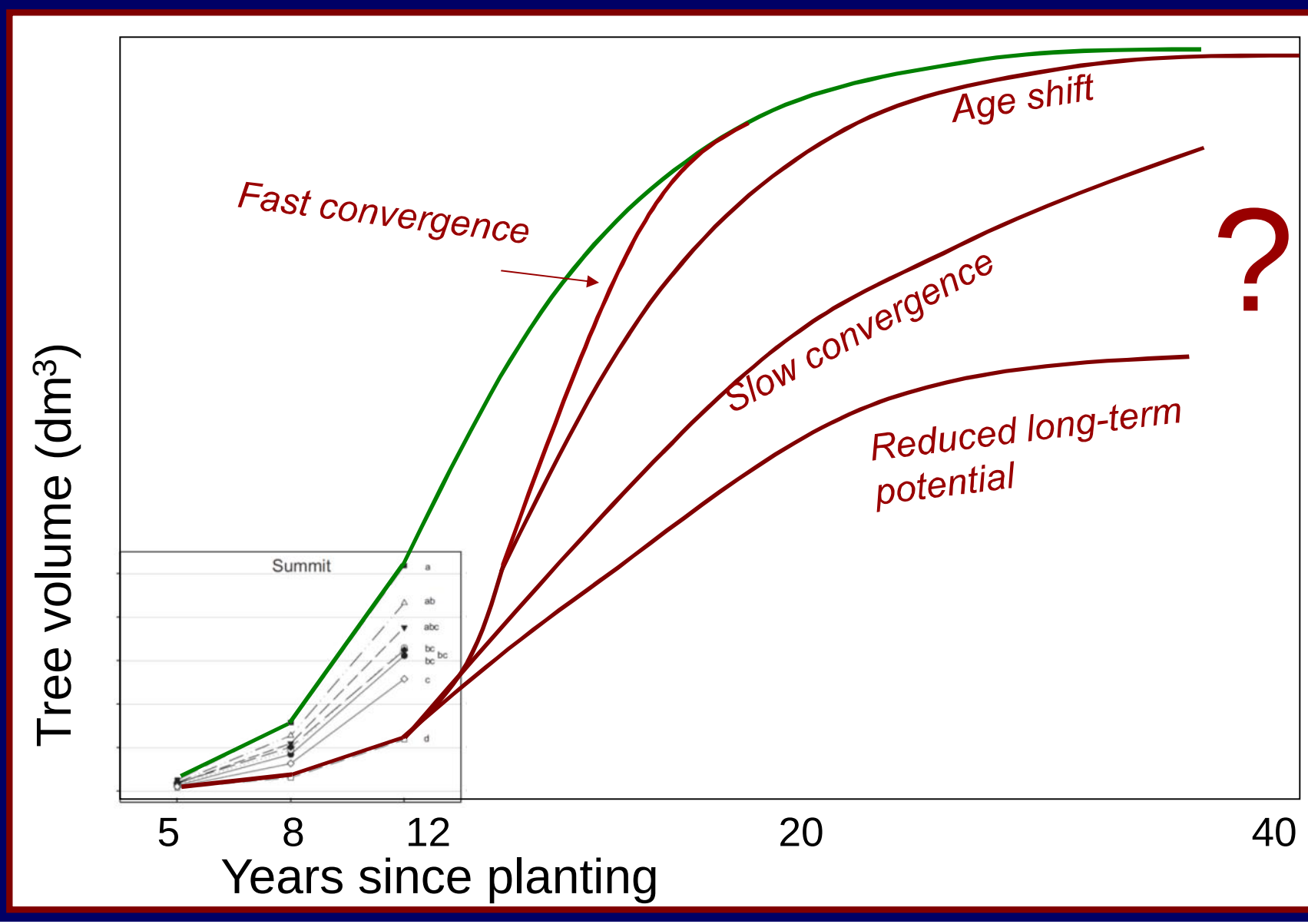
Competing vegetation control

Effects of competing vegetation control on tree growth



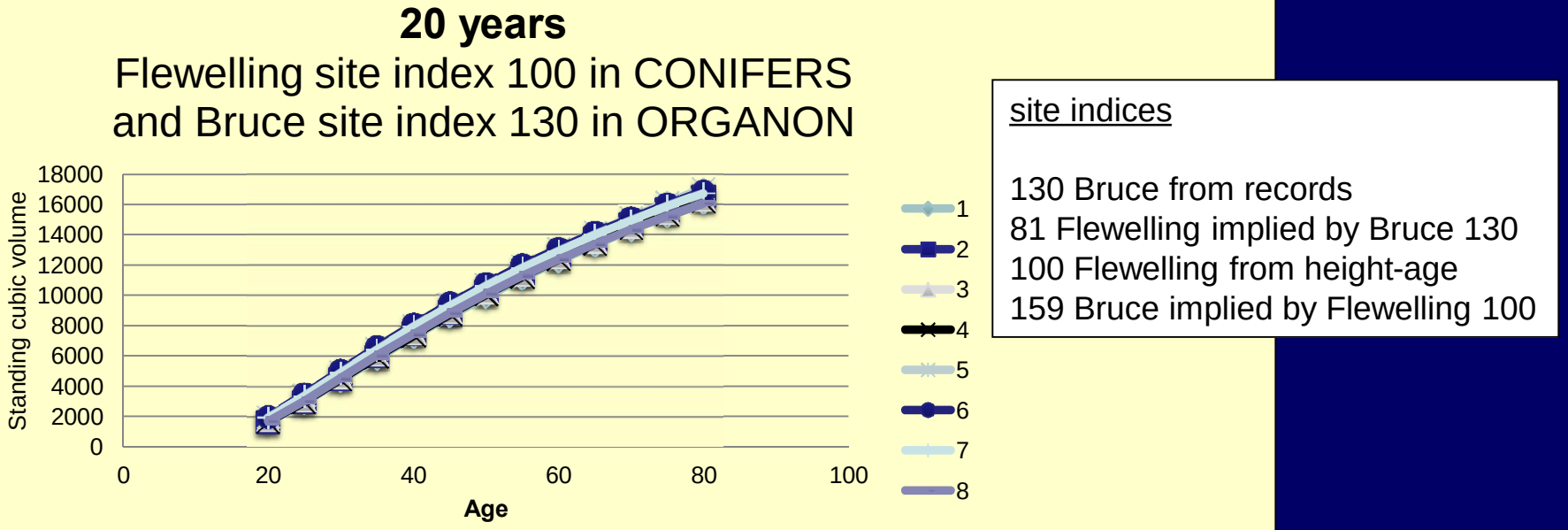
VMRC - Rose et al. 2006

Effects of competing vegetation control on YIELD?

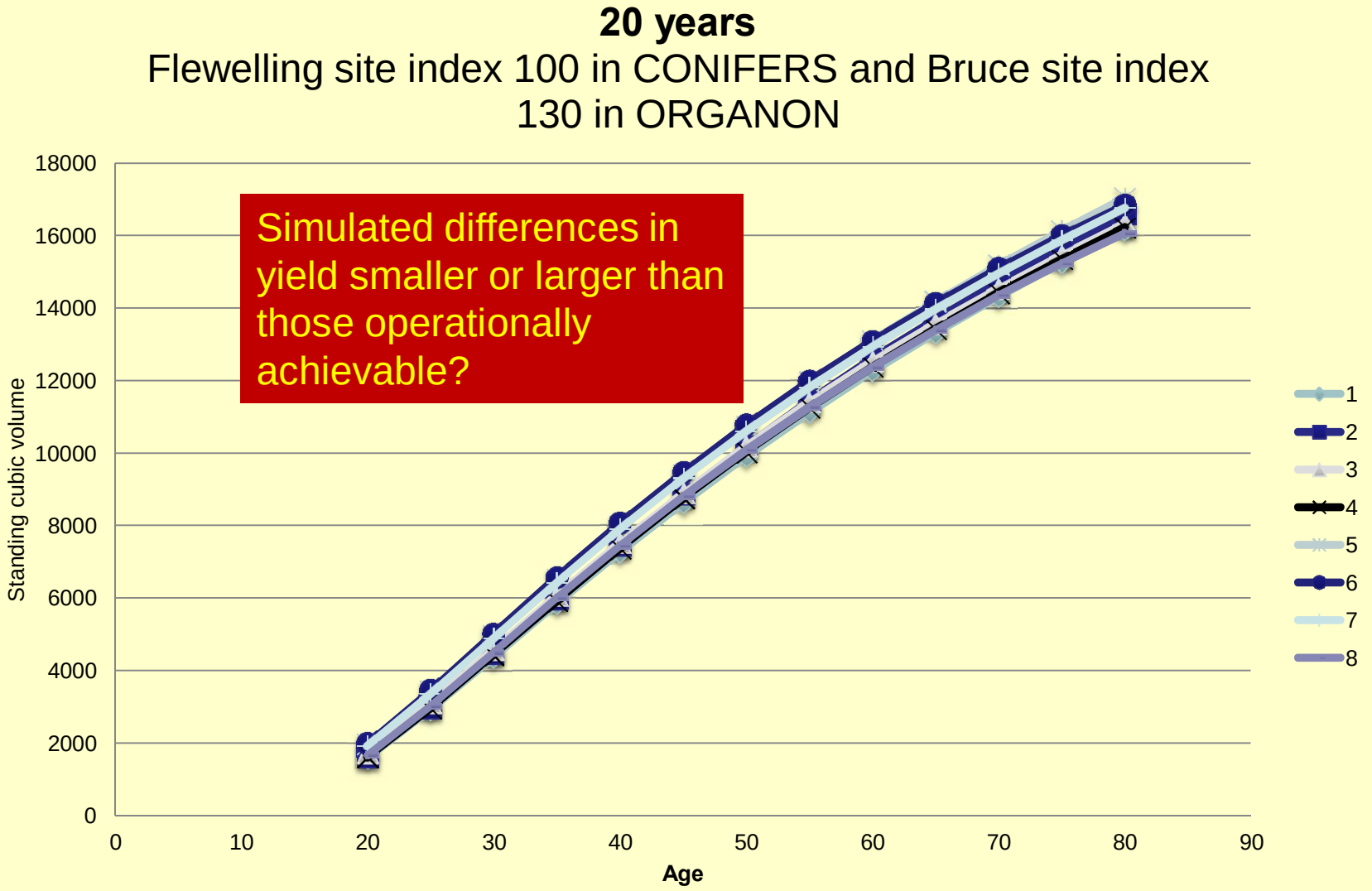


Role of silvicultural research

- Simulations by Derek Gourley
  - VMRC Critical Period Threshold tree data
  - Simulation with CIPS/VMRC variant of CONIFERS
  - Transfer tree list to ORGANON at various ages and assumptions about site index



Role of silvicultural research



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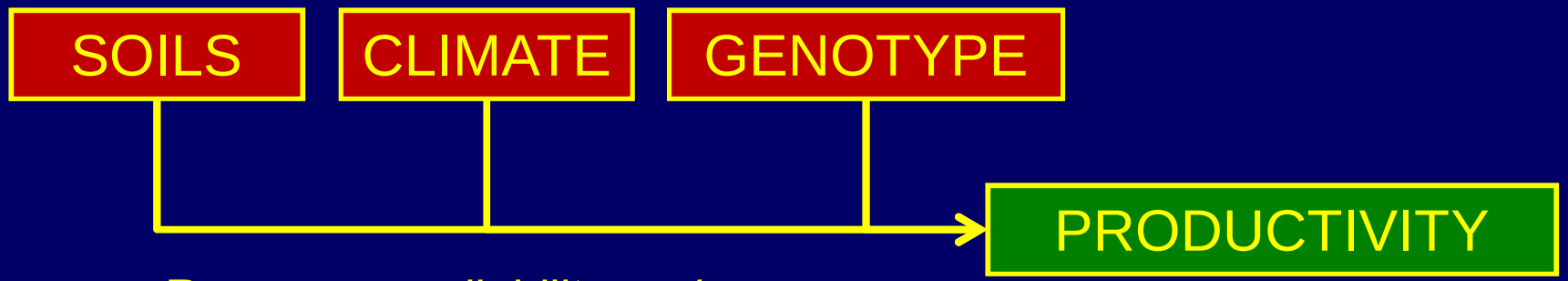
Role of silvicultural research

- Nutrition research
  - Stand Management Cooperative Type V installations (tremendous potential for refining site specificity)
  - Giustina fertilization trials
    - Mechanisms of response to N fertilization
    - Stronger ability to identify responding sites?
  - ñBeyond Nòfertilization trials



Resource availability and use

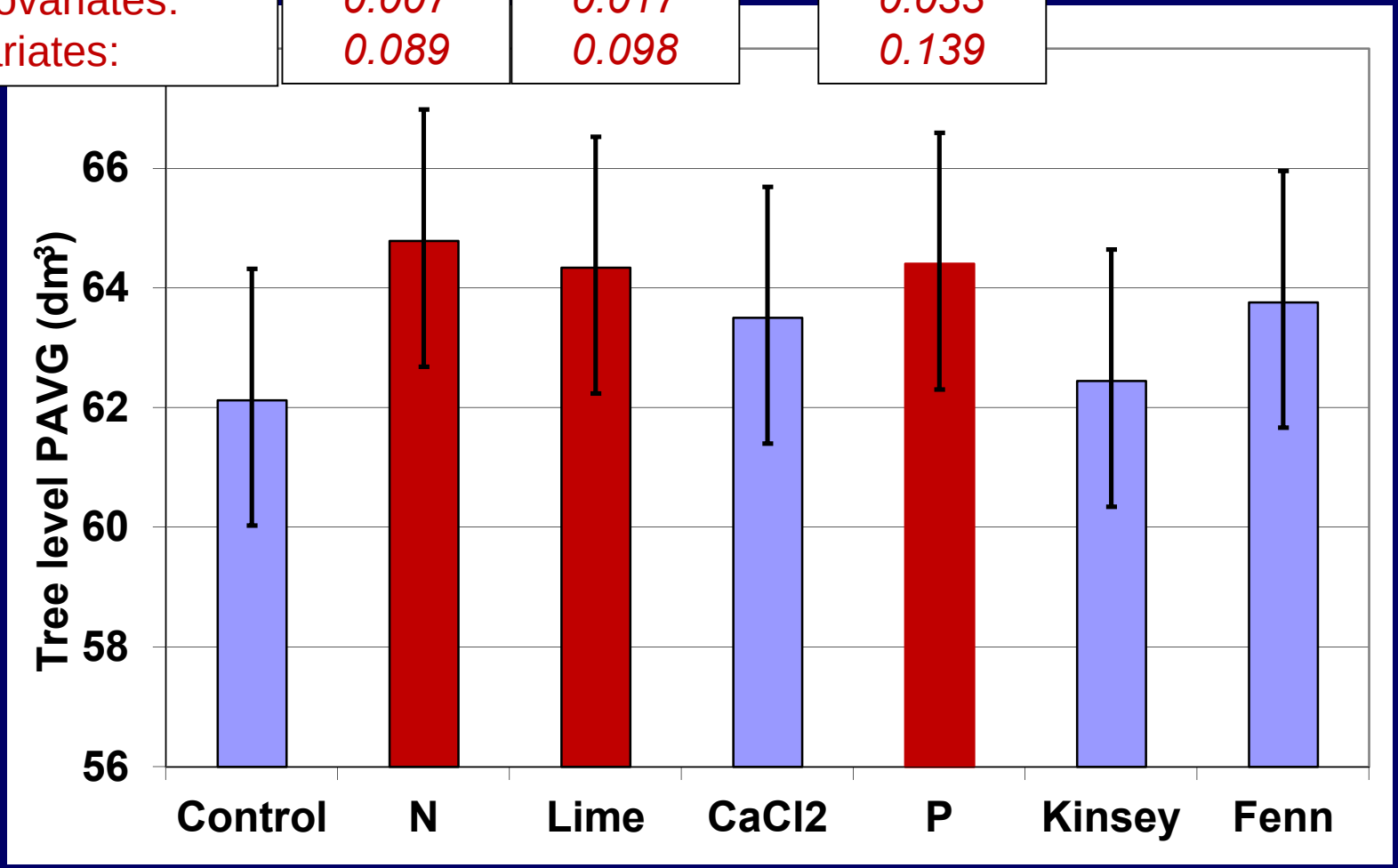
Growth, Yield, and Productivity

- Where to fertilize?
- Potential for new nutrient deficiencies
  - 3rd, 4th rotation forests
  - Intensification of biomass utilization ï bioenergy

Role of silvicultural research

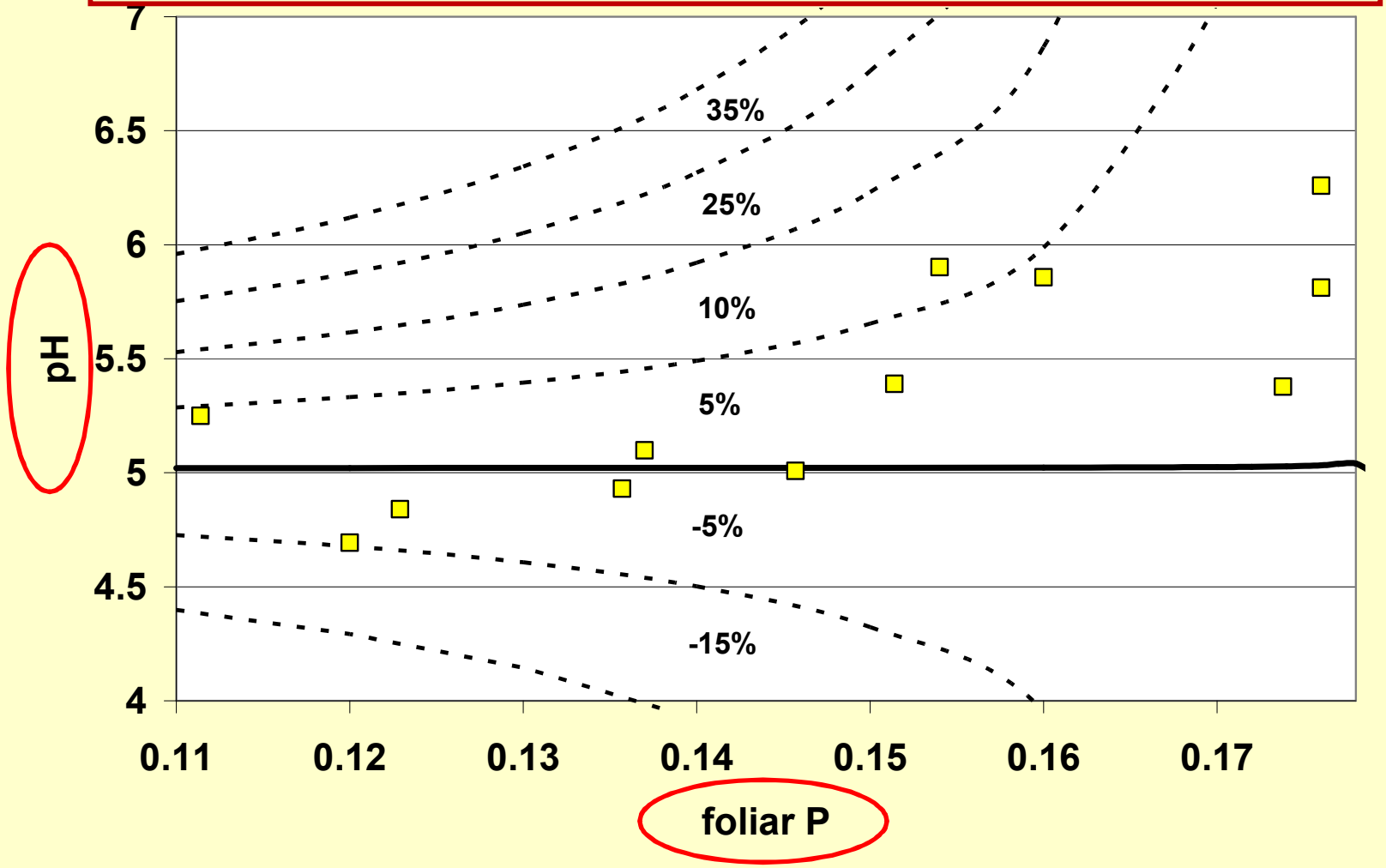
ñBeyond Nòfertilization trials- 3-yr growth response

P-values	Control	N	Lime	CaCl2	P	Kinsey	Fenn
without covariates:		*0.007*		*0.017*		*0.033*	
with covariates:		*0.089*		*0.098*		*0.139*	



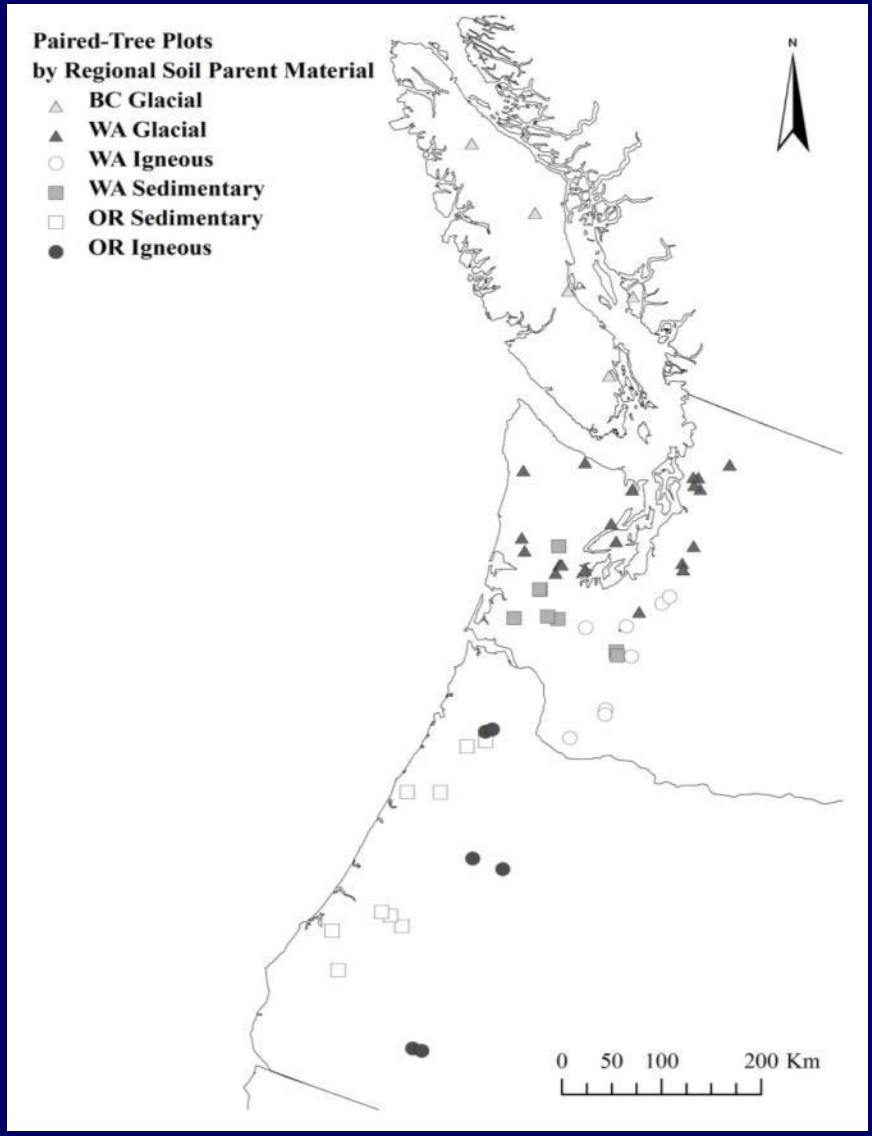
Role of silvicultural research

% volume growth response to P fertilization
(mono-sodium phosphate, 580 lbs P/ac)



Role of silvicultural research

- SMC Type V Paired Tree N Fertilization trials
- Objective: To identify site factors that can predict the level of response to N fertilization
- Kim Littke Ph.D. dissertation

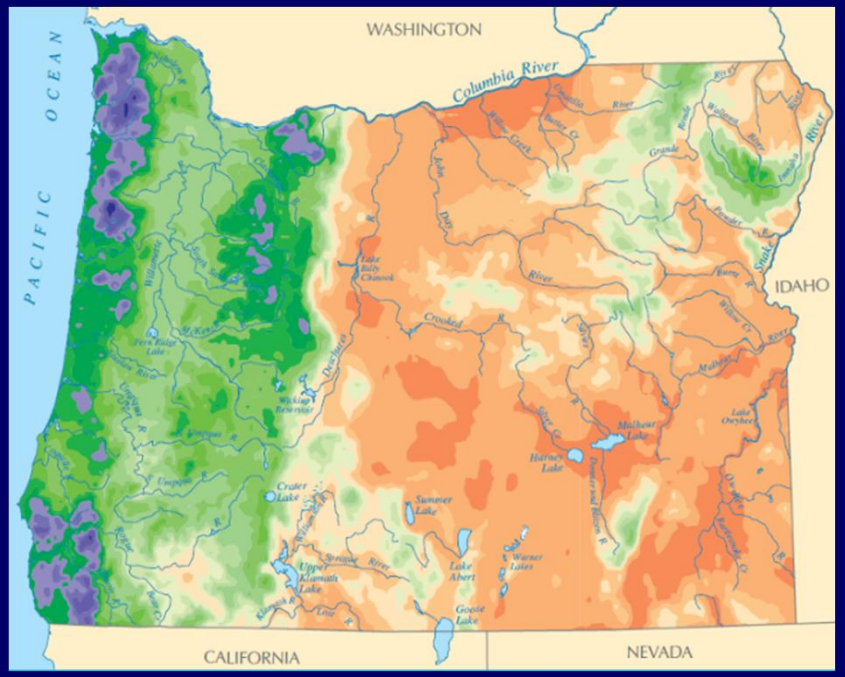


Role of silvicultural research

- Strong move toward more detailed (and hopefully accurate?) site information (parent material, soils and climate)

