Genetic Improvement of Wood Quality in Coastal Douglas-fir and Western Hemlock

Proceedings of a workshop organized by the

Pacific Northwest Tree Improvement Research Cooperative

and the

Northwest Tree Improvement Cooperative

Department of Forest Science, Oregon State University

June 27, 2002

OREGON STATE UNIVERSITY

COLLEGE OF FORESTRY

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June 27, 2002
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Compiled by Keith Jayawickrama,
Department of Forest Science
Format and design by Gretchen Bracher,
Forestry Communications Group
Oregon State University, Corvallis, OR 97331-5752

List of Speakers

Speaker	Affiliation	Topic
Megraw	Retired, Weyerhaeuser	*An overview of wood quality*.
Briggs	Univ. of Washington	*Wood quality and silviculture*.
Cannon/Miller	Boise Cascade	*Improving wood quality: is it important to the industry?*
Johnson/Gartner	USFS PNWRS/Oregon State Univ.	*An overview of wood specific gravity in coastal Douglas-fir*.
Johnson/Jayawickrama	USFS PNWRS/Oregon State Univ.	*Genetics of wood specific gravity in coastal Douglas-fir*.
Rozenberg	INRA, Orleans, France	*Wood quality research at INRA: implications for Douglas-fir tree improvement*.
Jayawickrama	Oregon State Univ.	*Genetic improvement of conifer lumber stiffness and strength*.
Howe/Jayawickrama	Oregon State Univ.	*Genetics of stem quality in coastal Douglas-fir*.
Cartwright	BC Ministry of Forests	*Genetics of wood