Geologic substrate

Annual precipitation



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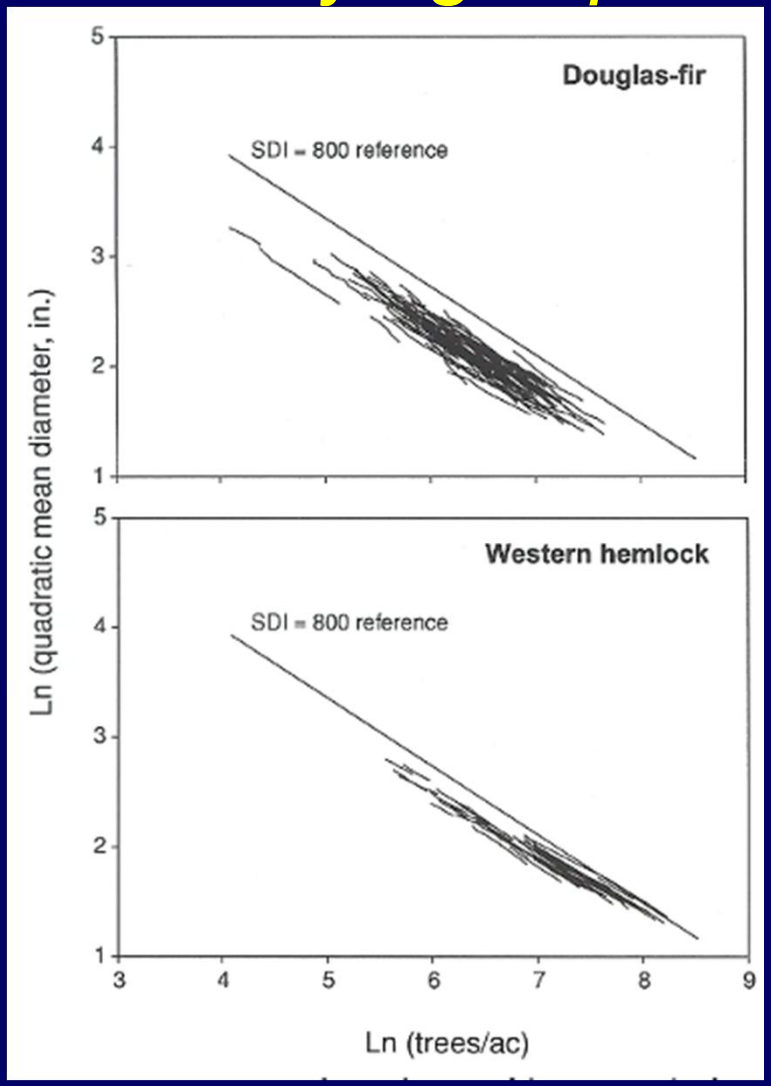
Growth, Yield, and Productivity

Carrying capacity is difficult to predict



Maximum SDI for individual permanent plots:

Douglas-fir

270-660

Western hemlock

470-780

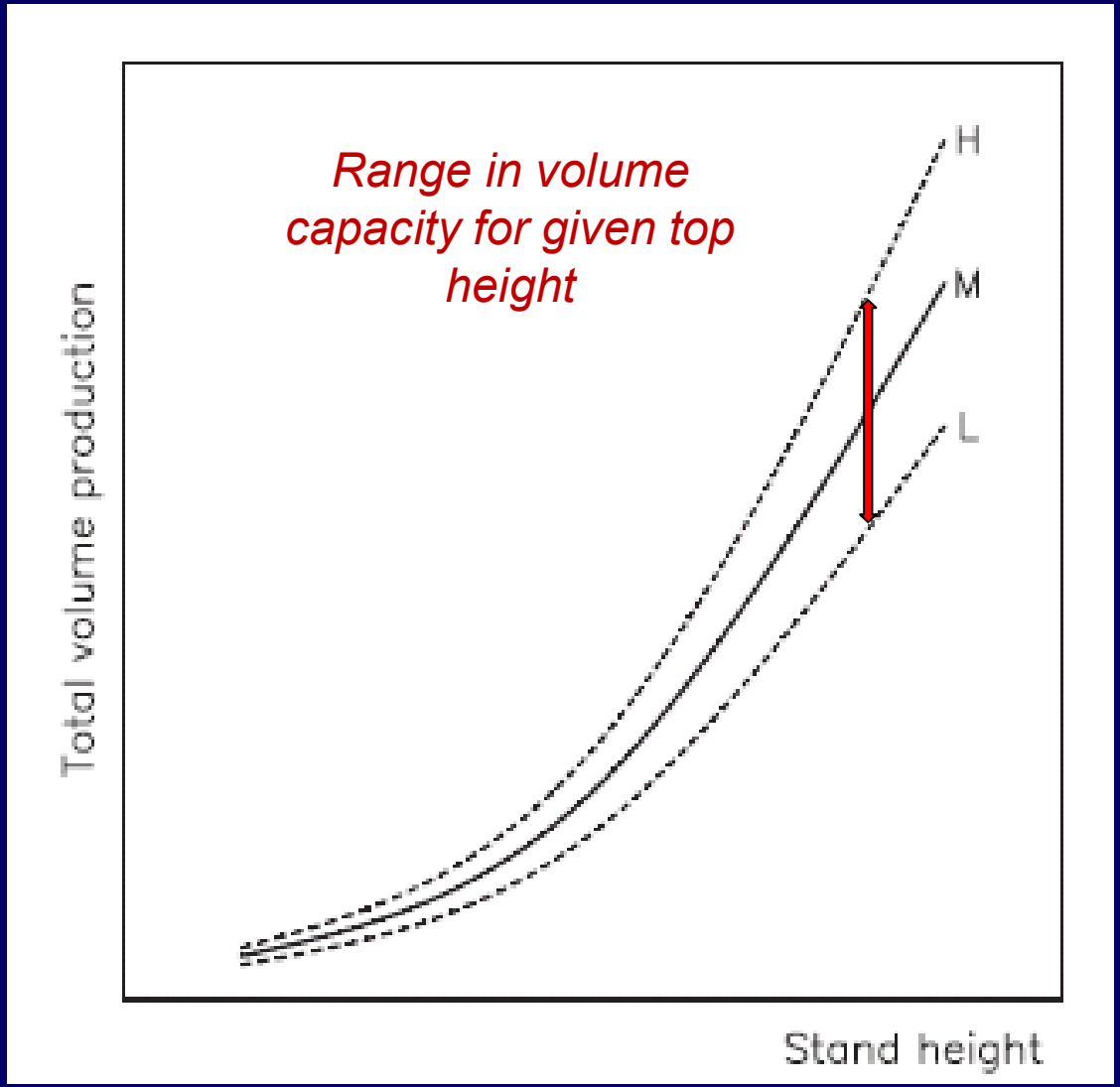
- Practical significance?
- Effects of spatial distribution or initial stand structure in general?

Hann et al. 2004

Assman's modification of Eichhorn's rule

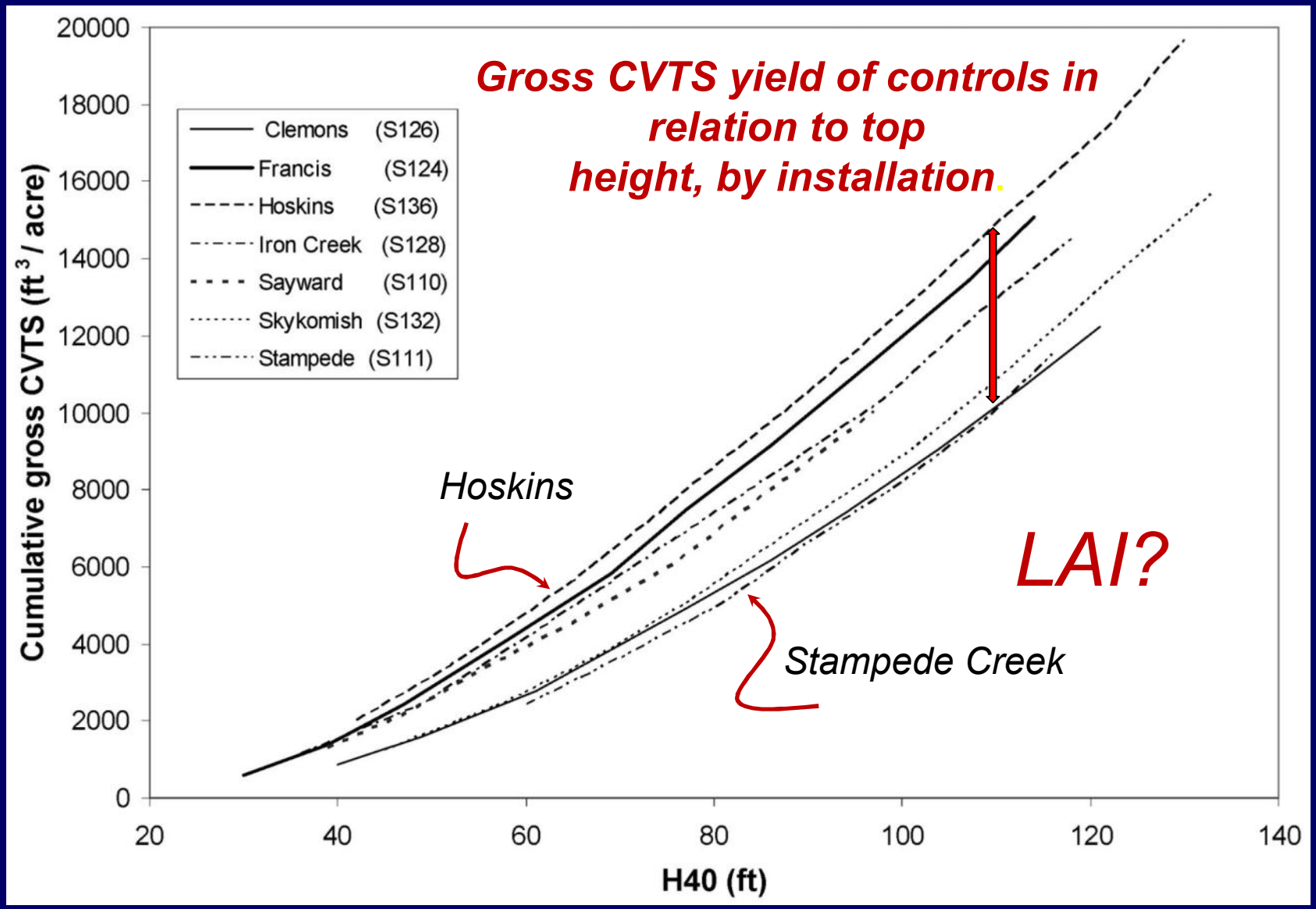
Eichhorn's rule: stands with a give top height at full stocking will have same volume

Assmann's yield level theory: stands have differing carrying capacity at given top height

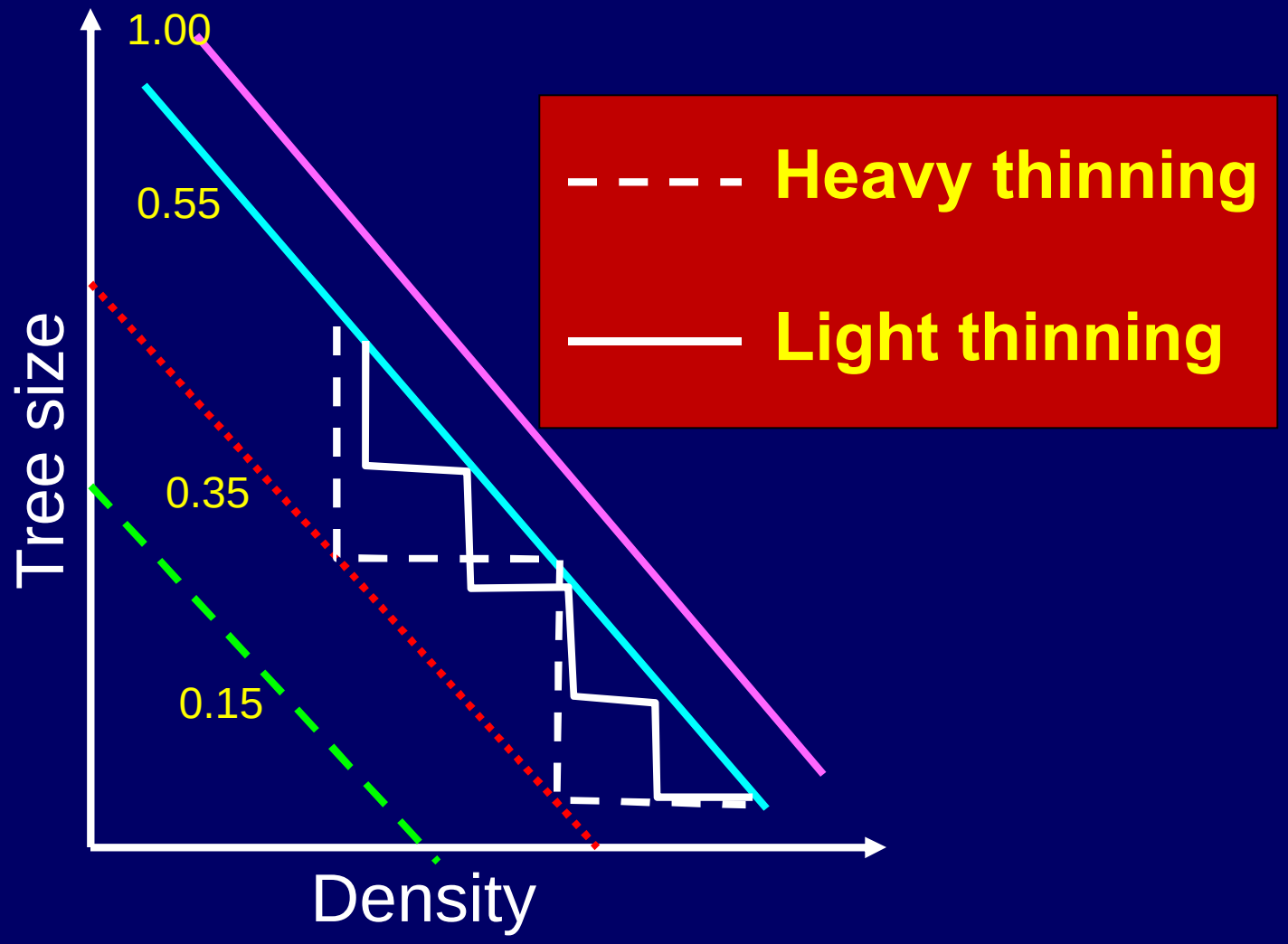


Douglas-fir Levels-of-Growing-Stock Study

(Curtis 2006)



Role of silvicultural research



Role of silvicultural research

Economic performance

(Stephen Levesque- 50% of investment growth from biological growth)

- IRR (Internal Rate of Return) (Cubbage 2005)
  - Exotic species plantations 10-24 %
  - Native species plantations 4-10 %
  - Managed natural stands 4-6%

Role of silvicultural research

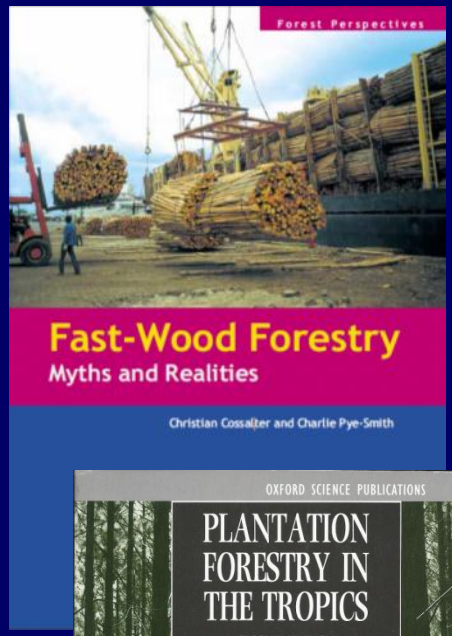
Table 2 Timber investment mean annual increments from Tomberlin and Buongiorno (2001), and Sedjo (1983); annual internal rates of return (IRRs) for forest plantation investments from Sedjo (2001)

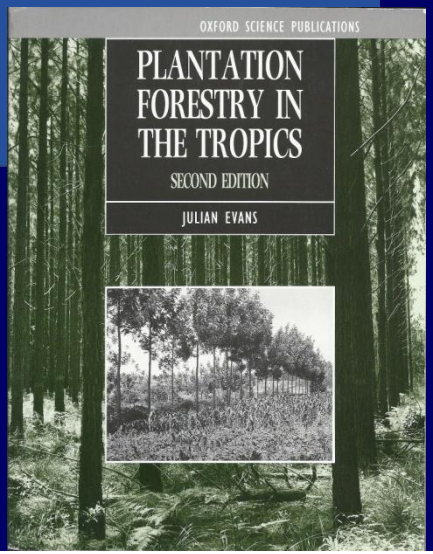
Country/Species	Mean annual increment (m^3/ha/year)		Internal rate of return (%) Sedjo (2001)	
	Tomberlin and Buongiorno (2001)	Sedjo (1983)	Pulpwood	Sawtimber
US South—*Pinus taeda*	10	11.9	12.0–13.9	12.4–14.1
US Pacific Norhwest—*Pseudotsuga menziesii*	Na		7.1–8.8	7.1–9.6
Brazil Central—*Eucalyptus sp.*	30–70	25.0	20.2	15.5
Brazil South—*Pinus taeda*	16	20.0	15.6	17.5
Chile—*Pinus radiata*	20–24	22.0	23.4	16.0–17.5
New Zealand—*Pinus radiata*	20–24	25.0	11.9	11.1–13.1
South Africa—*Pinus patula*	10–25	16.1	19.3	16.2–17.7
Europe—*Picea abies*	2.5	5.0	4.6	5.6

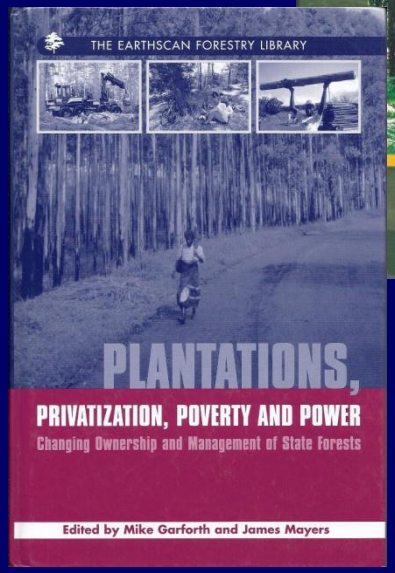
Cubbage et al. 2007. New Forests

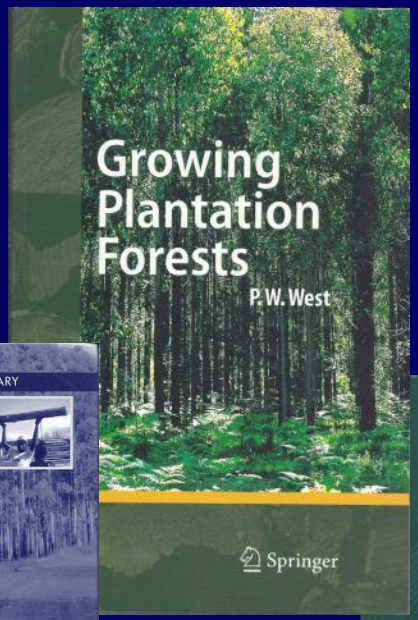
Role of silvicultural research

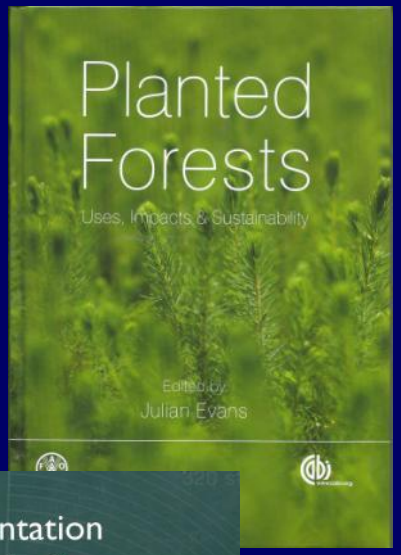
Social, political, environmental issues with respect to forest plantations

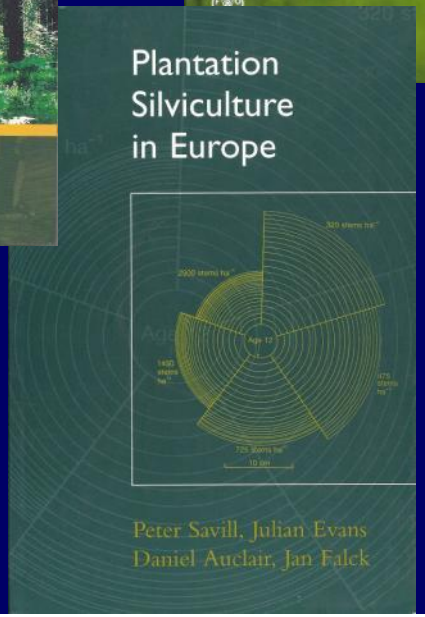












Role of silvicultural research

May 2006

The Possibility of Plantations:

Integrating Ecological Forestry into Plantation Systems

Role of silvicultural research

- Techniques which transcend the historically narrow and intensive focus on productivity need to be more vigorously explored and encouraged

- These complex plantation models would help to protect and retain the ecological resilience and economic productivity of our plantation landscapes.

- Maintenance of landscape connectivity
- Maintenance of landscape diversity
- Maintenance of structural diversity at stand level
- Maintenance of integrity and protection of aquatic ecosystems and riparian zones.
- Variability in management actions

Role of silvicultural research

- Options for timber production
  - Manage very intensively in "environmentally robust" areas, close to markets, sufficiently high productivity
  - Co-produce timber and other "ecosystem services" in all or only some areas
  - Bill Atkinson JoF article on "zonal forestry"



Role of silvicultural research

- Influence/impact on research?
  - Impacts by default (current approach): Implementation of silvicultural treatments/regimes that are affordable and appropriate to current markets, PLUS a little exploration beyond what is currently operationally feasible; THEN, assess effects on other ecosystem functions

Role of silvicultural research

- Influence/impact on research?
  - Impacts by design: Identify and implement treatments/regimes that have predictable ecosystem effects
    - Achieve balance/compromise between economic and environmental performance
    - Eliminate practices that have little effect on economic performance but significant environmental benefits

No thinning

Heavy thinning

Role of silvicultural research

Discussion at Stand Management Cooperative Spring Meeting (April 19, 2012)

- Research
  - Building science base
  - Hypothesis testing
  - Dose-response
  - Quantifying and simulating growth, yield, and wood quality
- Development
  - Decision-making tools
  - Growth simulation software
  - Synthesis of models and/or information from models
  - Economic analysis software

Role of silvicultural research

- Field trials as designed experiments ï building a robust science base
- By necessity we explore the ramifications of what we think we know ï long-term nature of forestry forces educated guesses
- Combining data and experience - growth models as our best shot at merging data and current concepts (e.g., CIPS)
- Professional experience as the reality check and feedback on growth models


Thanks for your attention !

Veracel pulp mill

photos by Jim Carr, Menasha

Role of silvicultural research

ÅIntensive management

- Applies to both even-age and uneven-age management
- Applies to both naturally regenerated stands and planted forests
- Management intensity is a gradient, as are ñplanted forestsòand ñplantationsò(e.g., enrichment plantings versus eucalypt clones)

Role of silvicultural research

Ponderosa pine plantation

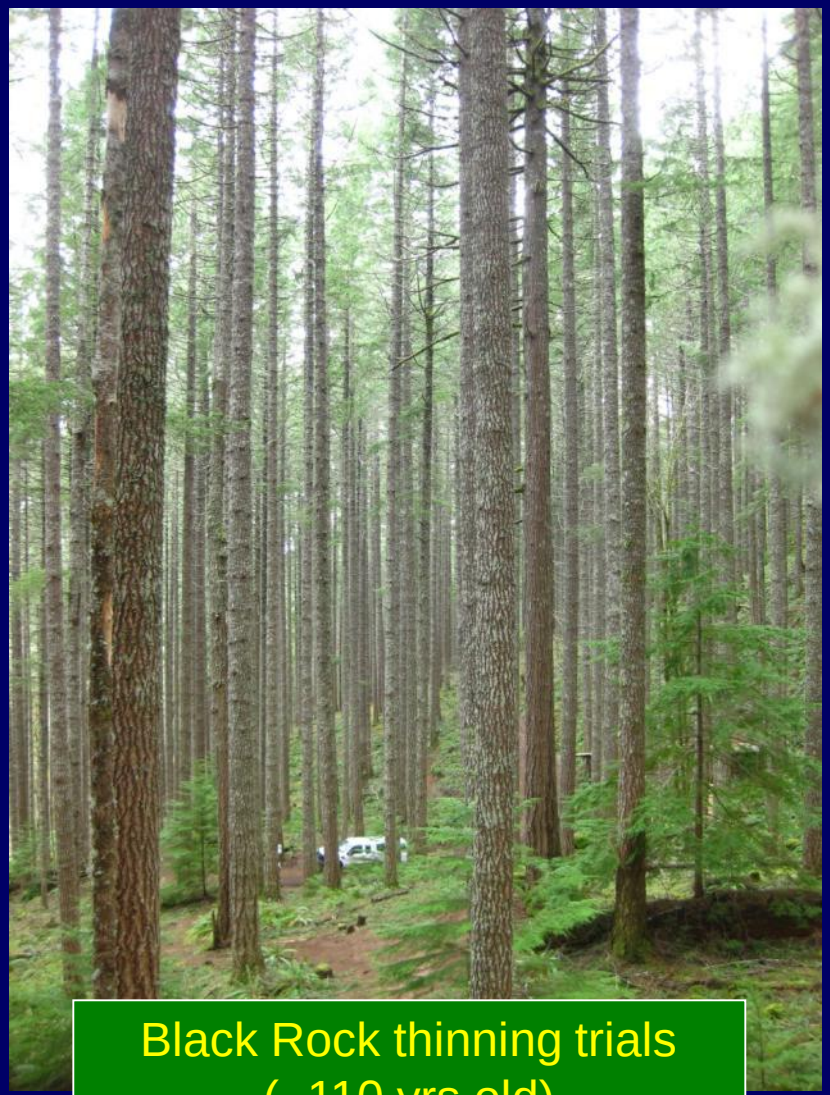
Ponderosa pine uneven-aged management

Role of silvicultural research

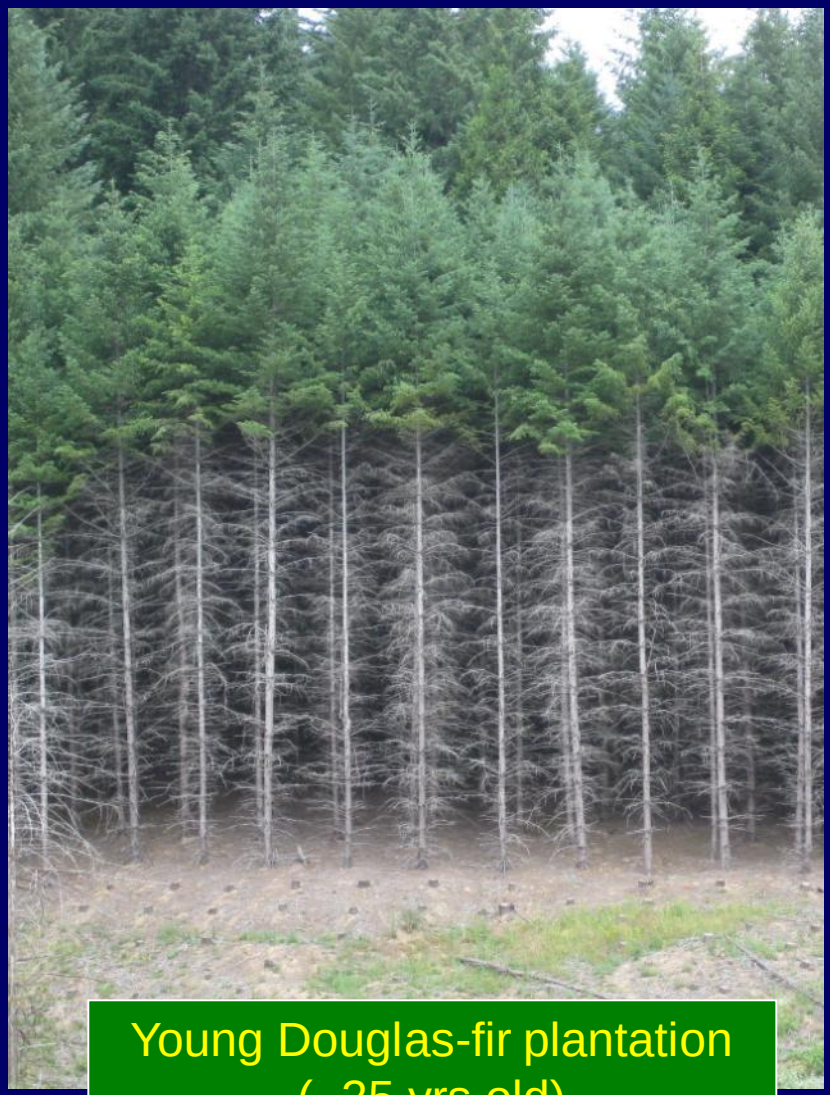
ÅIntensive management

- Applies to both even-age and uneven-age management
- Applies to both naturally regenerated stands and planted forests
- Management intensity is a gradient, as are ñplanted forestsòand ñplantationsò(e.g., enrichment plantings versus eucalypt clones)

Role of silvicultural research



Black Rock thinning trials
(~110 yrs old)



Young Douglas-fir plantation
(~25 yrs old)

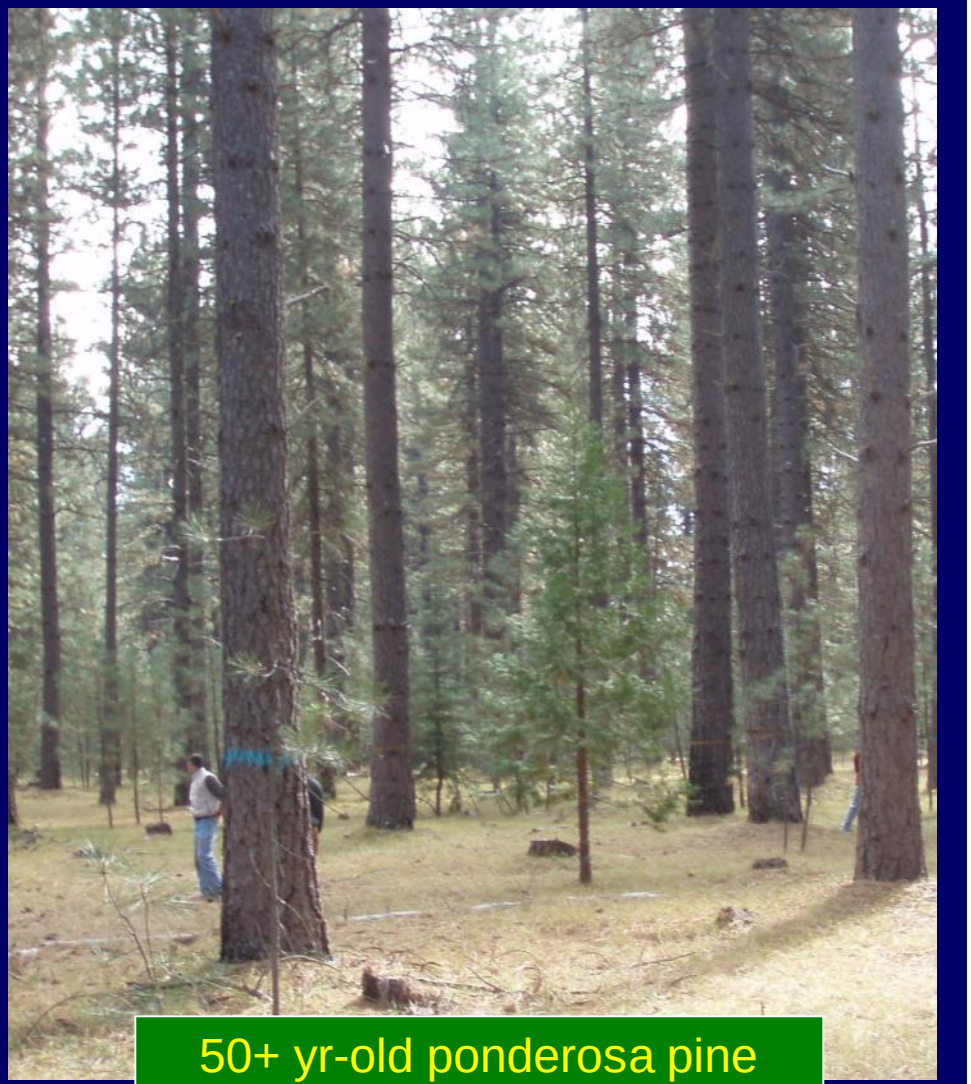
Role of silvicultural research

ÅIntensive management

- Applies to both even-age and uneven-age management
- Applies to both naturally regenerated stands and planted forests
- Management intensity is a gradient, as are ñplanted forestsòand ñplantationsò(e.g., enrichment plantings versus eucalypt clones)

Eucalyptus clonal plantations in Brazil

7-yr-old eucalypt plantation



50+ yr-old ponderosa pine plantation

Role of silvicultural research

Role of silvicultural research

- Landscape structure requires:
  - Constraints on and modifications to harvest schedules
  - Coordination among landowners

Role of silvicultural research

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Role of silvicultural research

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Role of silvicultural research

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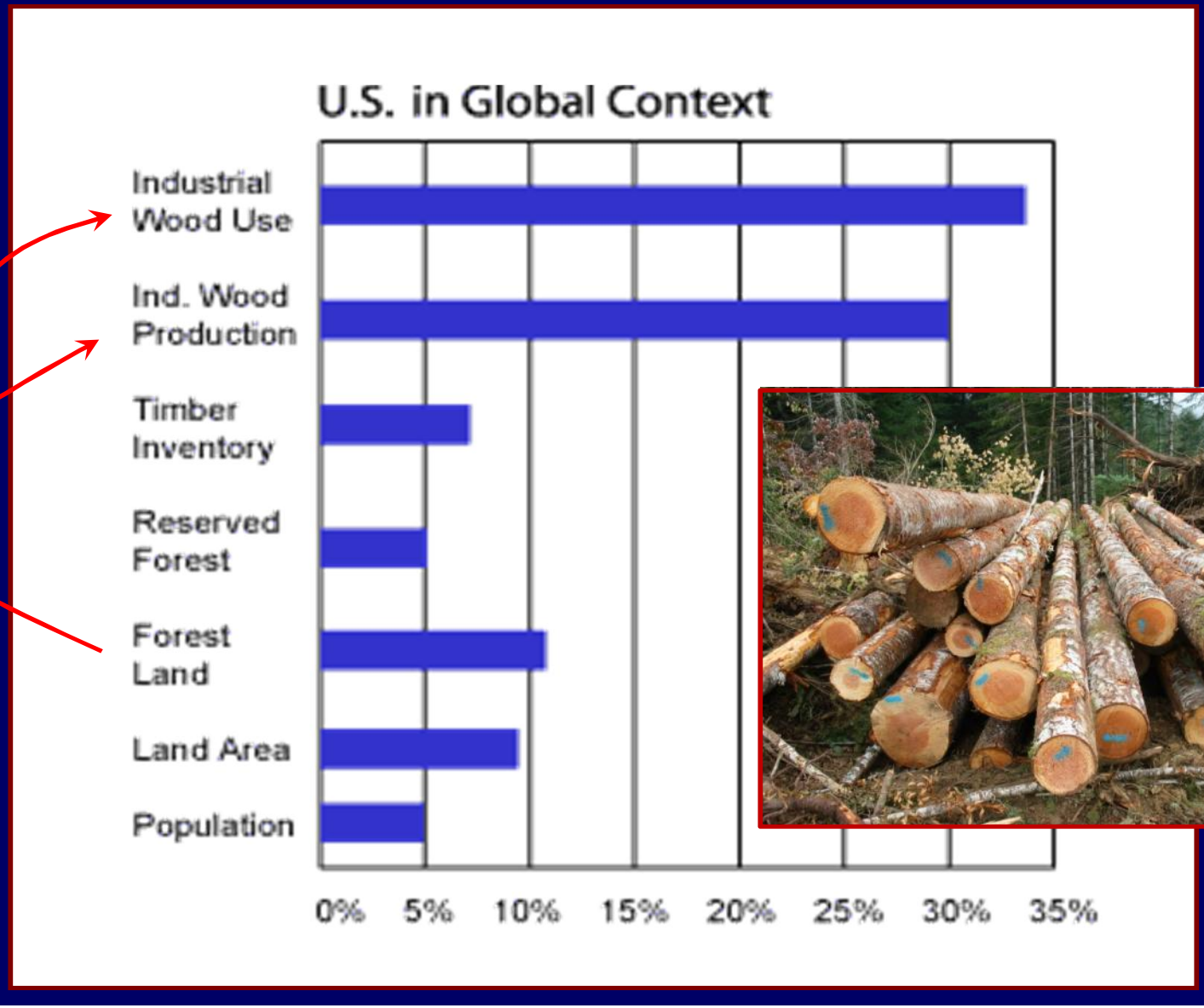
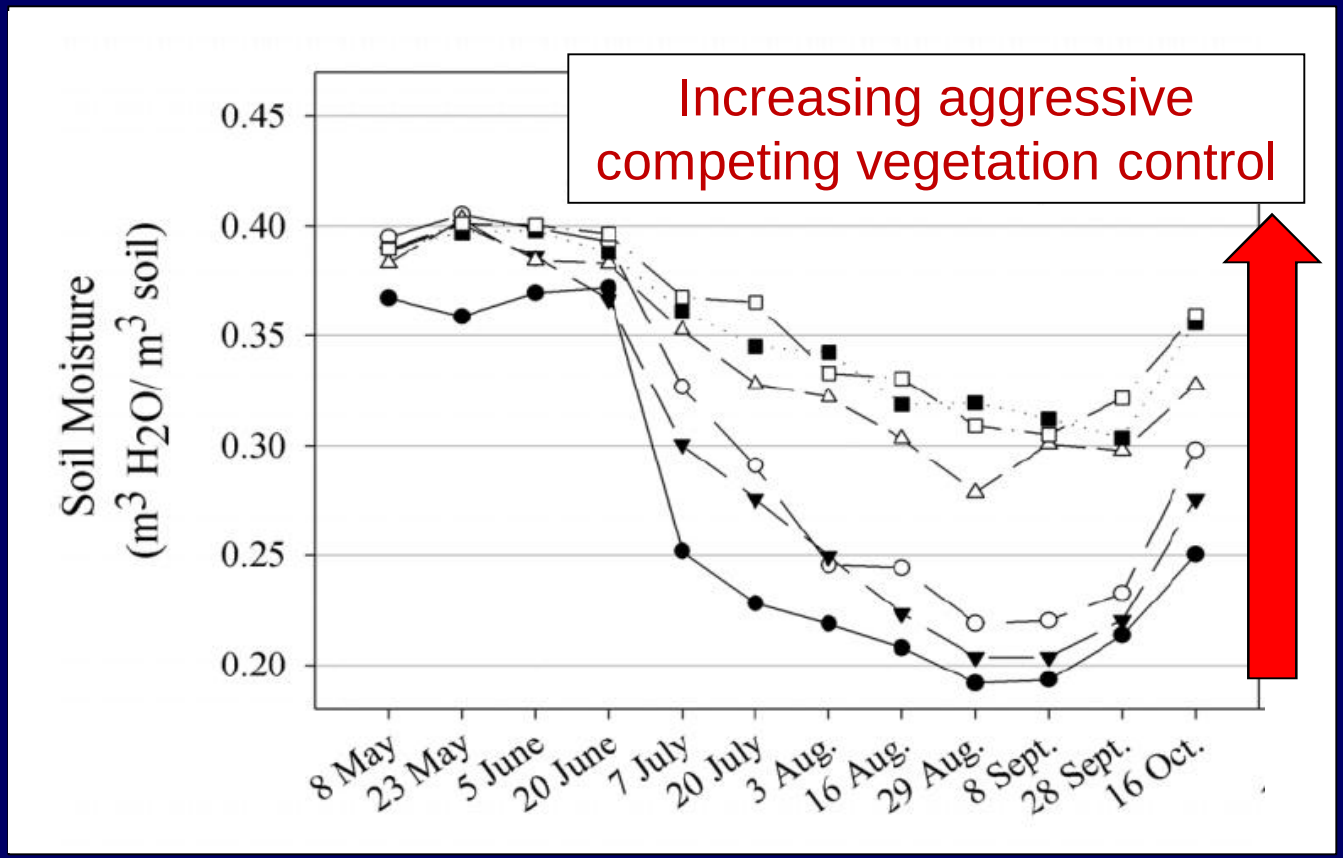
Role of Silvicultural Research in the Future of Forest Management in the Pacific Northwest



Role of silvicultural research

Vegetation Management Research Cooperative

Concurrent monitoring of soil moisture, seedling water stress, and growth over six alternative regimes for controlling competing vegetation

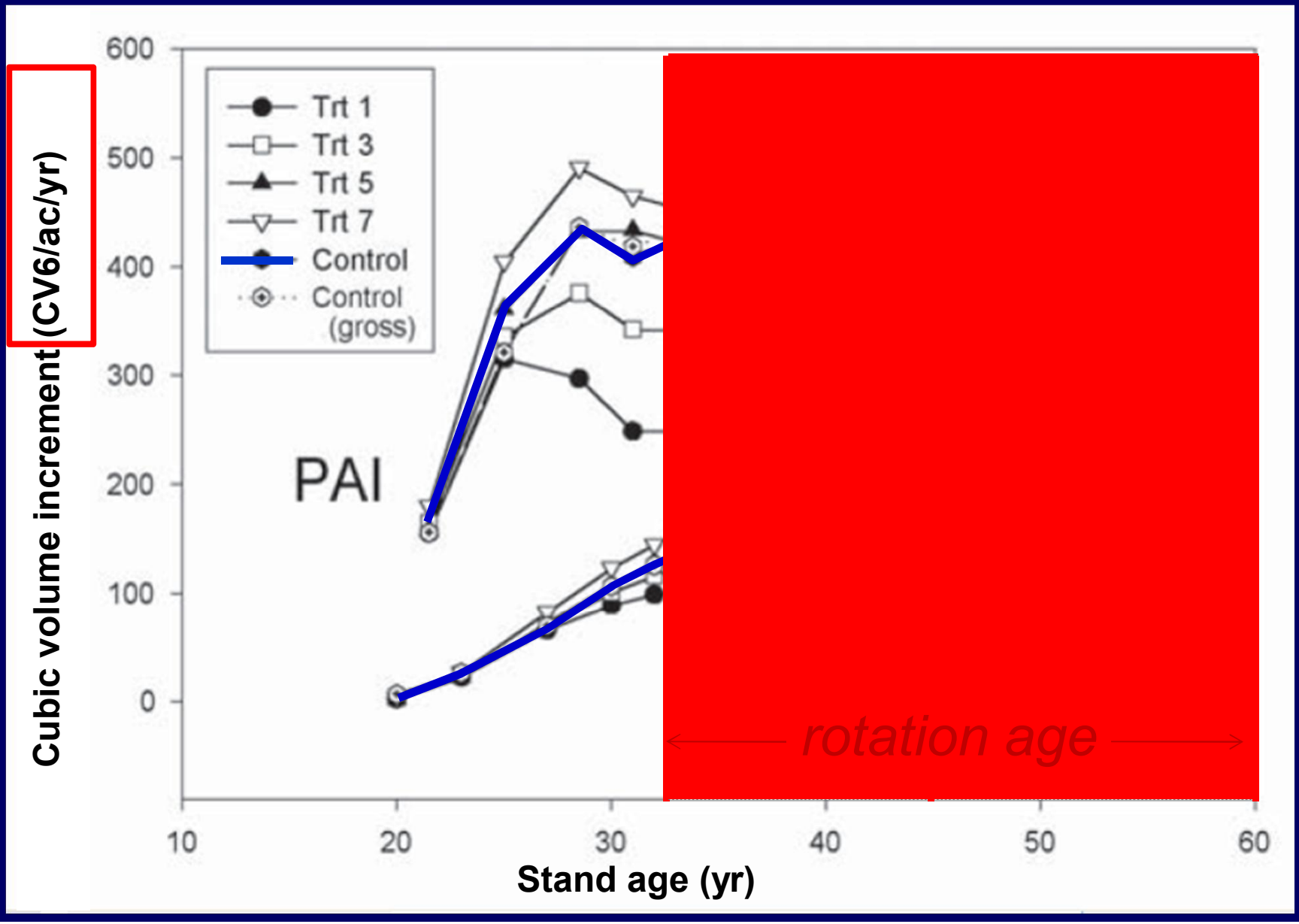


Dinger and Rose 2009

Role of silvicultural research

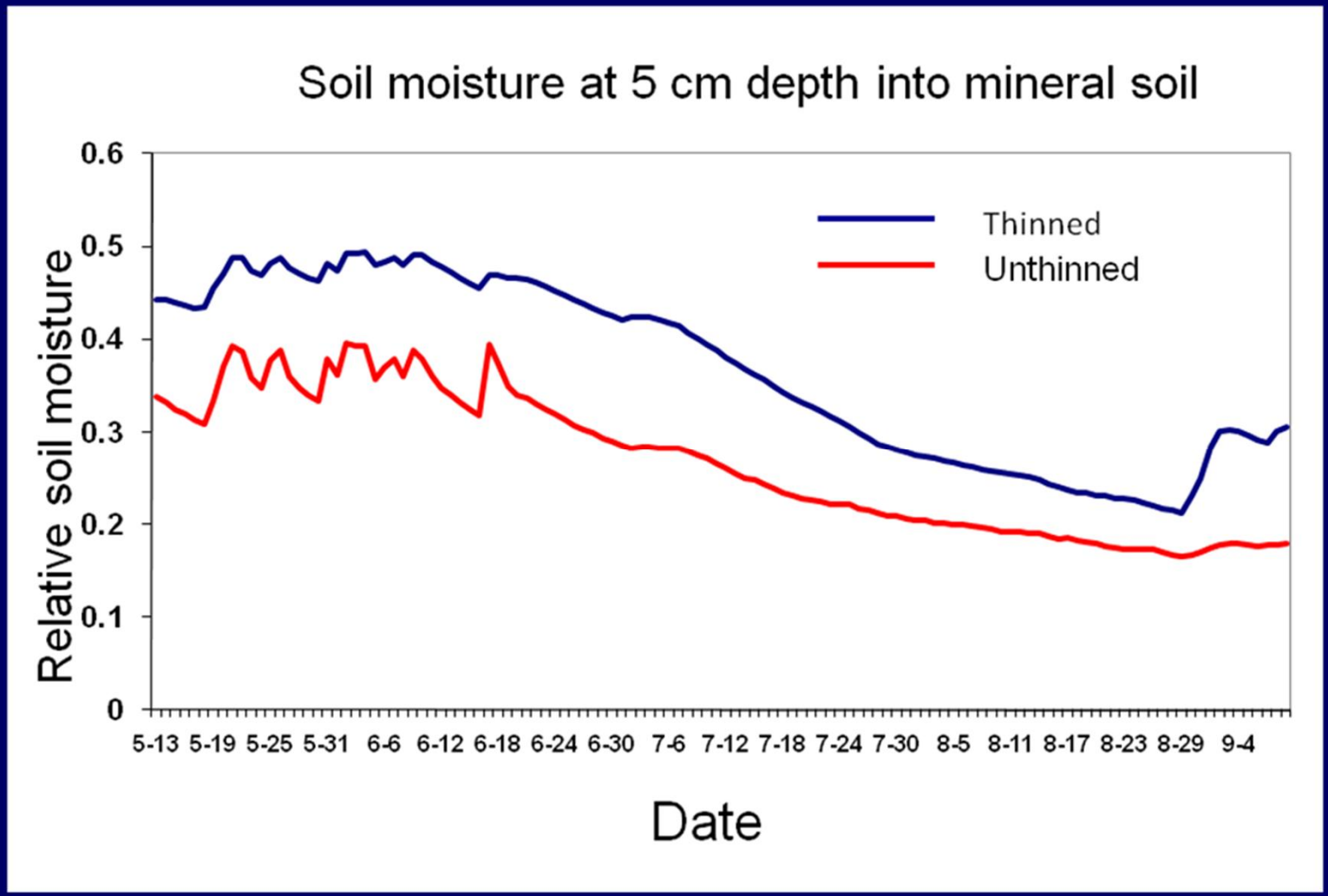
- Douglas-fir Regional Levels-of-Growing-Stock (LOGS) Study

Trends in MERCHANTABLE CUBIC VOLUME PAI and MAI on Hoskins LOGS plots



Role of silvicultural research

Soil moisture sensors at Starker Forests thinning site



Role of silvicultural research

Within-stand diversity can be imposed by density regime and variability in spacing in single-species stands (Douglas-fir LOGS)

No thinning

Heavy thinning

Role of silvicultural research

Å Options for vegetation structure with uncertain (unquantified) tradeoffs (exotic eucalypt plantations)

Role of silvicultural research

- Side benefits of improved nutrition from:
  - site preparation
  - competing vegetation control
  - pre-commercial thinning/cleaning
  - commercial thinning
- Mechanisms
  - release of nutrients from cut/treated plants
  - increase in soil temperature, moisture, organic matter -> accelerate mineralization
- Interplay between water availability and response to N fertilization (Garber, Littke)

Role of silvicultural research

- Product uniformity (contôd)
  - Can uniformity be improved in the PNW? Is it possible?
  - Will uniformity be environmentally acceptable in PNW with respect to other functions of plantation ecosystems?
  - Other functions of plantation ecosystems better met by lack of uniformity, e.g., variable spacing, species diversity, ñcomplexityò

Role of silvicultural research

- Issues/topics of current research
  - Logging slash treatments: soil carbon dynamics; growth effects (Harrington and Schoenholtz)

Role of silvicultural research

- Chemical site prep
  - Reduce intensity of more risky release treatments?
    - favorable weather for treatment application and treatment efficacy
    - potential damage to crop trees
    - known and unknown environmental effects
    - political liabilities from chemical use
  - "Trees and dirt" discussion from Reforestation conference in Eugene

OSU College of Forestry

Scholarship & stewardship working together for a sustainable future

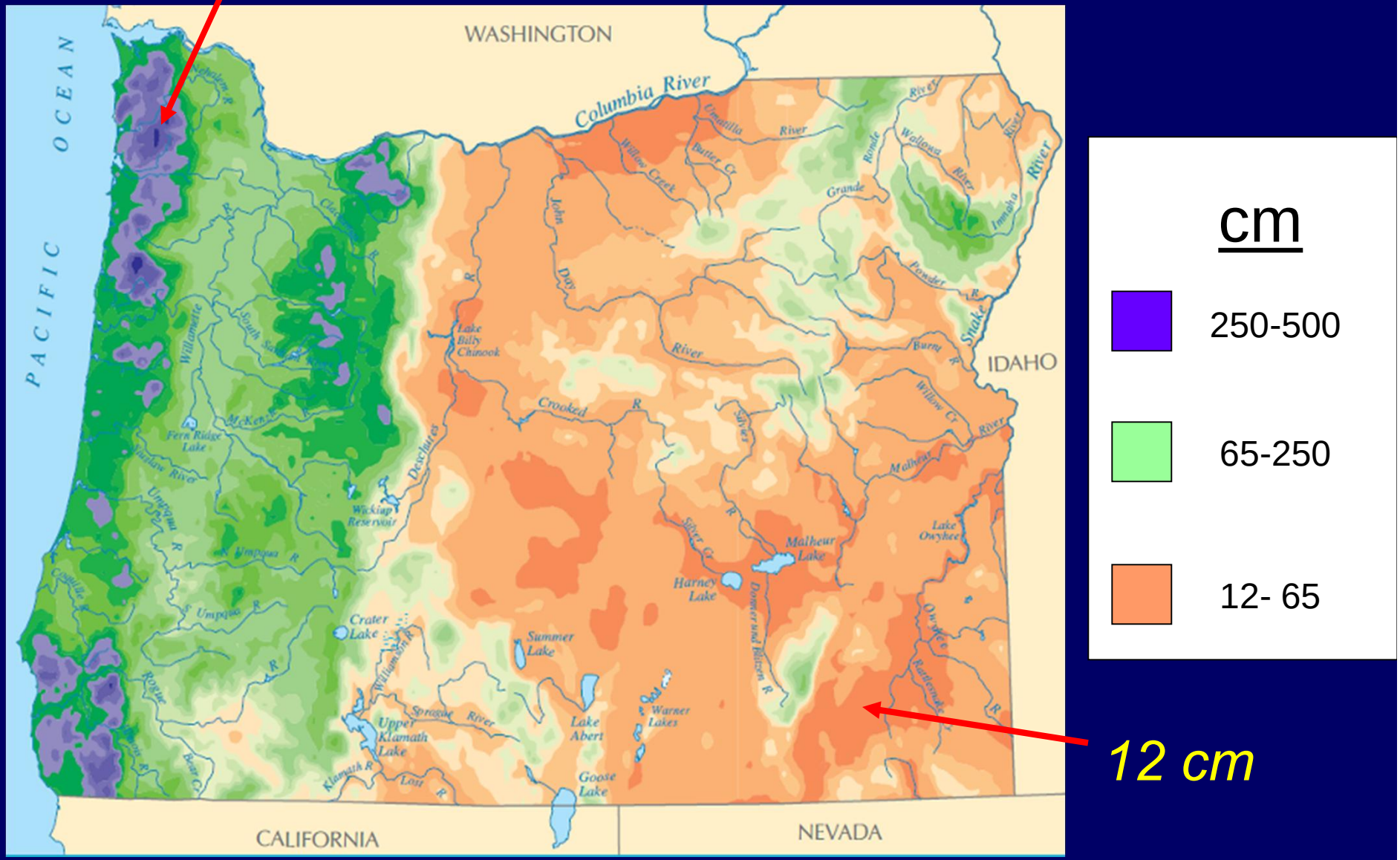
CIPS

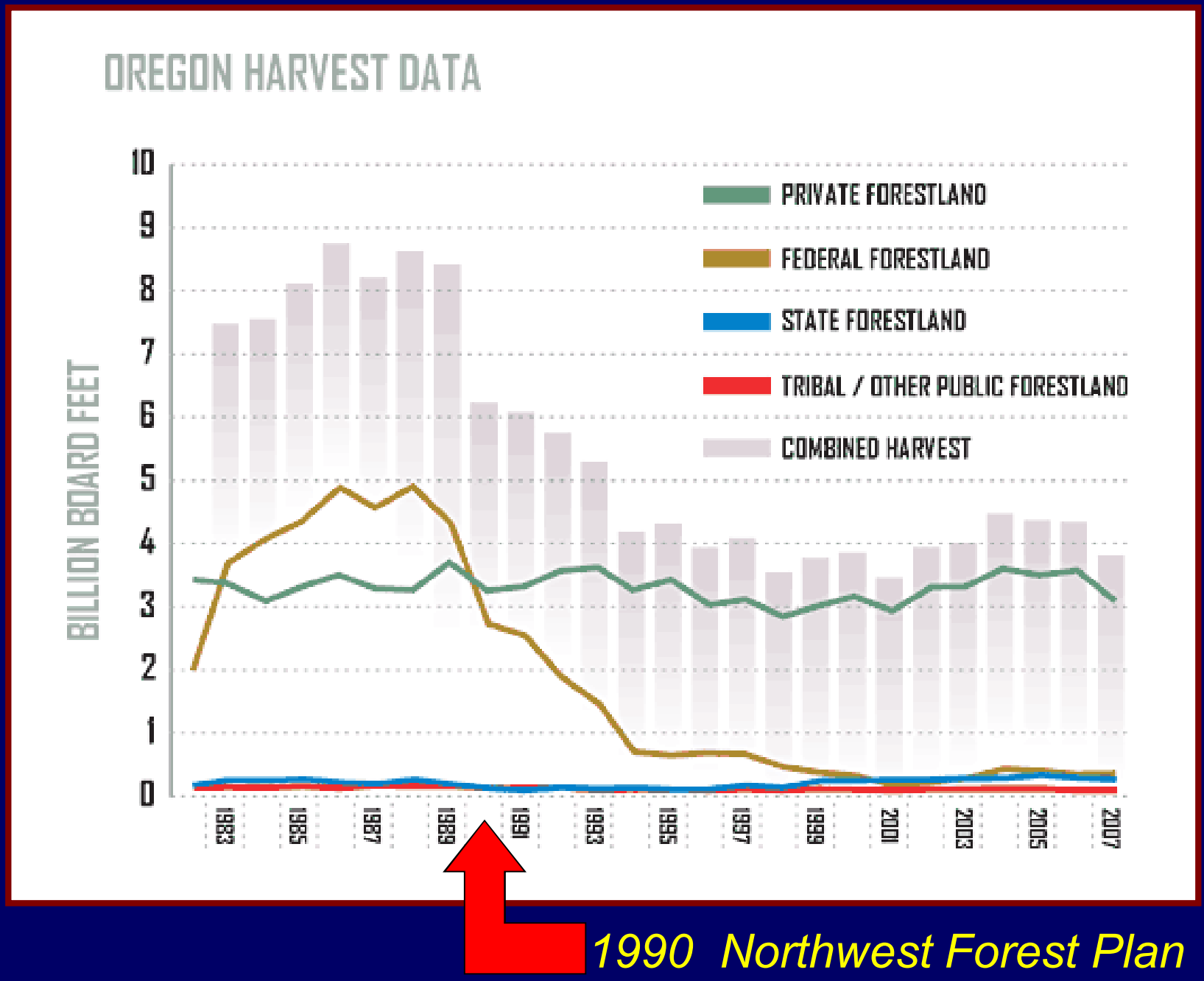
Fertilization Trials
15 installations

Cascade Timber
Giustina
Green Diamond (2)
Hampton (2)
Lone Rock
Menasha (2)
ODF
OSU
Port Blakely
West ForkTimber
Weyerhaeuser (2)

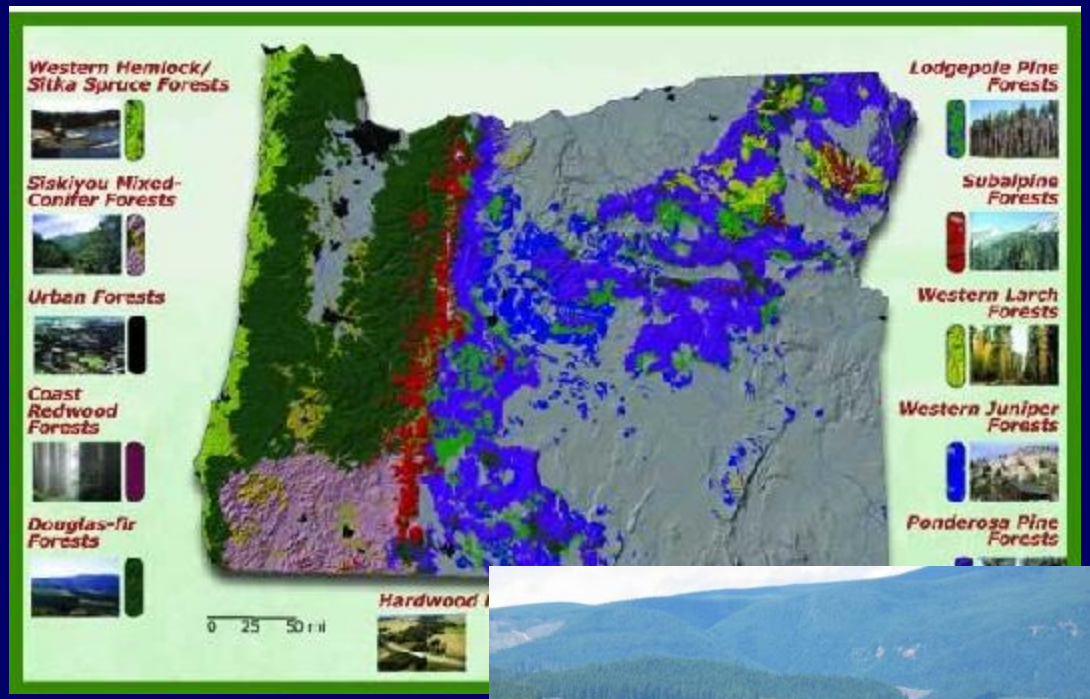
Treatment	Form	Amount	Reason for inclusion
Kinsey	Blend	Site specific	Scientific and industry interest in overall nutritional limits to productivity
Fenn	Blend	Site specific	Scientific and industry interest in overall nutritional limits to productivity
Control	- -	- -	Statistical reference for treatments
Lime	$CaCO_3$	1000 kg Ca / ha	Preliminary success, elevates pH, reduces Al, adds Ca: compare to Ca-only treatment
N	Urea	224 kg N / ha	Standard approach, examine effects of adding N to N-rich sites
P	Na_3PO_4	500 kg P / ha	Can limit growth in highly weathered soils, some sites have P-fixing soils
Ca	$CaCl_2$	100 kg Ca / ha	Low soil and foliar Ca is common at our sites, attributable to high soil N

Annual precipitation

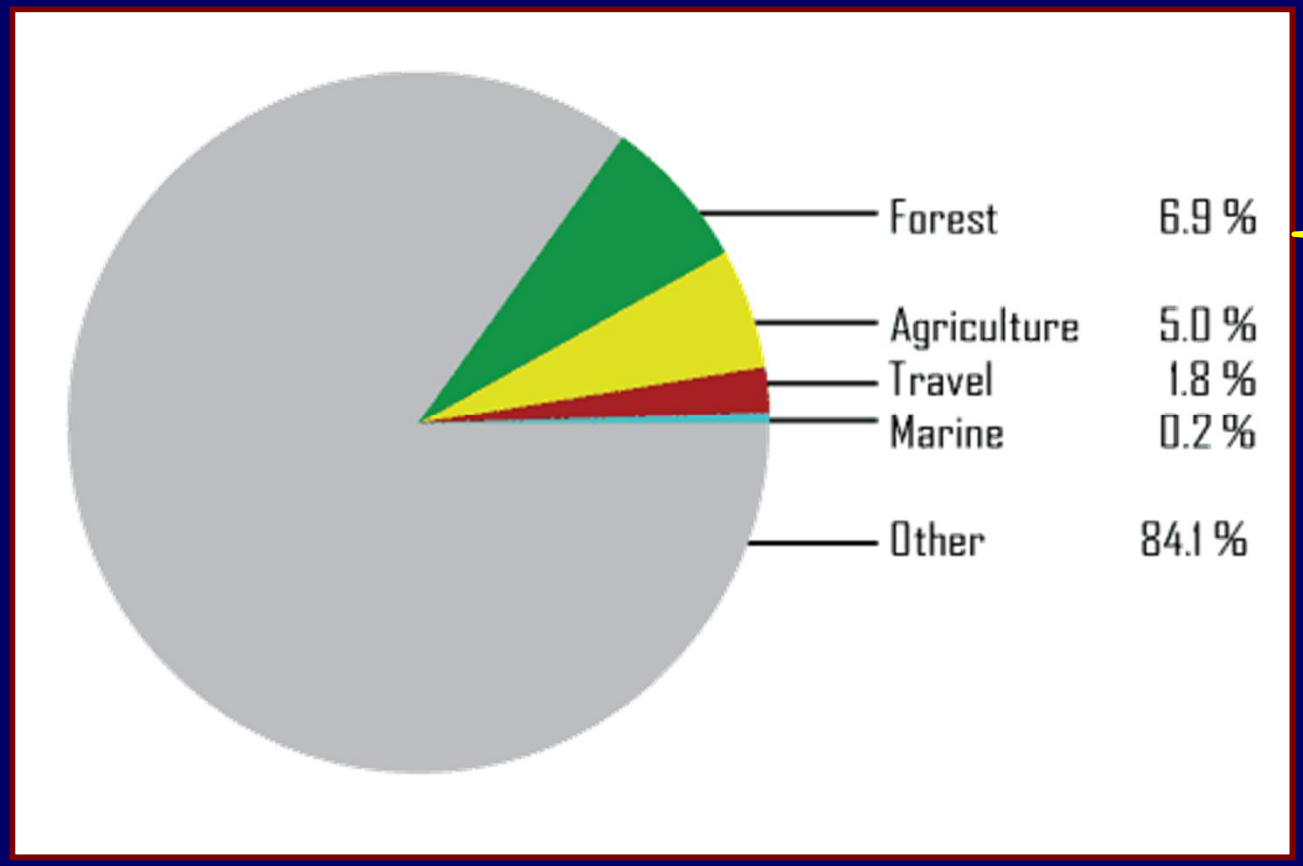



OREGON HARVEST DATA
BILLION BOARD FEET
10
9
8
7
6
5
4
3
2
1
0
PRIVATE FORESTLAND
FEDERAL FORESTLAND
STATE FORESTLAND
TRIBAL / OTHER PUBLIC FORESTLAND
COMBINED HARVEST
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
1990 Northwest Forest Plan

Management objectives in Oregon forests



In year 2000 the forestry sector contributed $12.6 billion to the stateôs economy.



Primary wood products (lumber, veneer, plywood)

Secondary wood products (doors, windows)

Forestry services (consulting, fire fighting, reforestation)

OSU College of Forestry

Scholarship & stewardship working together for a sustainable future

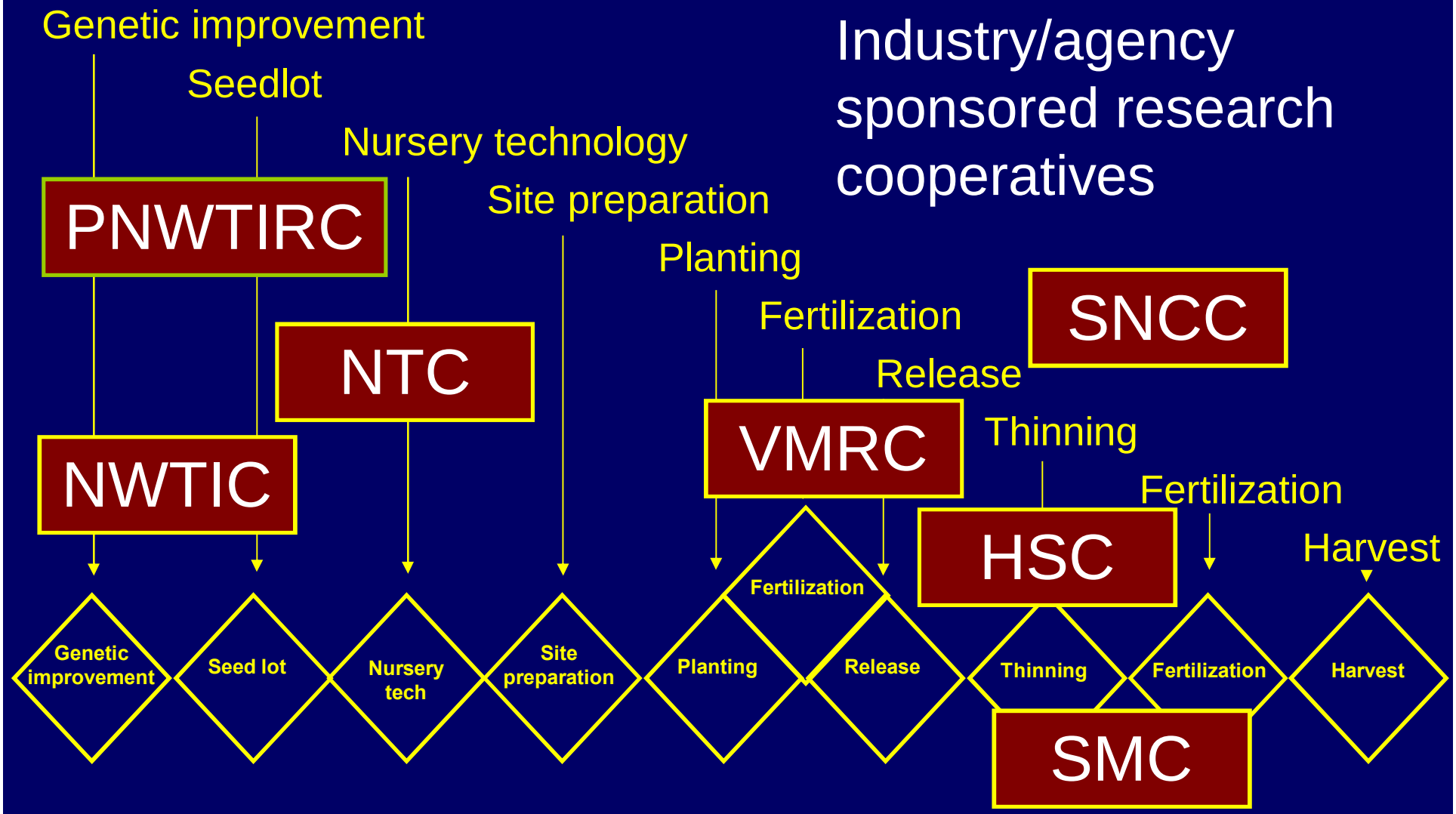
Center for Intensive Planted-forest Silviculture

Compromise:

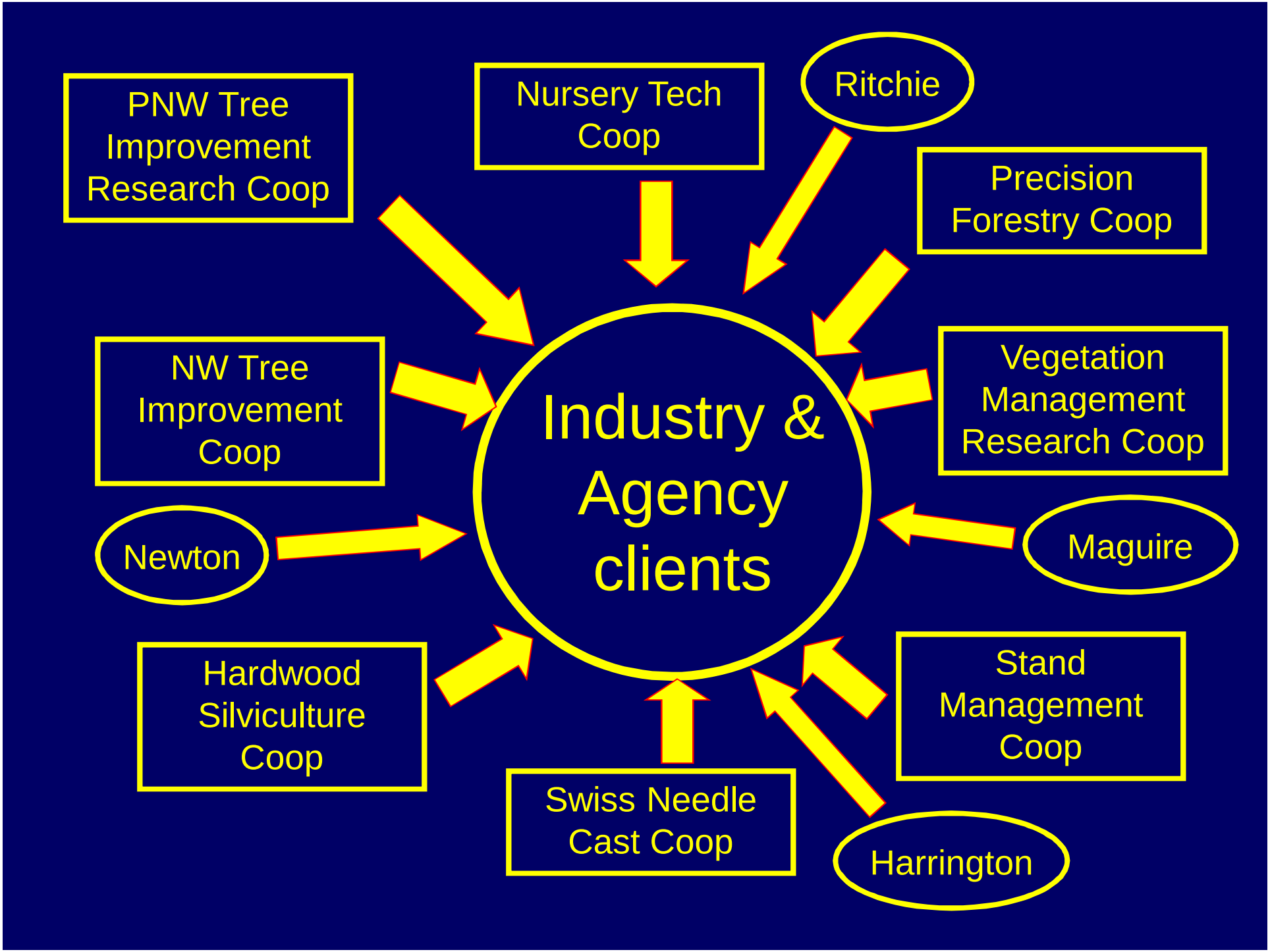
- Synthesis
- Science base
- Reword system
- Software complexity

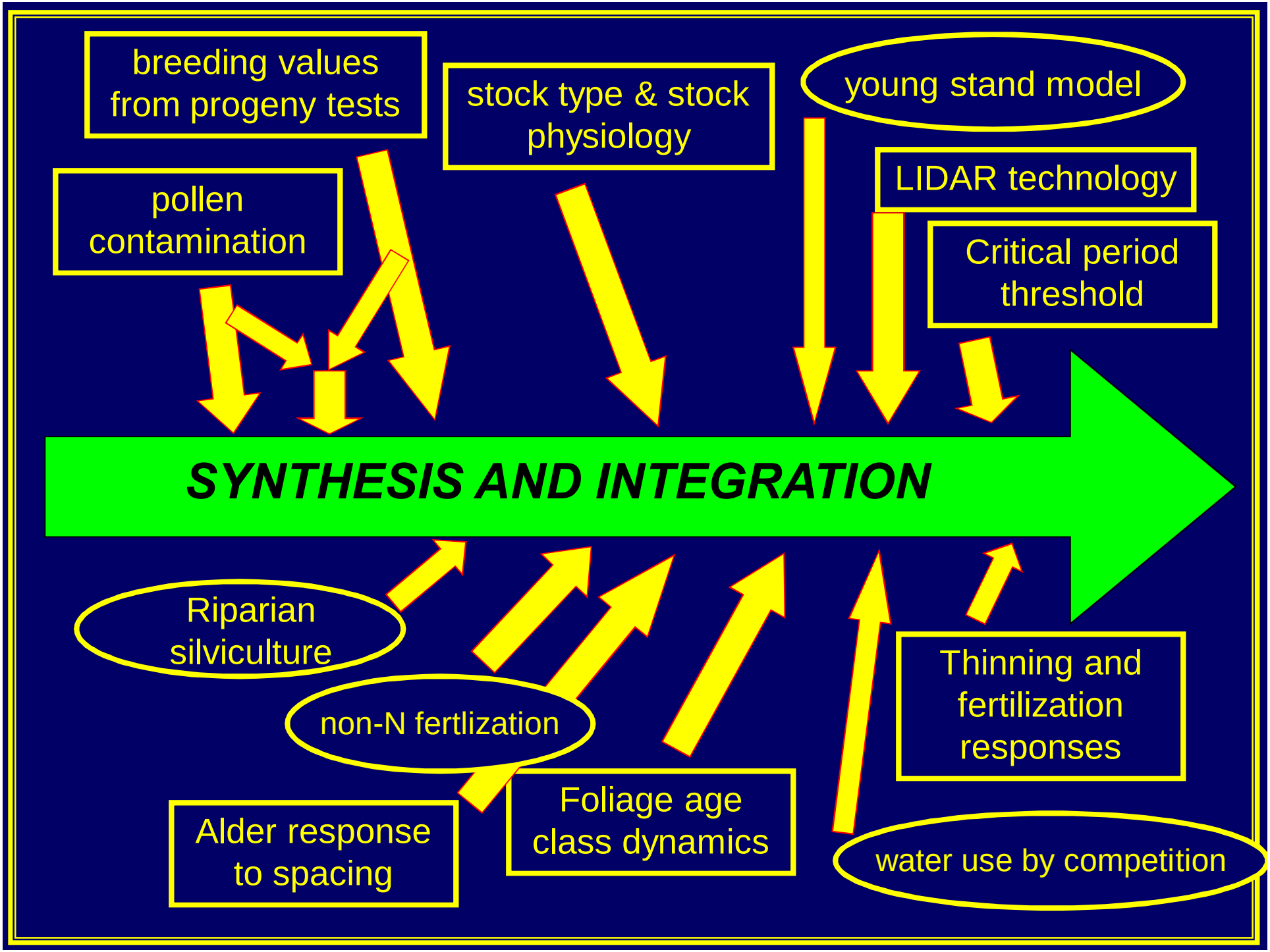
Project initiation 2009

Silvicultural technology



Industry/agency sponsored research cooperatives


PNW Tree Improvement Research Coop
Nursery Tech Coop
Ritchie
Precision Forestry Coop
NW Tree Improvement Coop
Industry & Agency clients
Vegetation Management Research Coop
Newton
Maguire
Hardwood Silviculture Coop
Stand Management Coop
Swiss Needle Cast Coop
Harrington


breeding values from progeny tests
stock type & stock physiology
young stand model
pollen contamination
LIDAR technology
Critical period threshold
SYNTHESIS AND INTEGRATION
Riparian silviculture
non-N fertlization
Foliage age class dynamics
Thinning and fertilization responses
Alder response to spacing
water use by competition

CIPS Mission

To understand the interactive effects of genetics, silviculture, protection (from insects, disease, and animal damage), competition, nutrition, and soils on the productivity, health, and sustainability of intensively-managed, planted forests.

CIPS Vision

To develop and maintain a comprehensive, science-based decision-support system for intensive silviculture of planted forests in the Pacific Northwest,

By conducting collaborative research between existing cooperatives, institutions, and researchers to address long-term and interactive effects of the chain of treatments constituting a silvicultural regime

With a major emphasis on identifying priorities for research from the perspective of knowledge gaps in the decision-support system

For the purpose of enhancing the global competitiveness of Pacific Northwest forests and producers of forest products.

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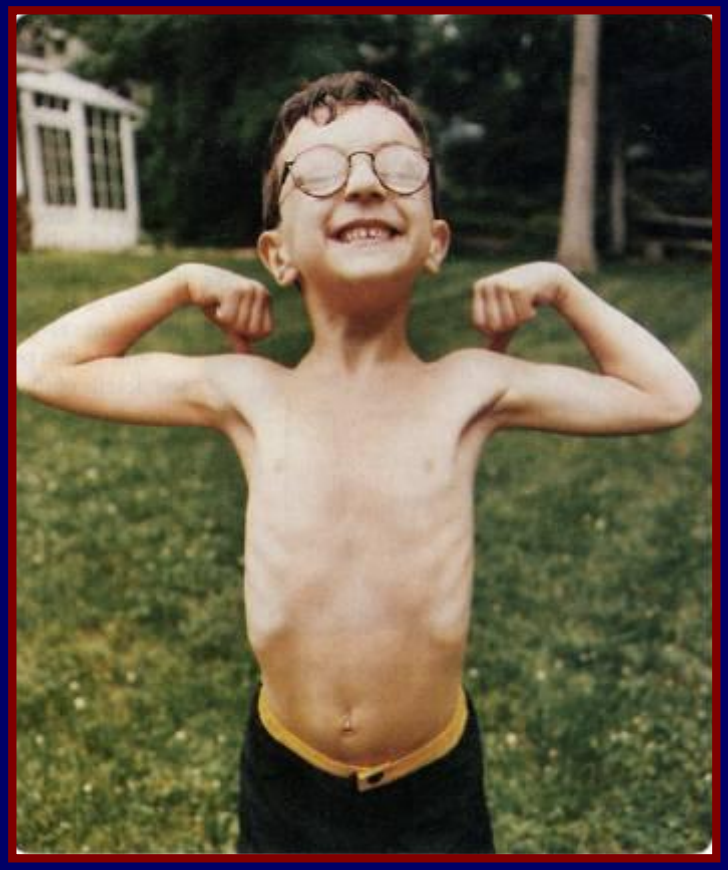
Good nutrition ï should foresters worry about it?



Until very recently, many if not most, corporate landowners fertilized Douglas-fir with 220 kg N / ha.

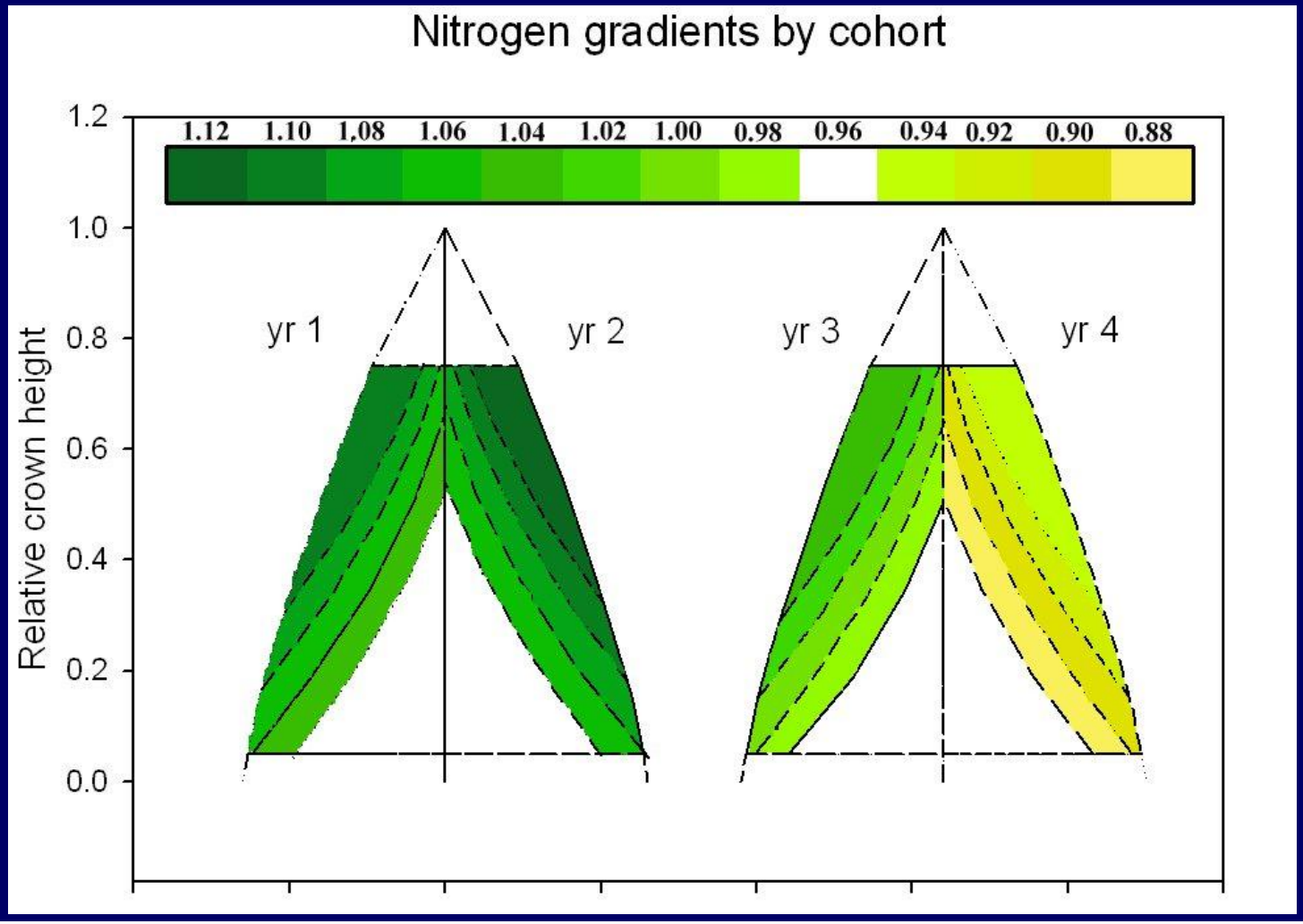
On average, growth was increased by about 3 m^3/ha/yr for 5-8 years.

About 40% of Douglas-fir stands do not respond, but we have poor predictability for what stands and sites will respond.

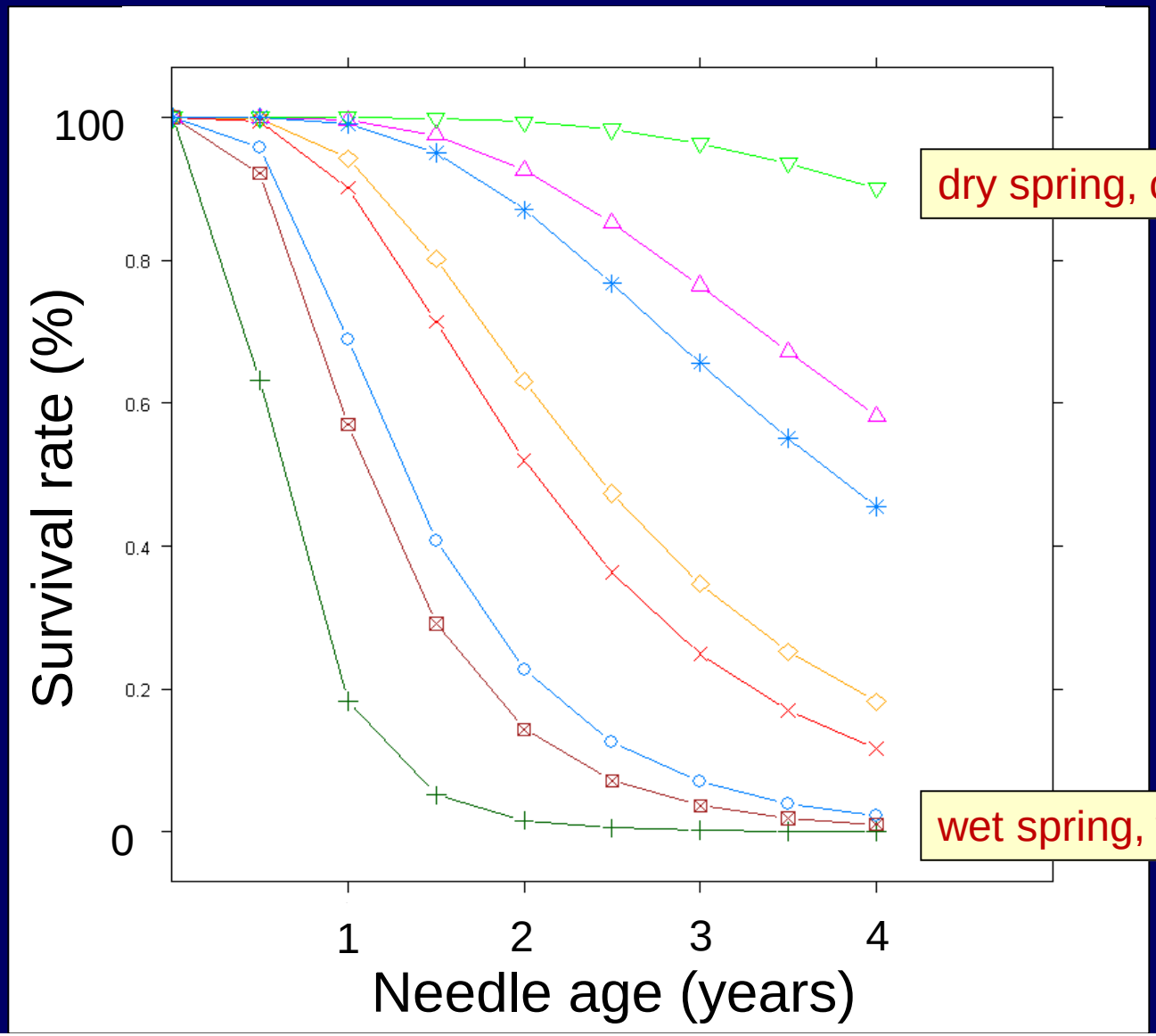
Are other nutrients important?

Growth, Yield, and Productivity

Mechanisms of response to nitrogen fertilization: Dynamics of foliar N



Douglas-fir needle survival rate under different weather conditions



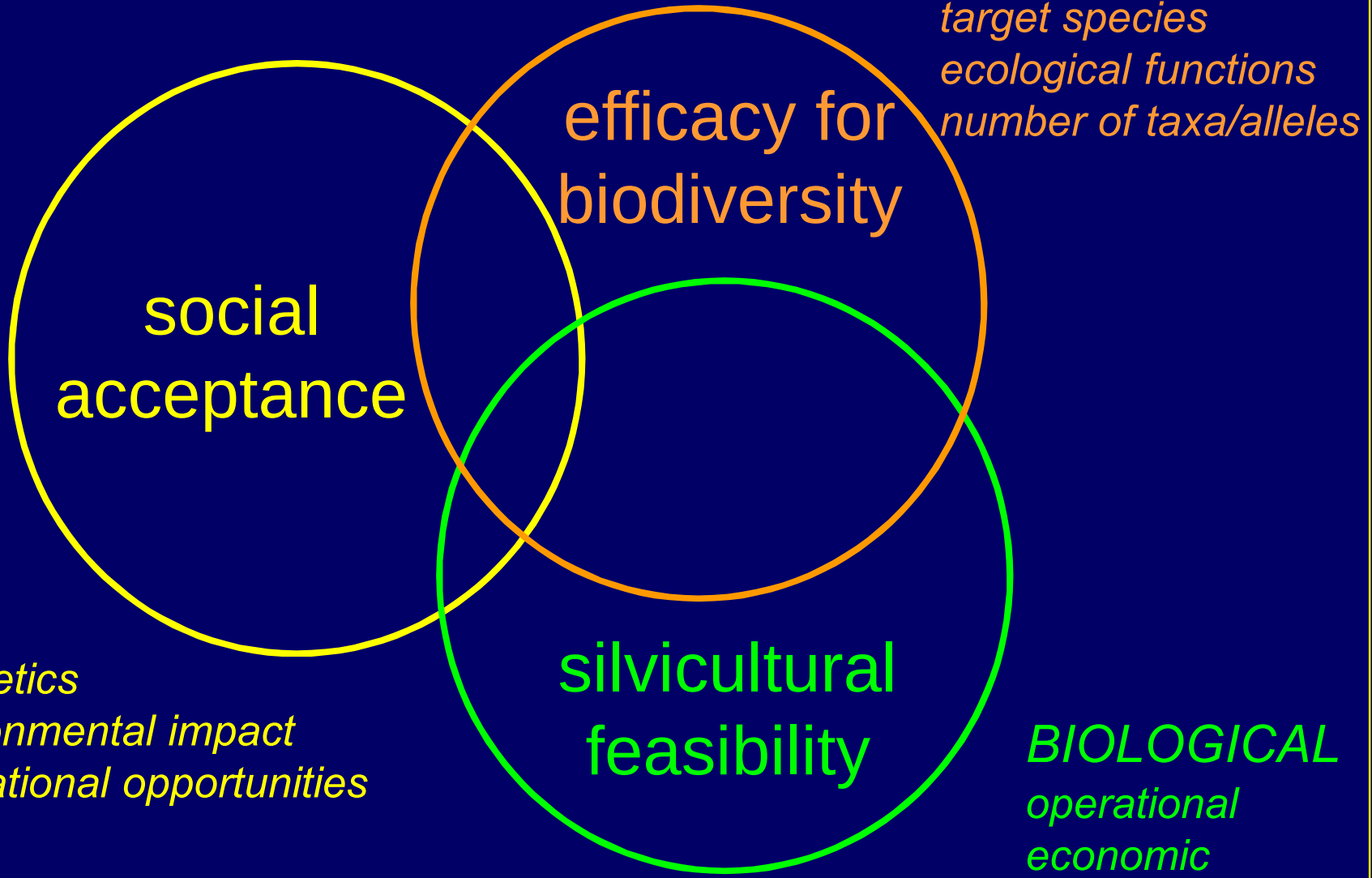
Working hypothesis

	Genetics	Competing vegetation control
GPP	+	ð (→+?)
NPP	+	ð (→+?)
NPP / GPP	0	0
Tree / other vegetation	0	+
Crop tree / other trees	0	+
Shoot / root	+	0
Stem / crown	+	0
Merchantable / non-merch	+	0
Stem form	+	0

Working hypothesis

	Fertilization	Thinning
GPP	+	ð
NPP	+	ð
NPP / GPP	0	0
Tree / other vegetation	0	ð
Crop tree / other trees	0	+
Shoot / root	+	0
Stem / crown	0	ð
Merchantable / non-merch	0	+
Stem form	ð	ð

Silvicultural systems



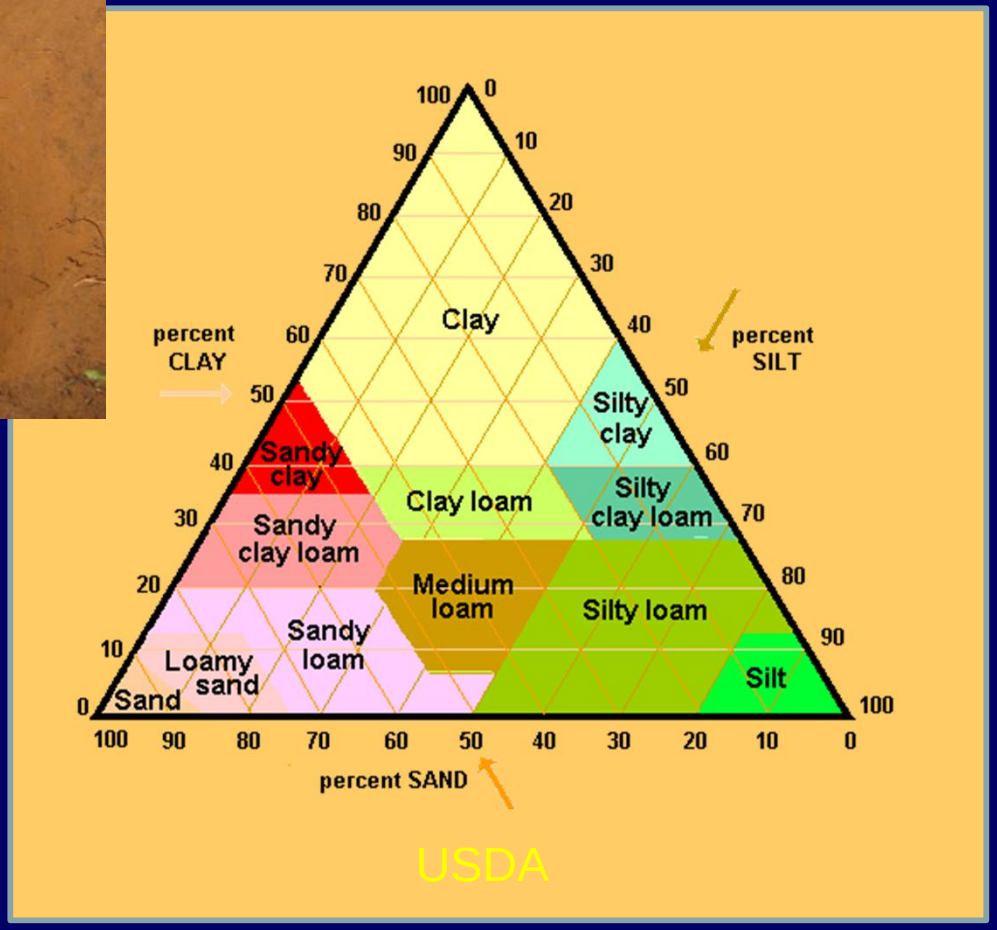
target species
ecological functions
number of taxa/alleles

aesthetics
environmental impact
recreational opportunities

BIOLOGICAL
operational
economic

At 391 mixed conifer plots, soil pits dug to 140 cm

Depth, volumetric rock content, and soil textural class recorded for each horizon



Available soil water holding capacity

Estimated total water held between -33 and -1500 kPa for each horizon

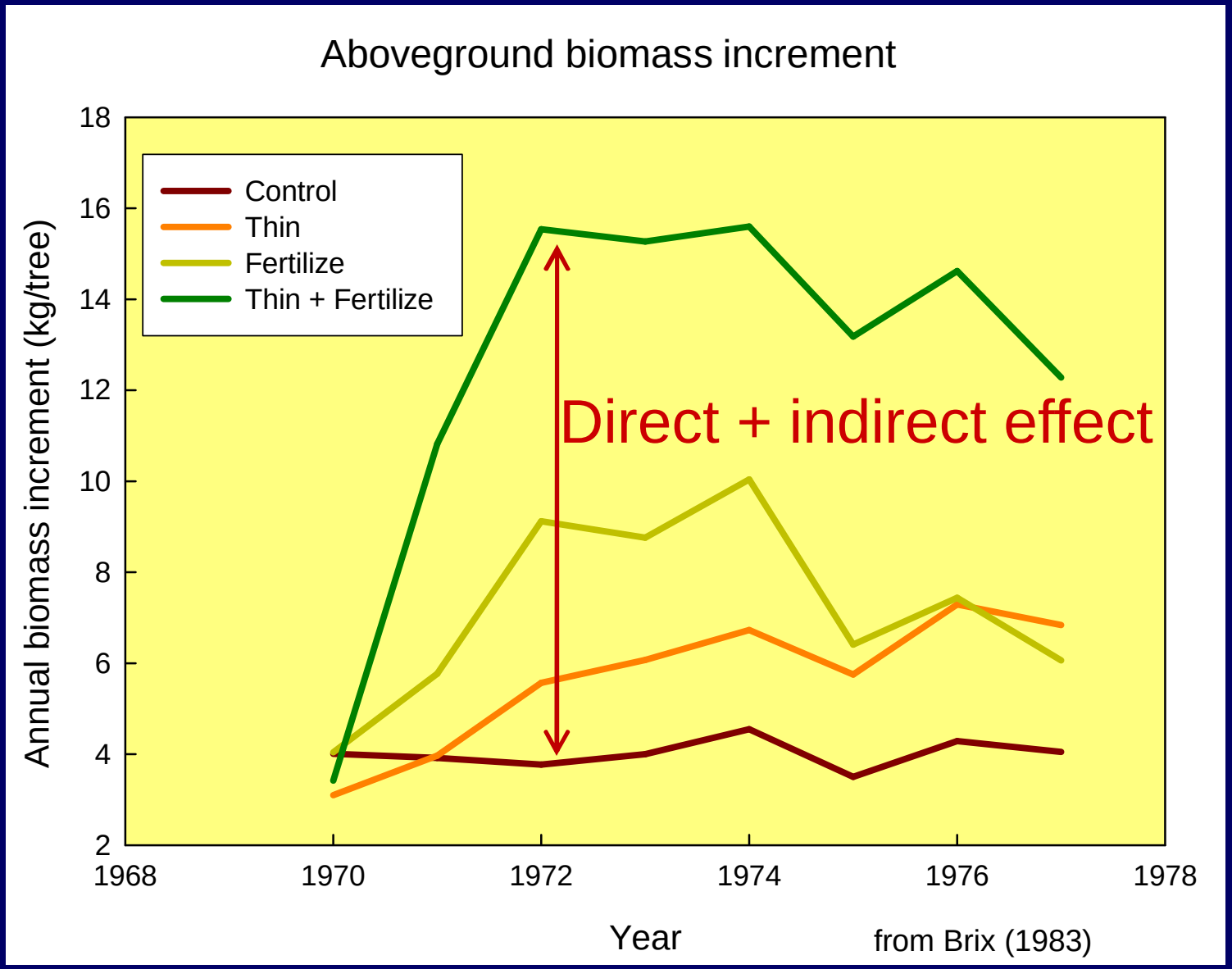
$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{[1 + (\alpha h)^n]^{1 - 1/n}}$$

where

θ_r, θ_s, α, and n

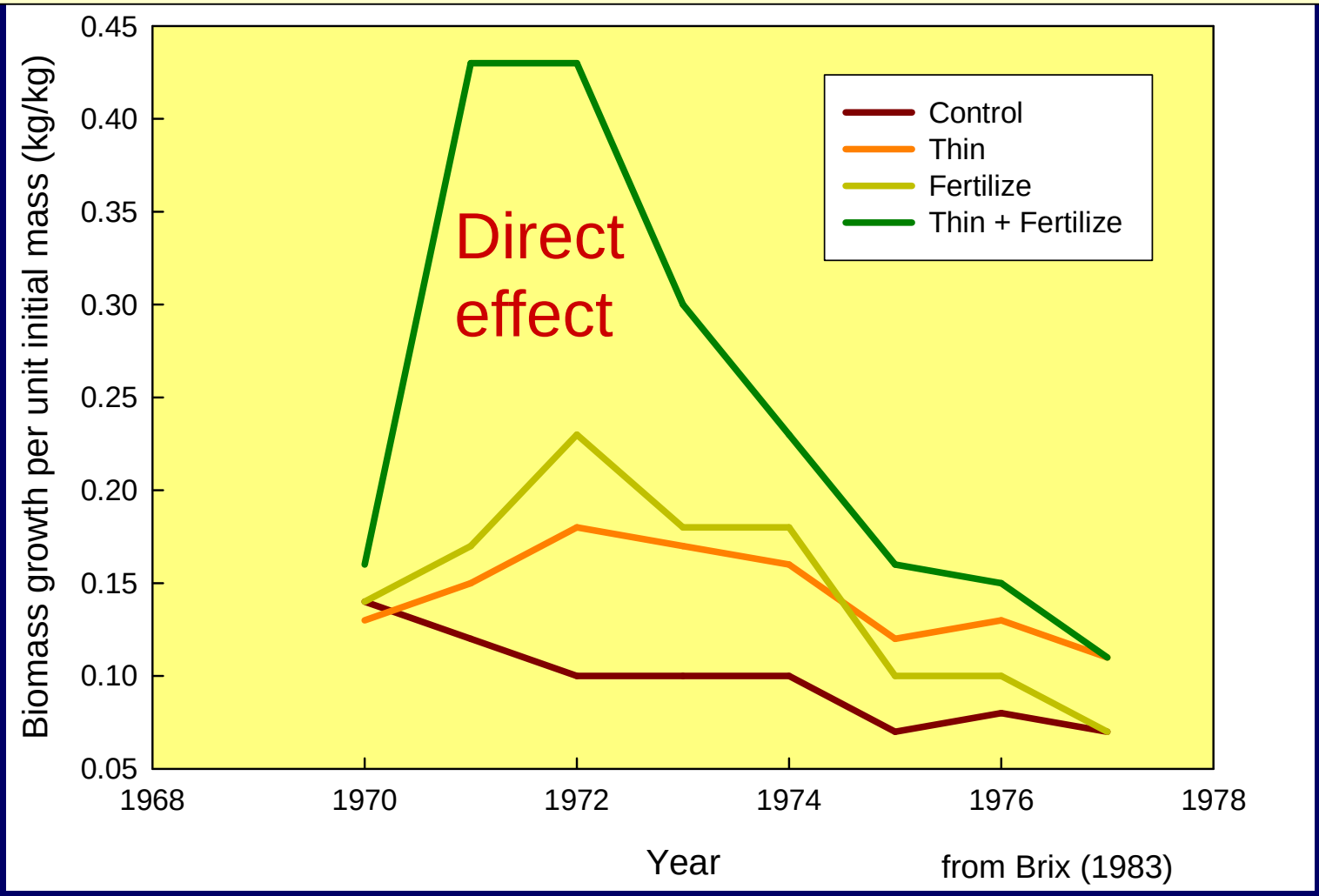
depend on soil textural class

Growth, Yield, and Productivity

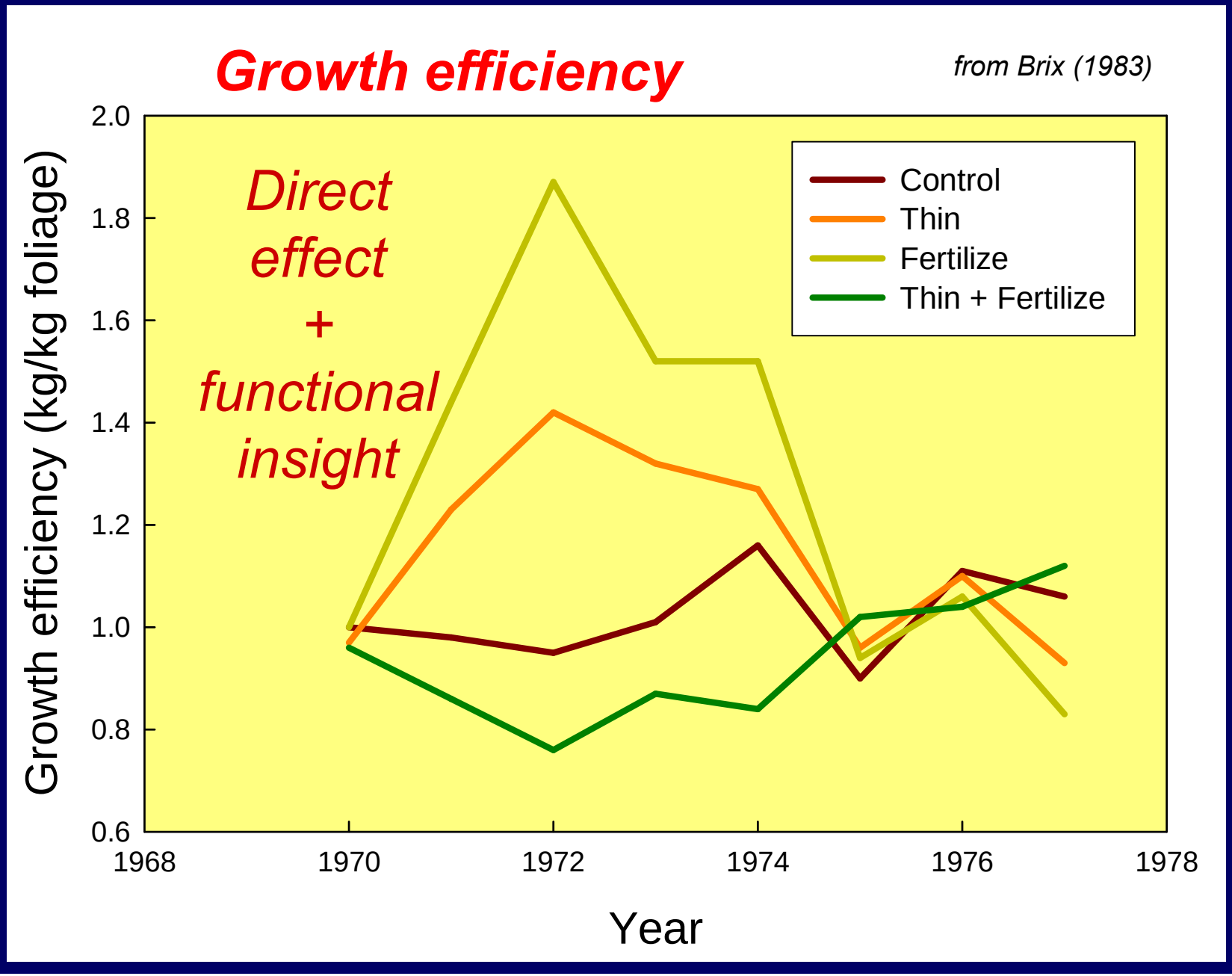


Growth, Yield, and Productivity

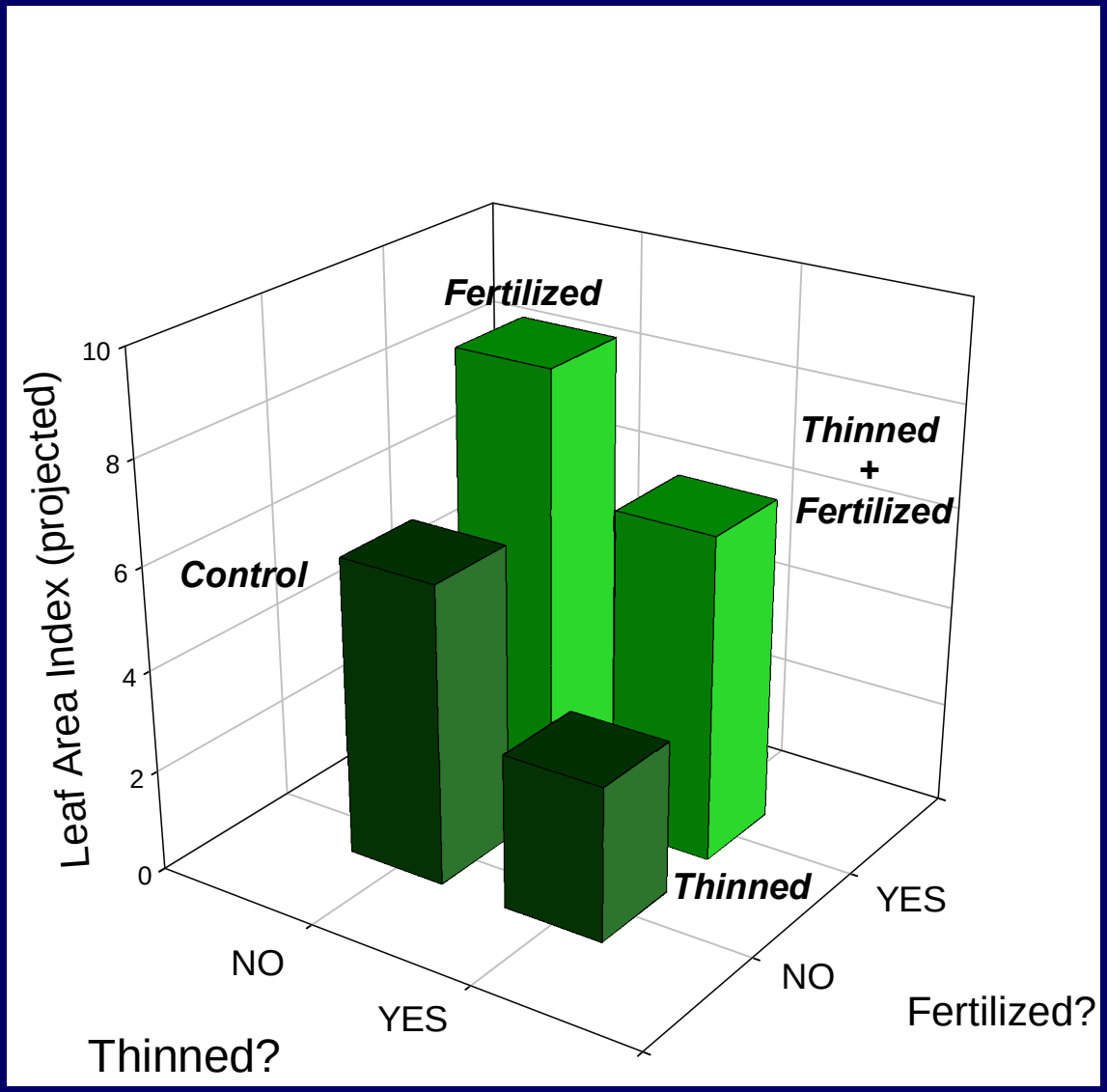
Growth rate corrected for initial size at start of each growing season (analogous to relative growth rate)



Aboveground biomass increment per unit initial foliage mass



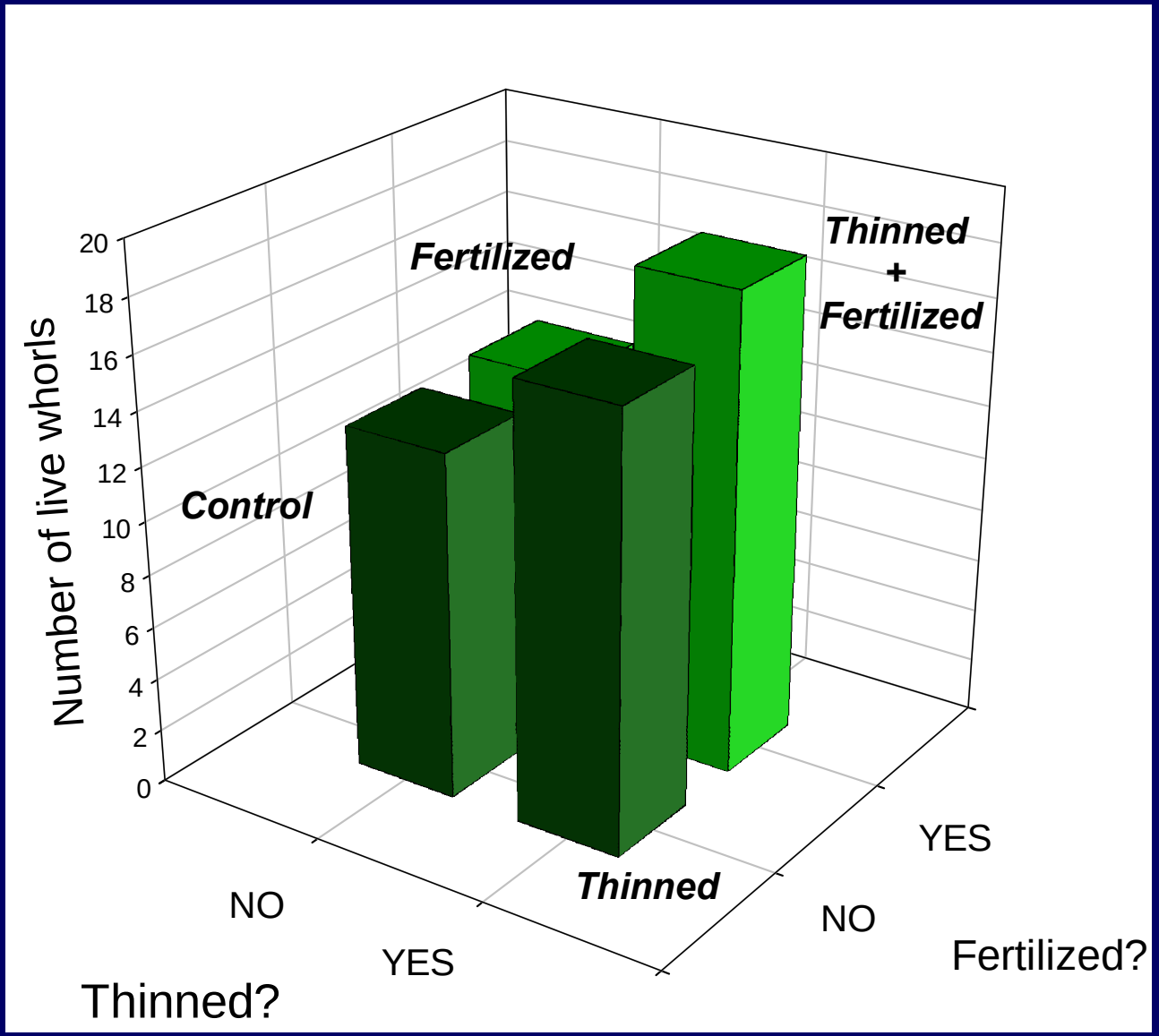
Increase in total leaf area as long-term response to N fertilization



From Brix (1981)

Growth, Yield, and Productivity

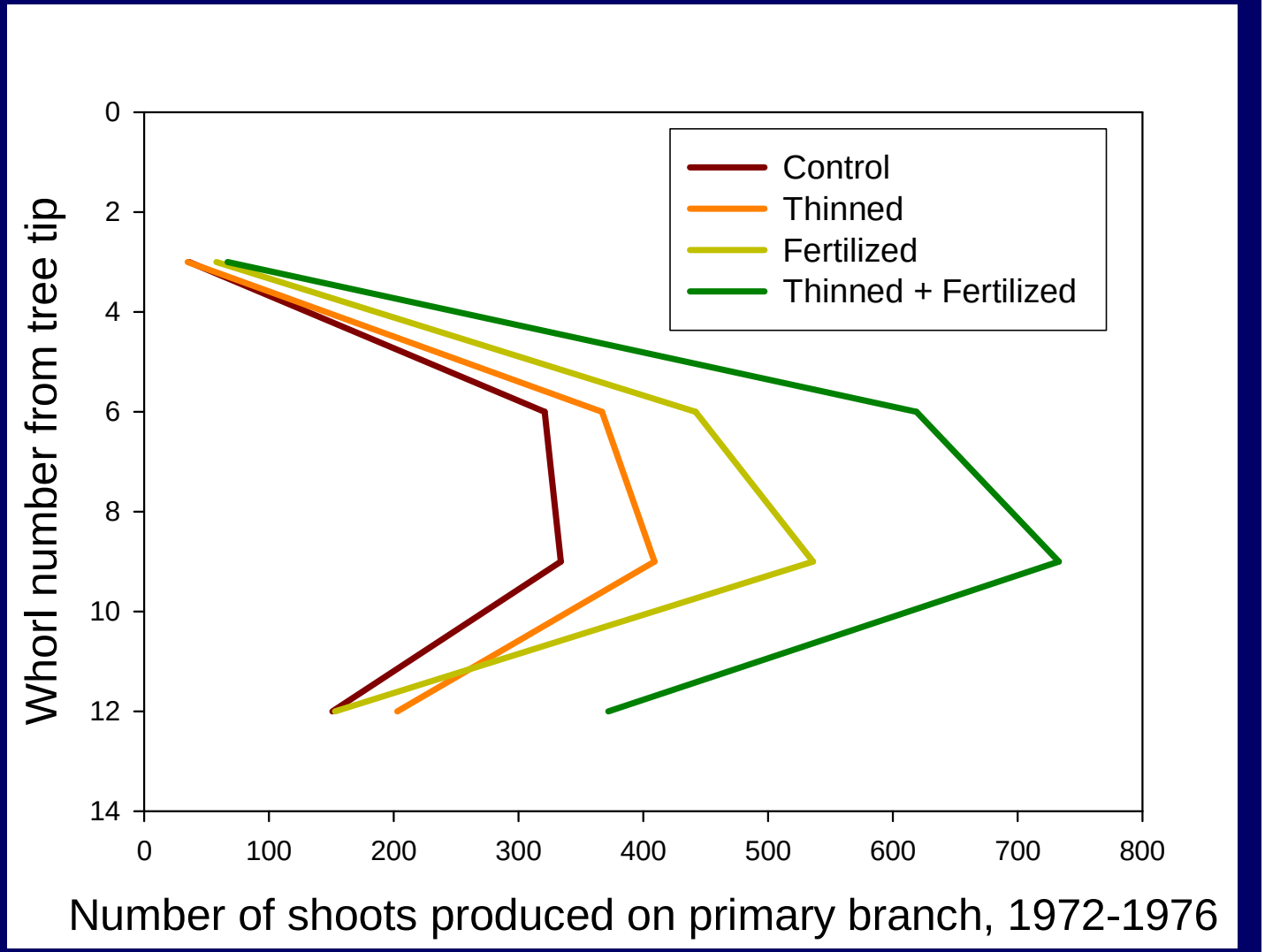
Treatment effects on number of live whorls (live crown length)



From Brix (1981)

Growth, Yield, and Productivity

Treatment effects on crown density (number of shoots on each primary branch)

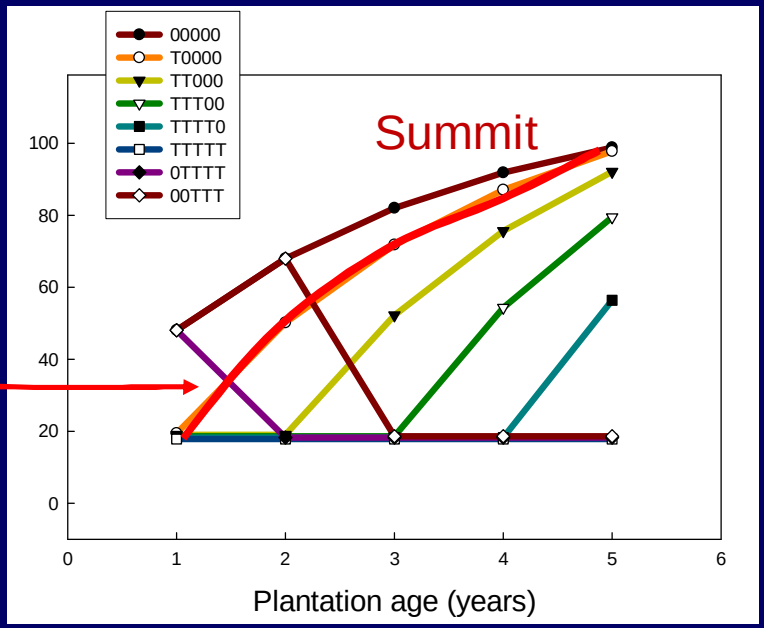


From Brix (1981)

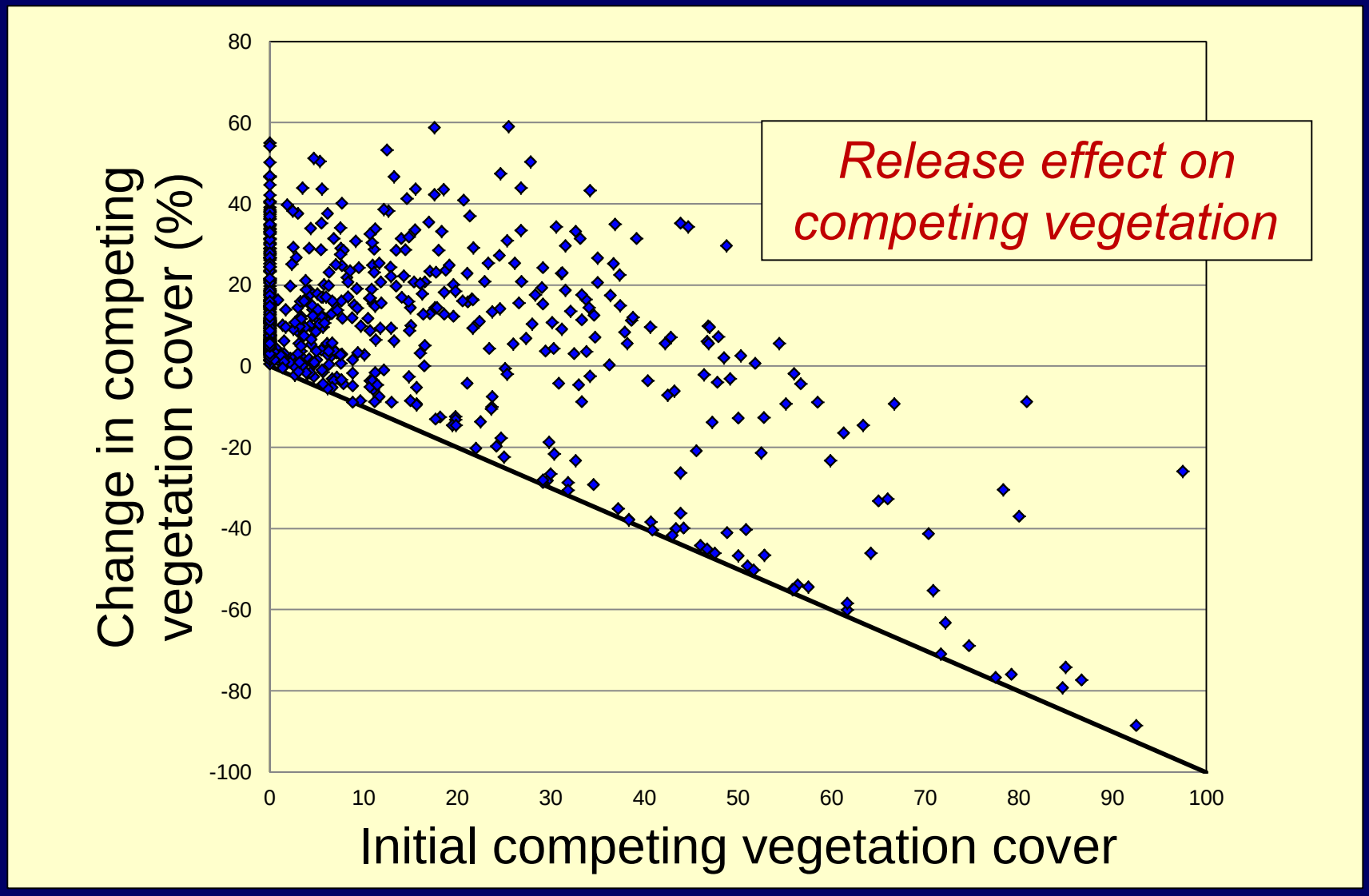
Responses to critical period threshold regimes

$$TCOV = (\alpha_0 + \alpha_1 I_{2002} + \mu) + [100 - (\alpha_0 + \alpha_1 I_{2002} + \mu)] \cdot [1 - \exp(-(\alpha_2 + \alpha_3 \cdot SS + \alpha_4 \cdot NH + \alpha_5 \cdot SS \cdot NH) \cdot YSH)] + \varepsilon_6$$

Rate of increase in competing vegetation cover after termination of releases



The Future of Forest Management in the Pacific Northwest



Release effect on competing vegetation cover

All four VMRC studies

$$\Delta V = (\beta_1 + \beta_2 I_{2m2y} + \beta_3 I_{ECR} + \beta_4 I_{HERB}) * \exp[\beta_5 R (V_0 + 1)] (V_0 + 1)^{\beta 6} - V_0$$

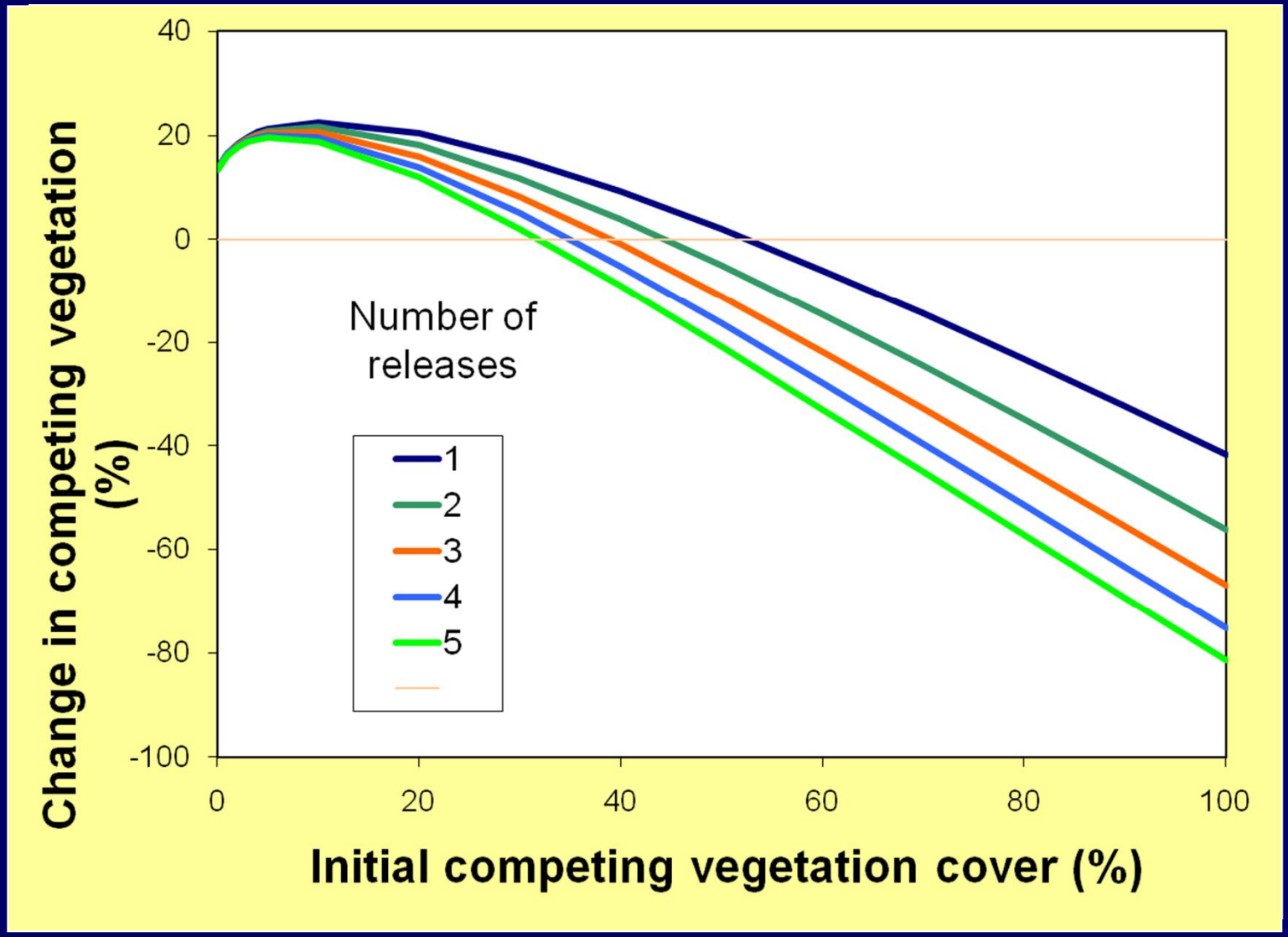
ΔV = 1-yr change in competing vegetation cover (%)

V_0 = Initial competing vegetation cover (%)

R = number of releases

β_1 = 7.2773
β_2 = 7.3384
β_3 = 10.1553
β_4 = 6.3112
β_5 = - 0.00283
β_6 = 0.3777

Average release effect on CPT, 2m2y, HERB1, and ECR studies



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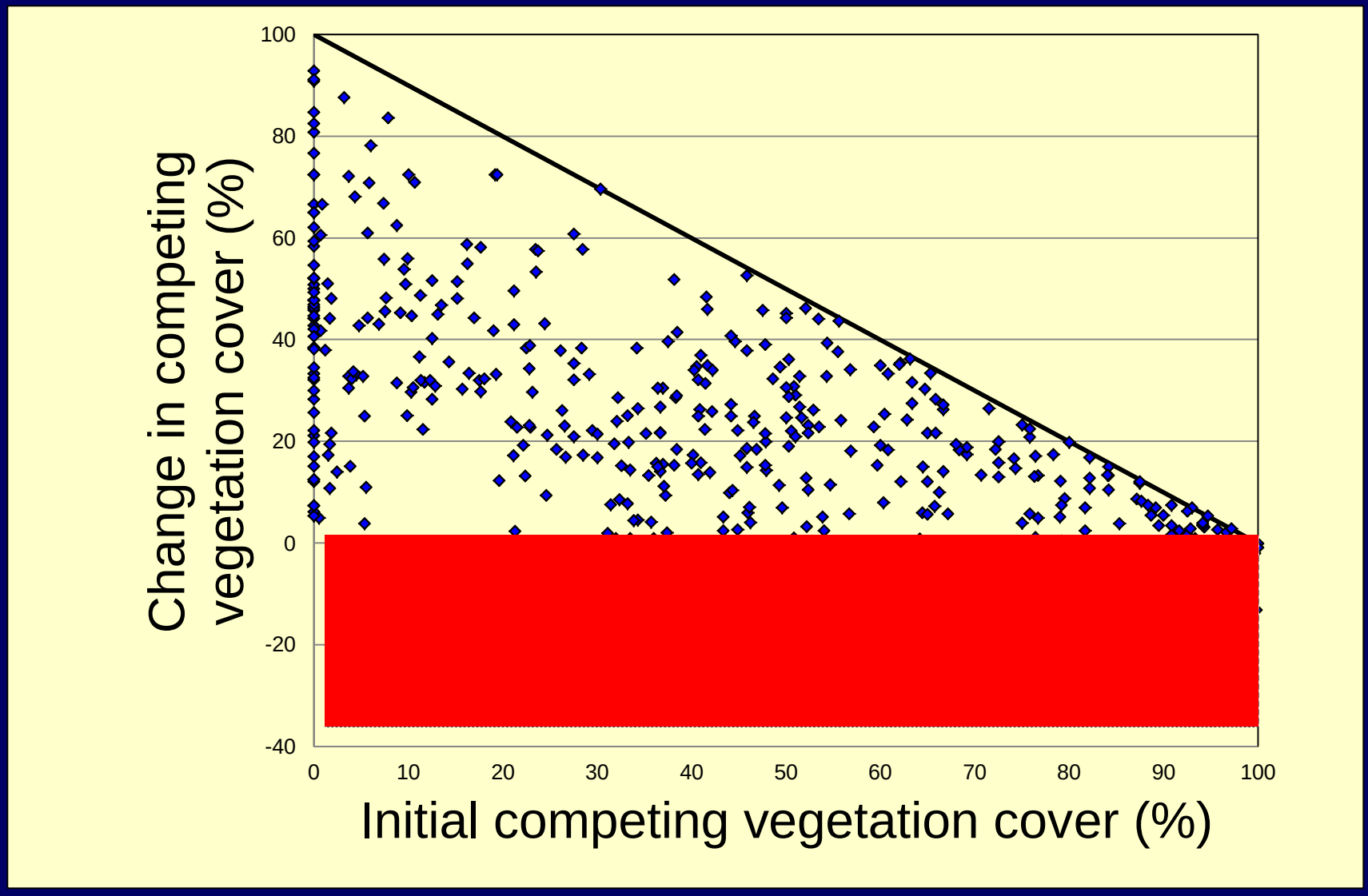
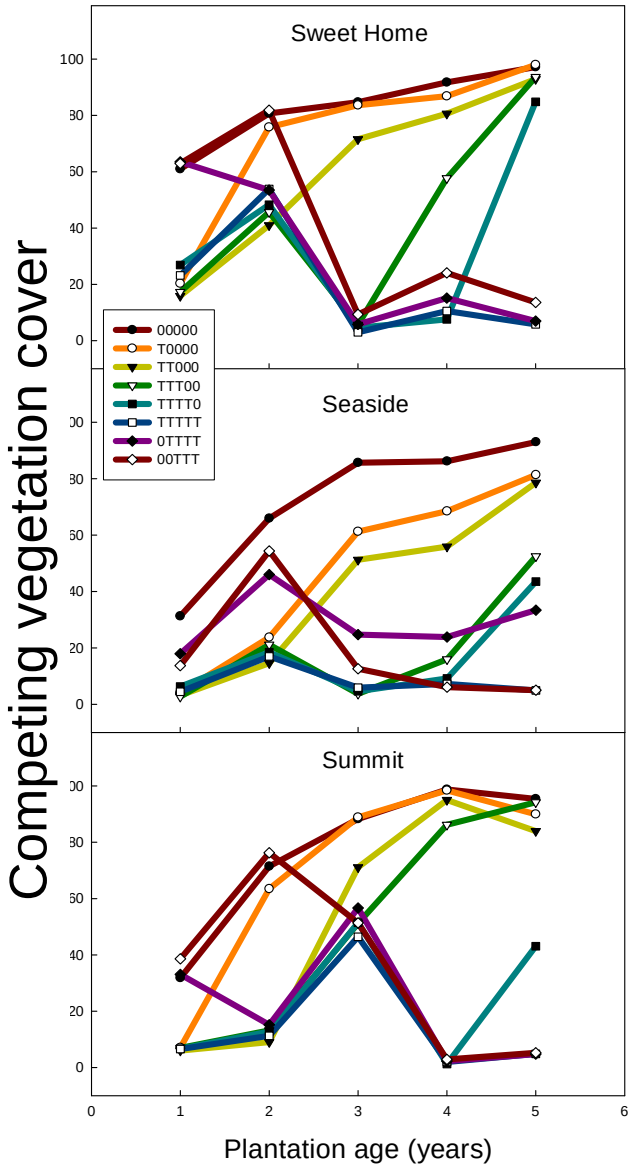
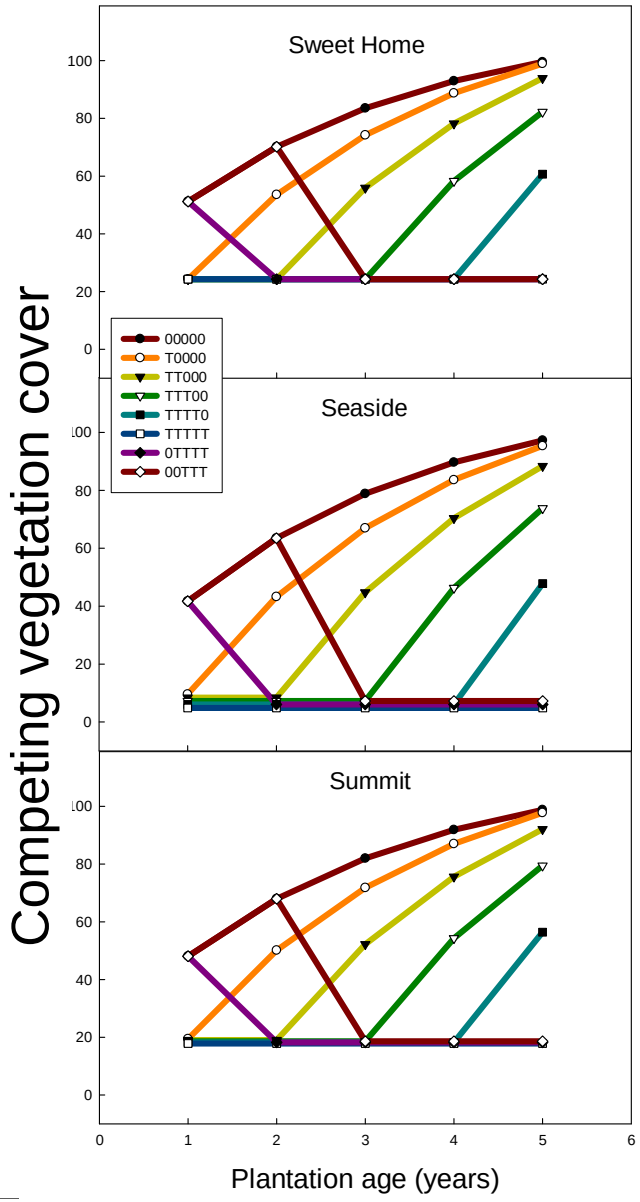


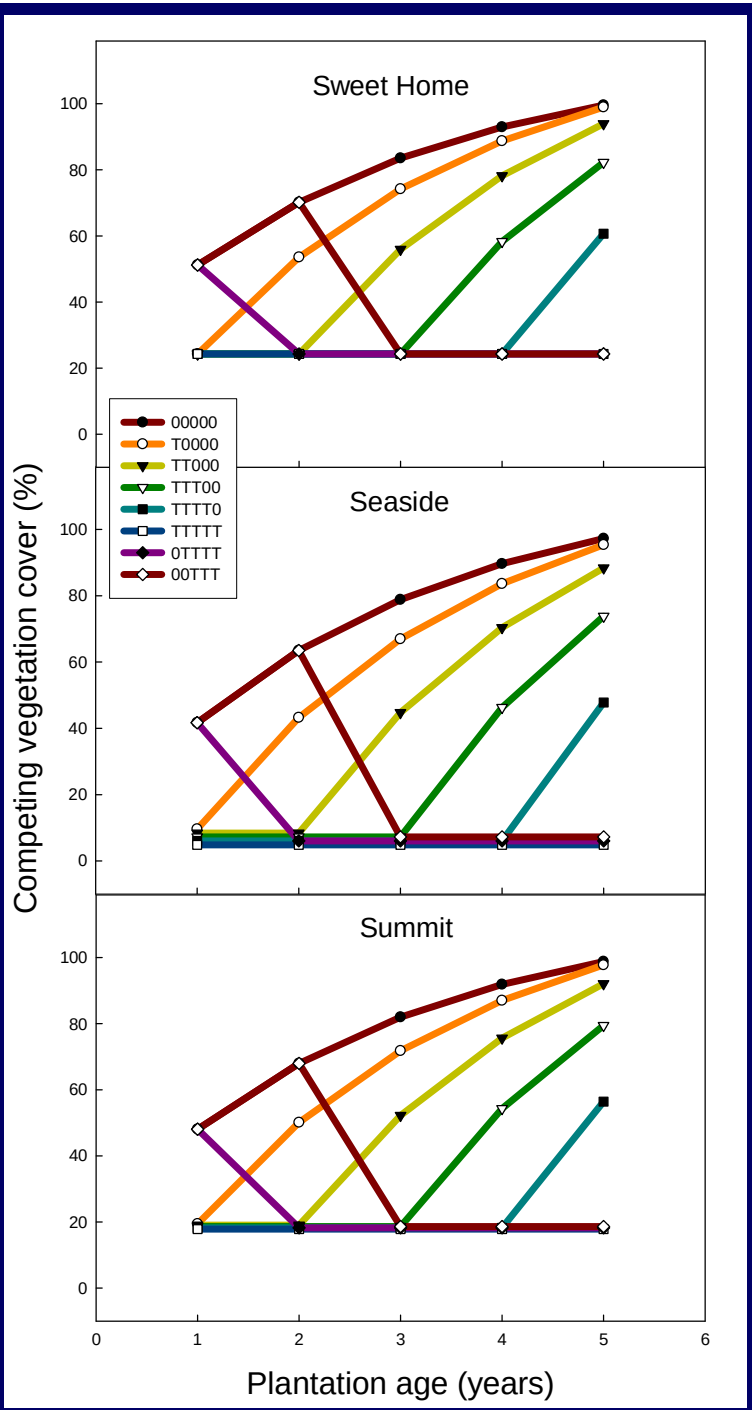
Collaborations with VMRC



Predictive models for competing vegetation dynamics

Ÿ water and other resource use by competing vegetation



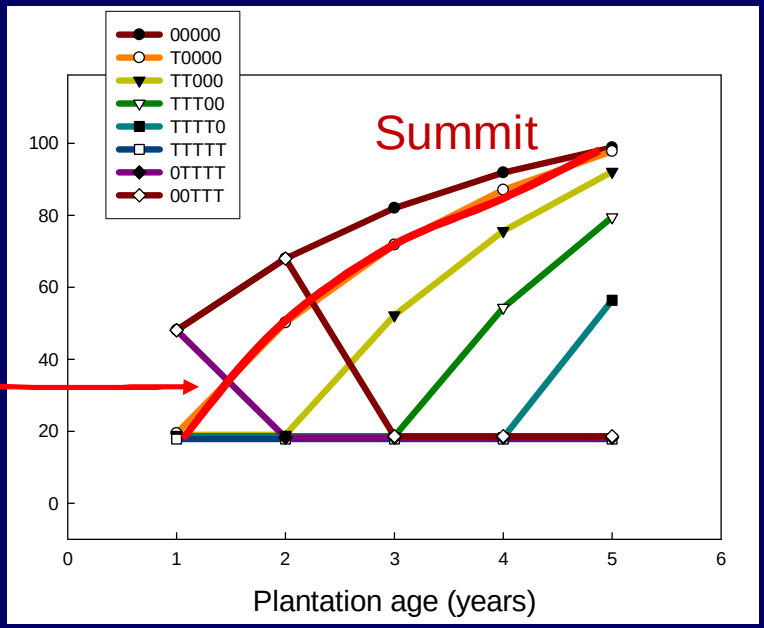


- Competing vegetation cover was knocked back to 5-20% after release treatments
- The greater the number of previous releases, the greater the rate of increase in cover after termination of treatments
- Cover converges on 100% with increasing time since last release

Responses to critical period threshold regimes

$$TCOV = (\alpha_0 + \alpha_1 I_{2002} + \mu) + [100 - (\alpha_0 + \alpha_1 I_{2002} + \mu)] \cdot [1 - \exp(-(\alpha_2 + \alpha_3 \cdot SS + \alpha_4 \cdot NH + \alpha_5 \cdot SS \cdot NH) \cdot YSH)] + \varepsilon_6$$

Rate of increase in competing vegetation cover after termination of releases



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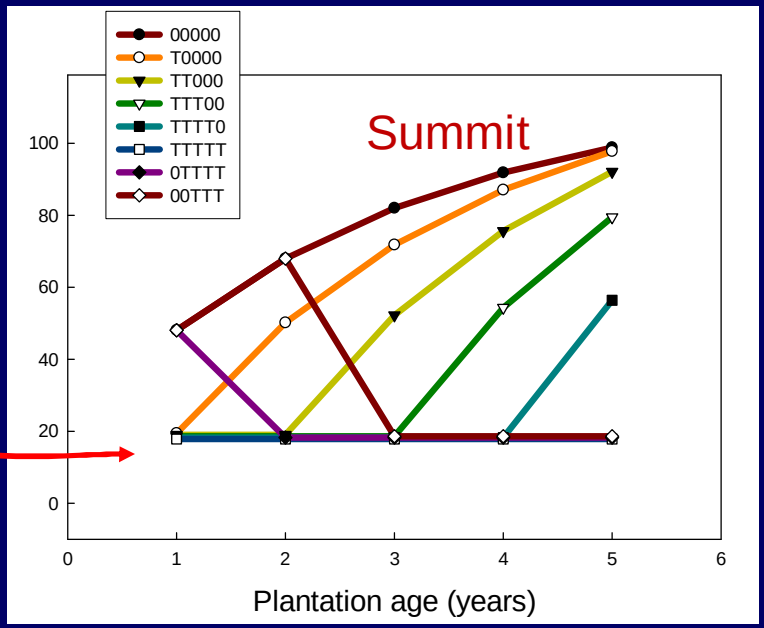
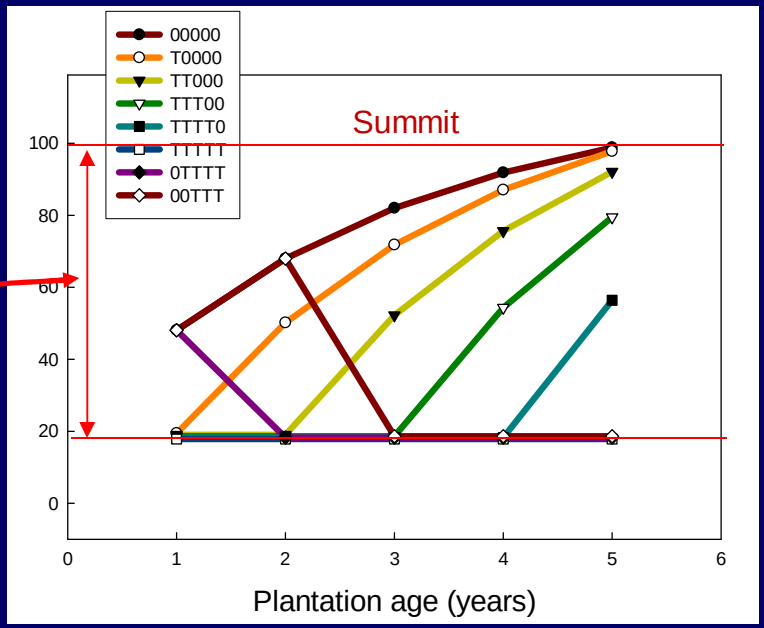
Minimum competing vegetation cover



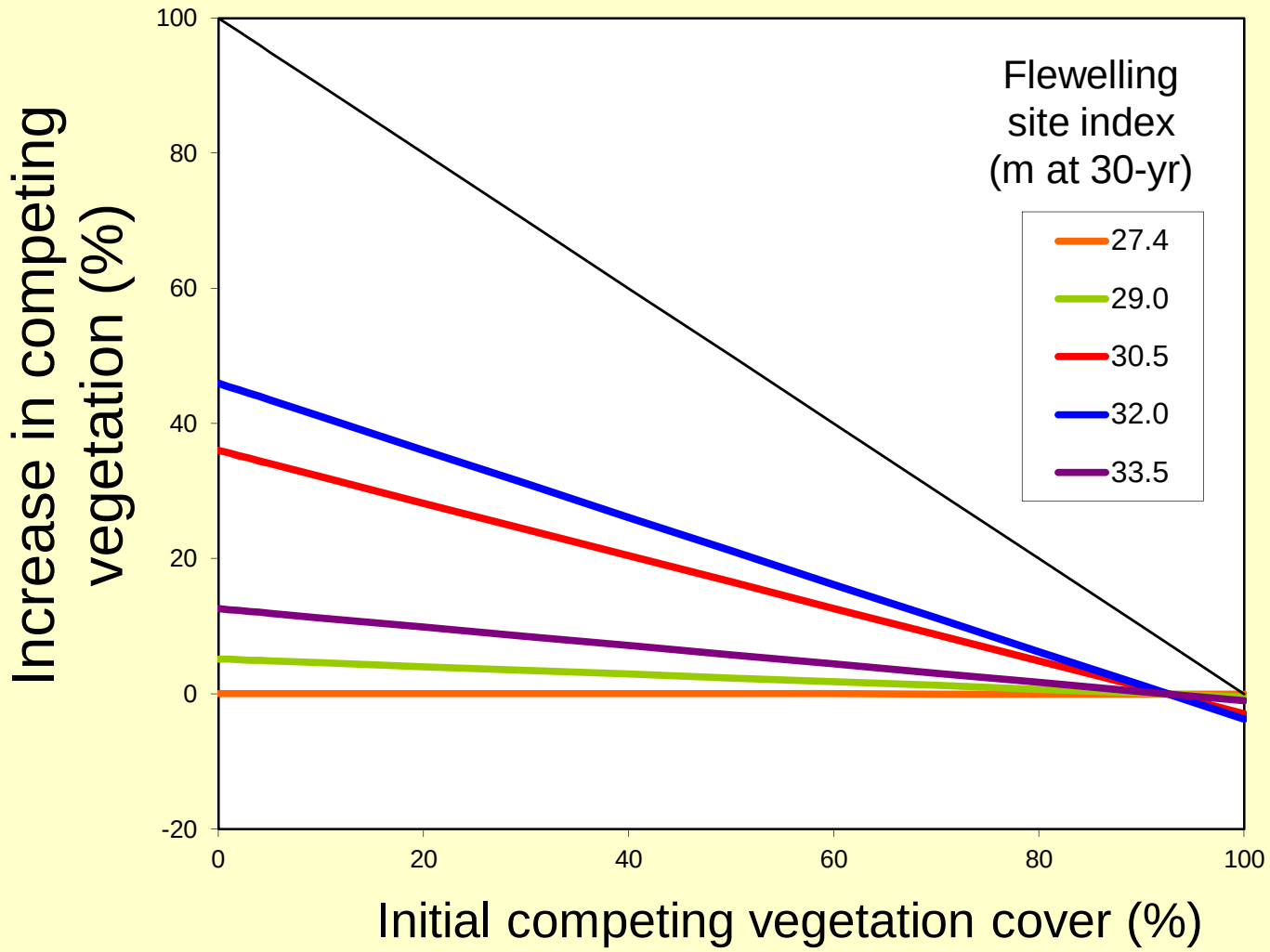
Responses to critical period threshold regimes

$$TCOV = (\alpha_0 + \alpha_1 I_{2002} + \mu) + [100 - (\alpha_0 + \alpha_1 I_{2002} + \mu)] \cdot [1 - \exp(-(\alpha_2 + \alpha_3 \cdot SS + \alpha_4 \cdot NH + \alpha_5 \cdot SS \cdot NH) \cdot YSH)] + \varepsilon_6$$

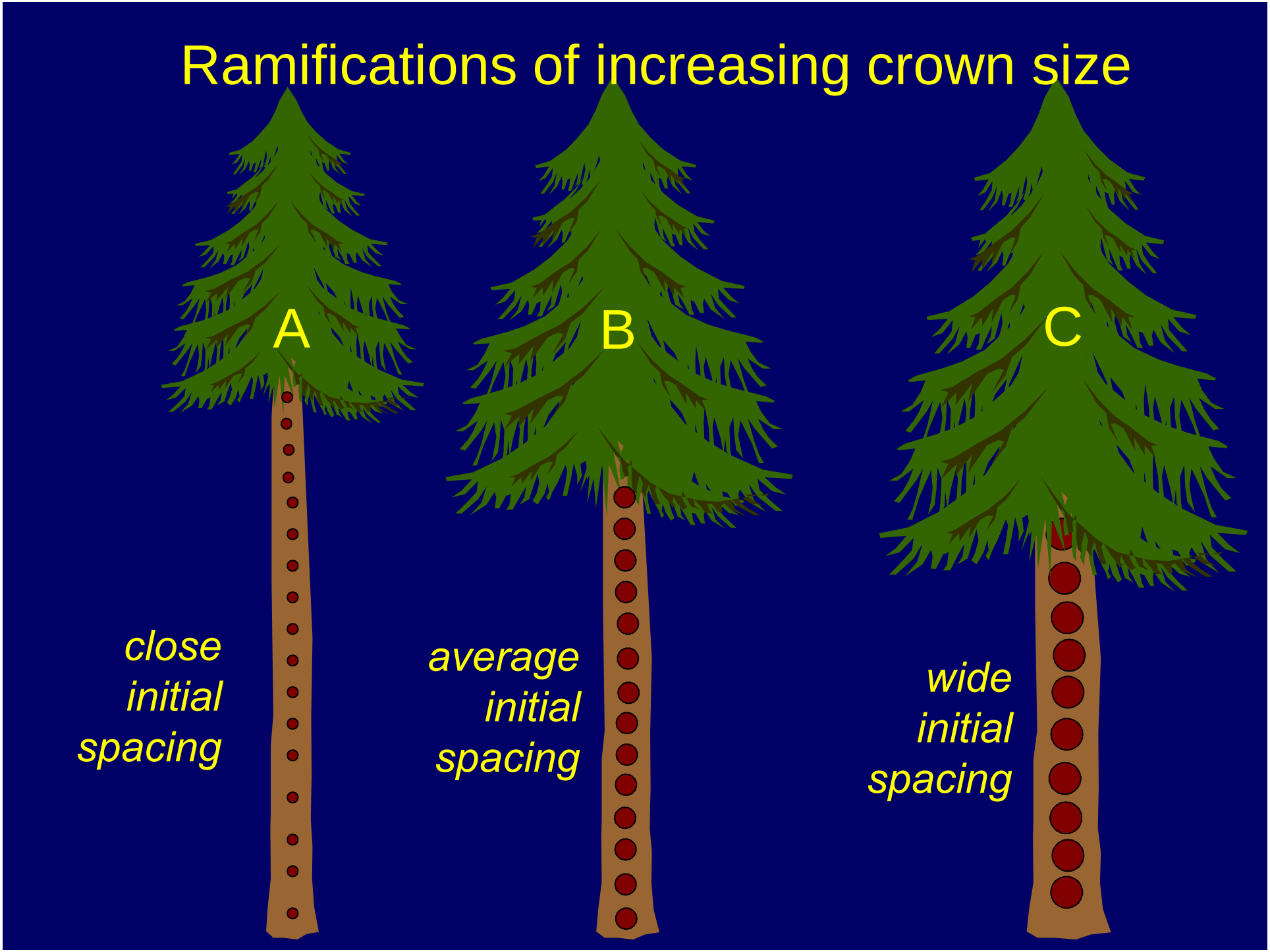
Maximum gain in competing vegetation cover (upper asymptote – minimum cover)



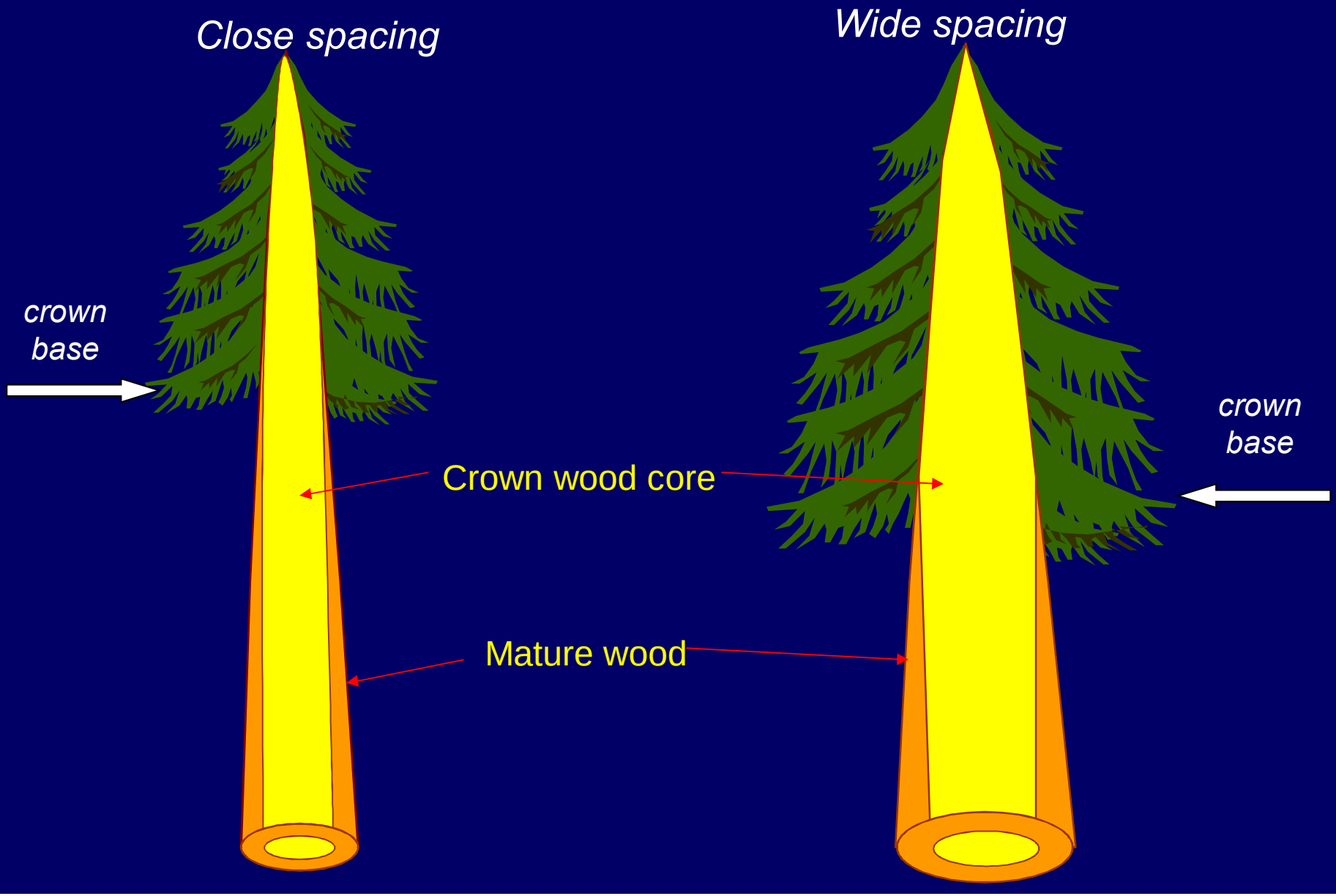
The Future of Forest Management in the Pacific Northwest



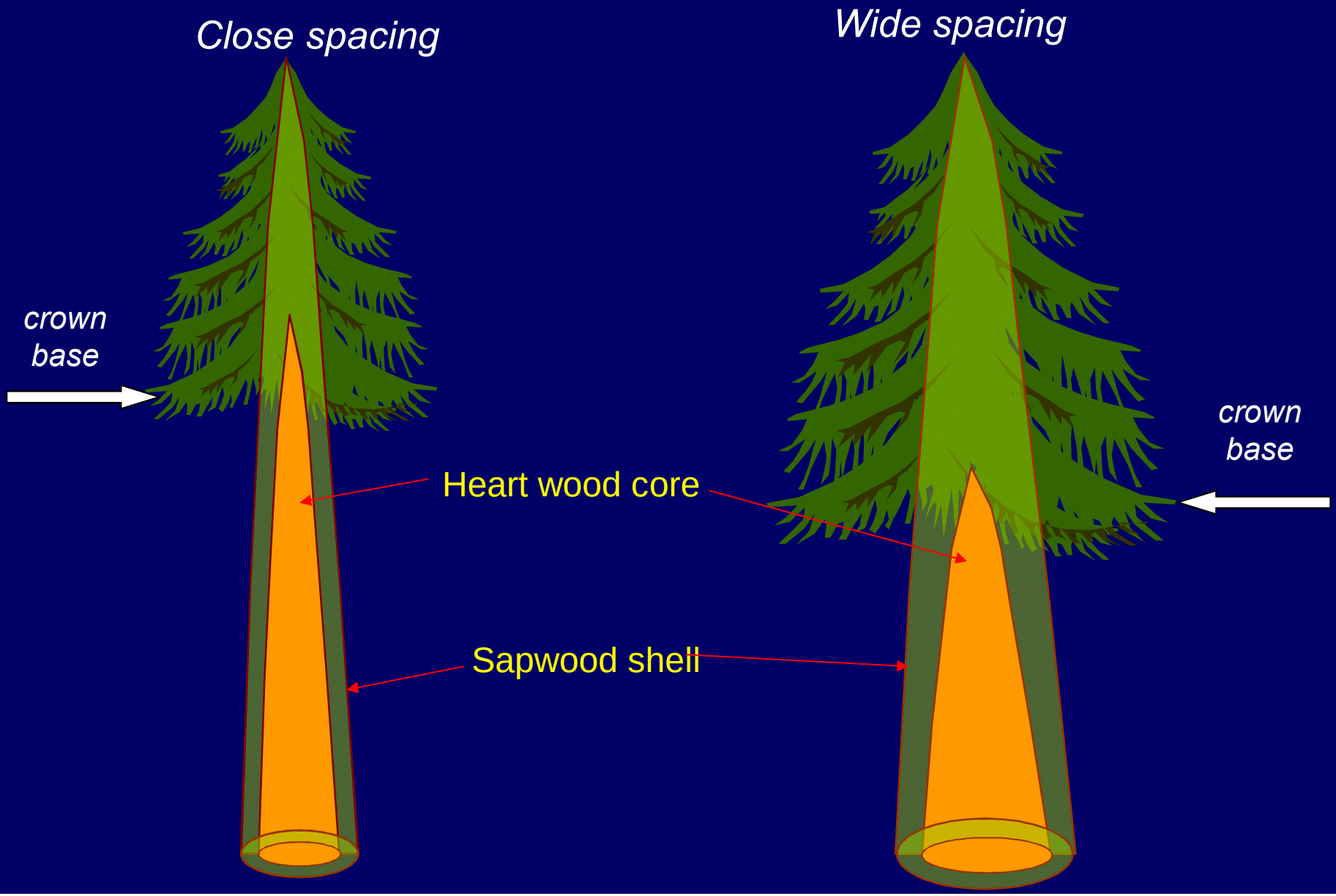
Ramifications of increasing crown size



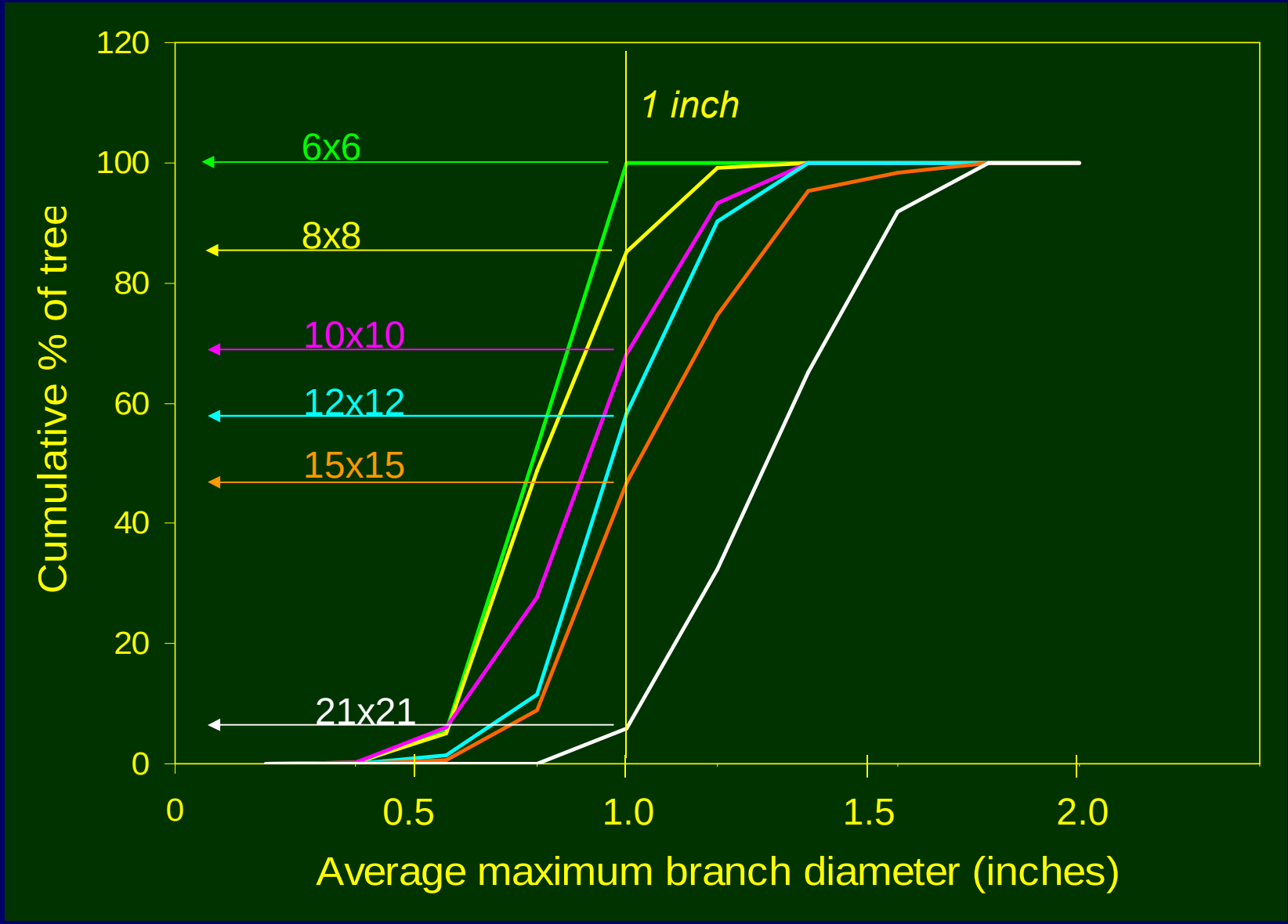
Crown wood/juvenile wood core



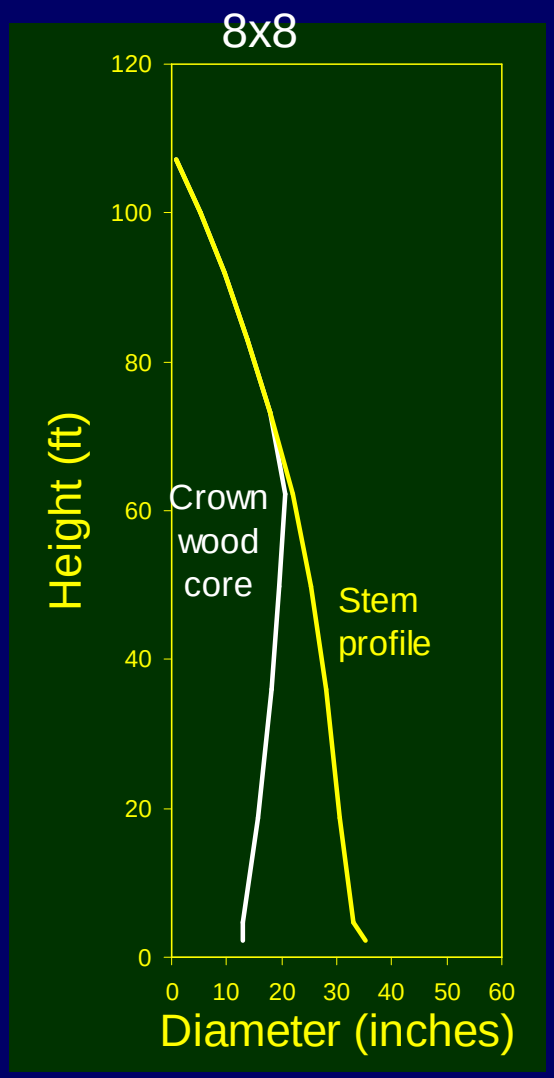
Heartwood/sapwood zones

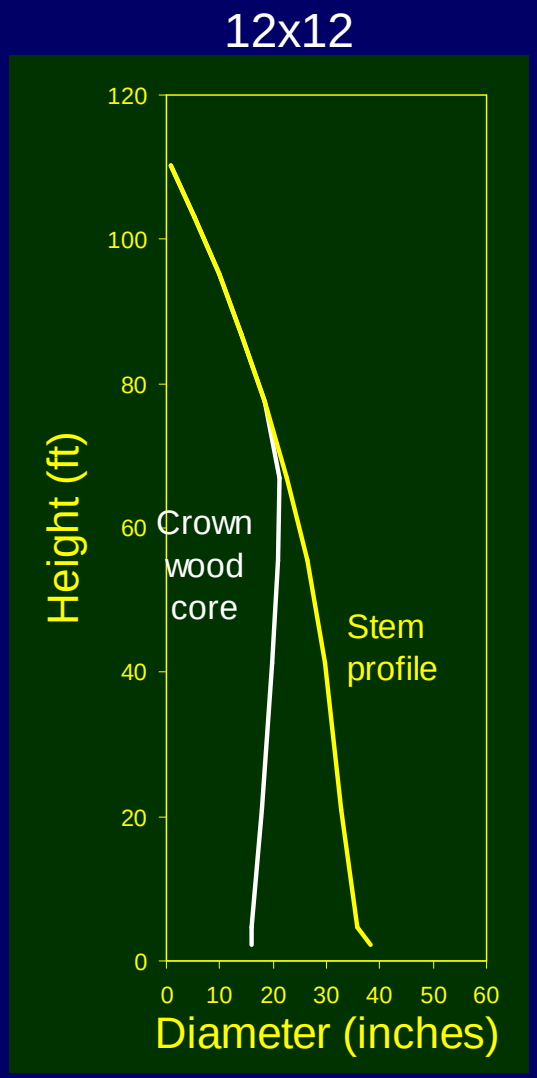


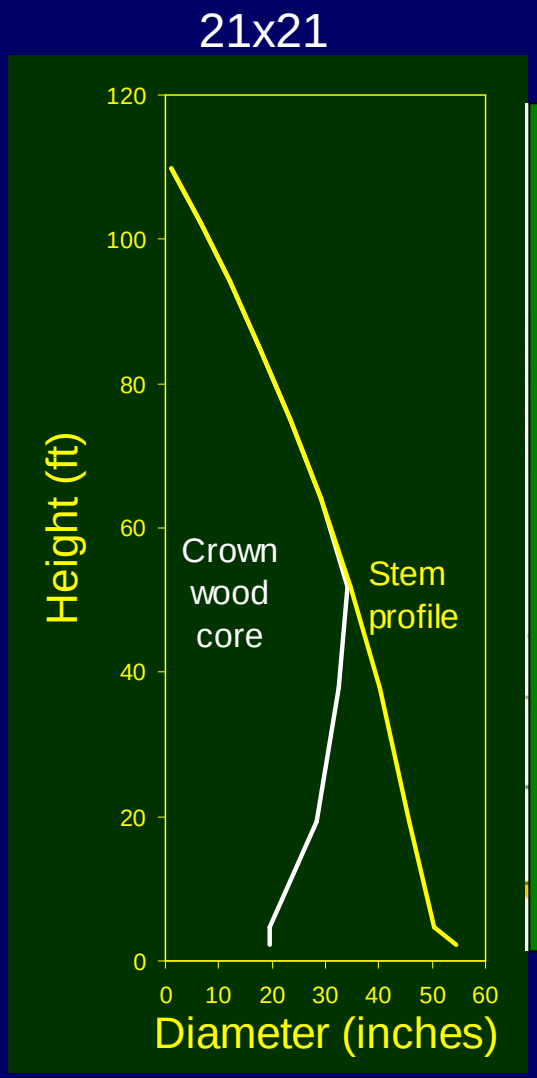
Cumulative number of trees with smaller average branch diameter in 1st 16-ft log

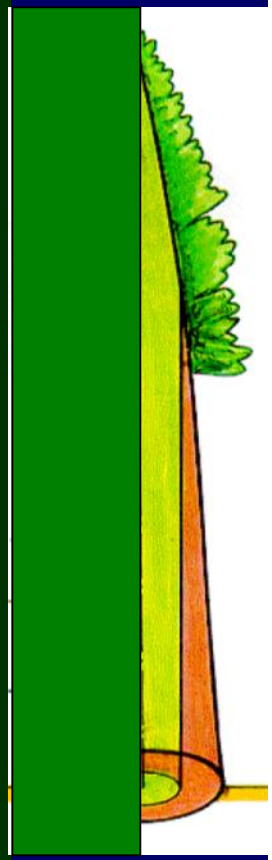


Crown wood core under three initial spacings (tree representing 90 percentile)

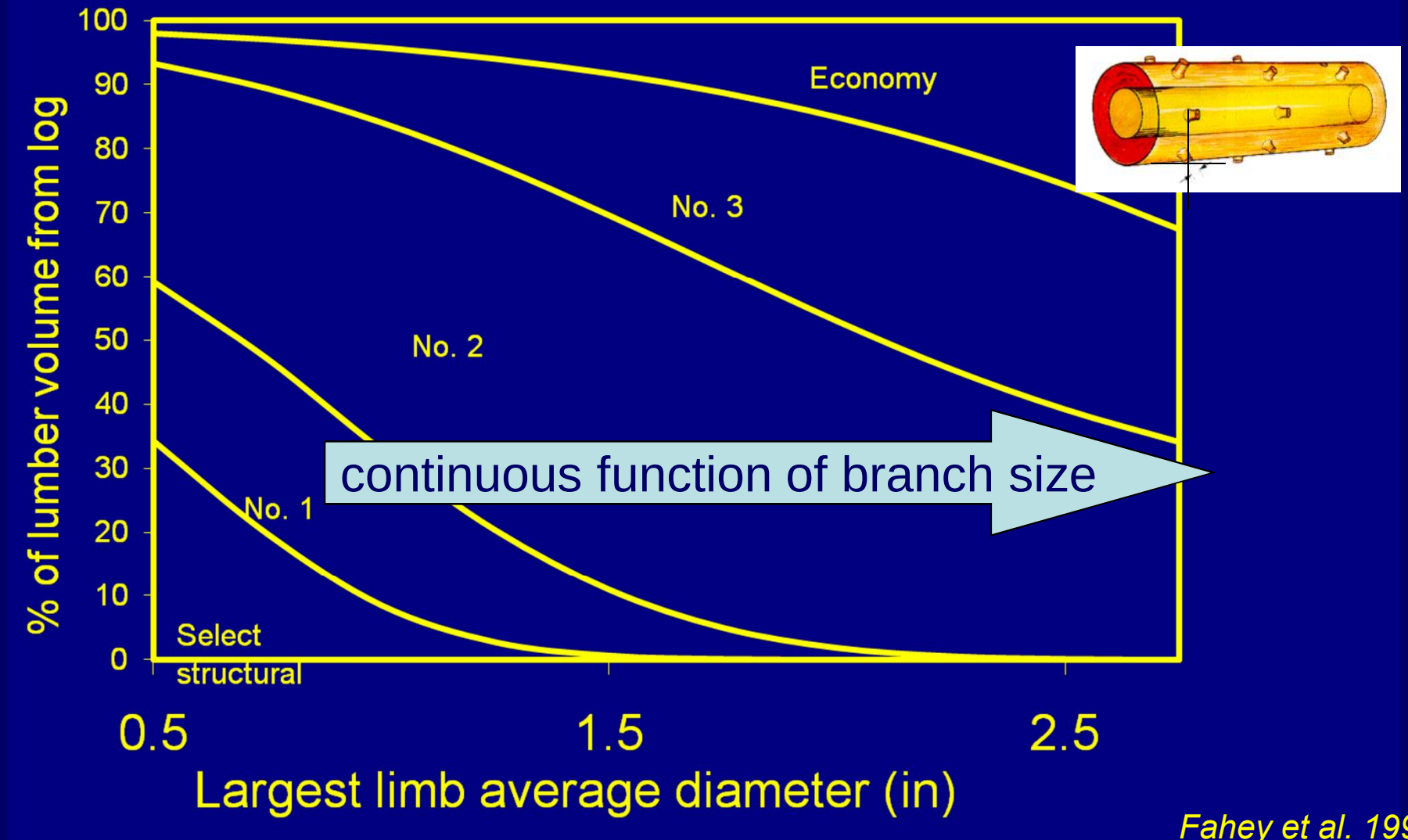






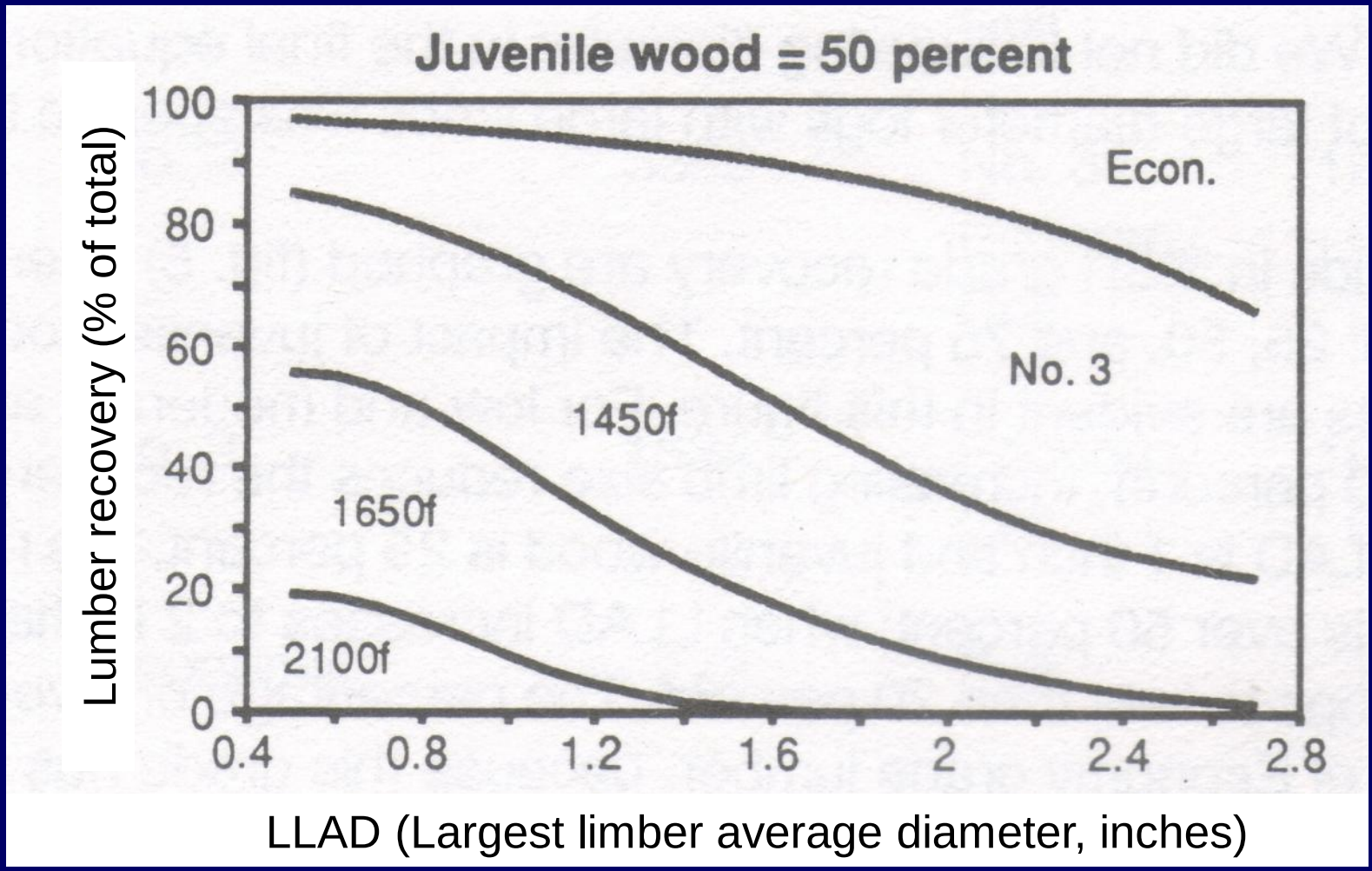


Douglas-fir lumber, visual grade recovery



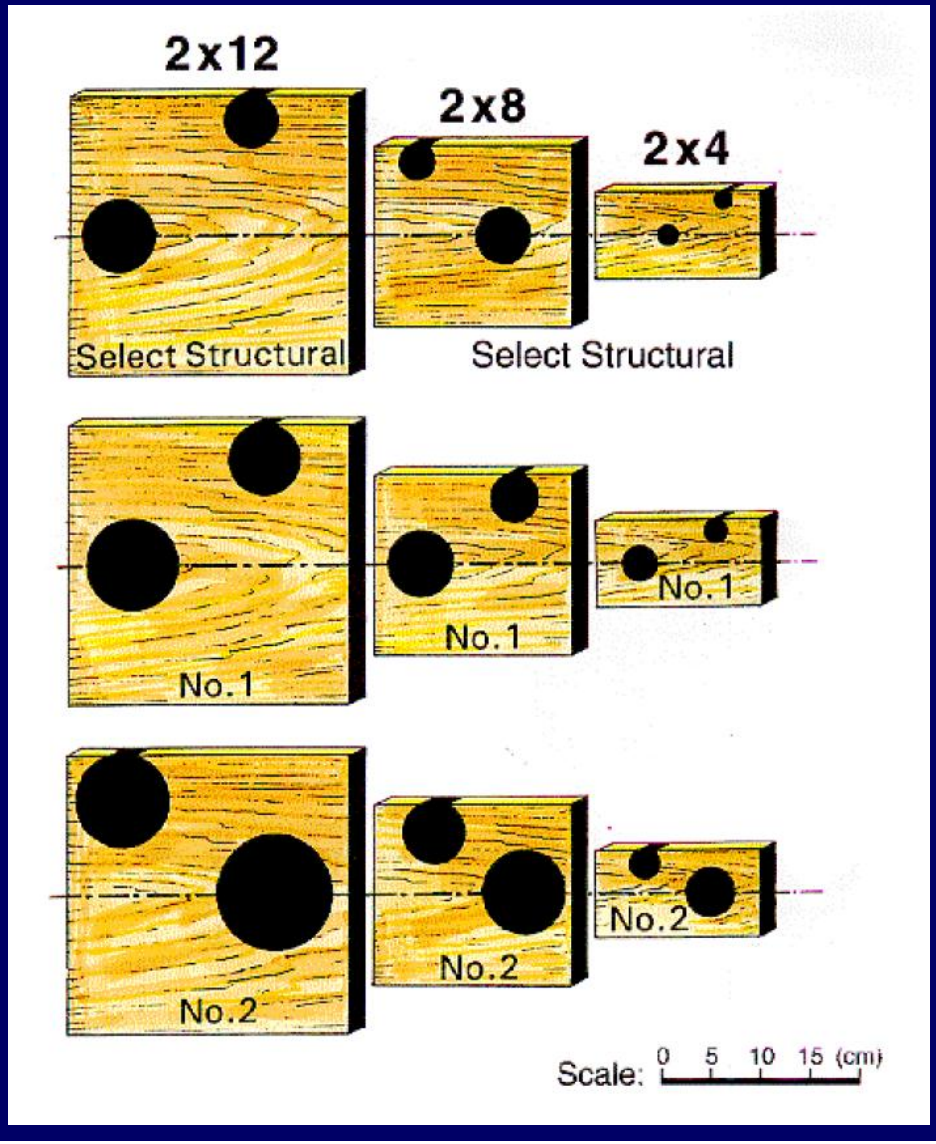
Fahey et al. 1991

Douglas-fir lumber, machine stress rated



Fahey et al. 1991

Role of knots in visual lumber grades



Maximum knot sizes allowed on the edge and on the center line of 2x4, 2x8, and 2x12 lumber.

Josza and Middleton 1994

Random thoughts

- Interactions among silvicultural treatments
- Accurate estimates of genetic gain
  - realized gain trials
  - family deployment study
- Where to fertilize?
- Potential for new nutrient deficiencies
  - 3rd, 4th rotation forests
  - intensification of biomass utilization bioenergy
- Wood quality
  - Silvicultural targets
  - Sorting and value recovery
- Climate change
  - Adaptation
  - Mitigation

Role of silvicultural research

- How do we maximize the economic and environmental performance of our intensively managed forestlands?
- To what extent do we achieve the desired environmental performance on the stand versus landscape scale?

Role of silvicultural research

- Does knowledge from silvicultural research contribute to the performance of our wood-producing plantations in the PNW?
- How do we maximize the economic and environmental performance of our intensively managed forestlands?
- To what extent do we achieve the desired environmental performance on the stand versus landscape scale?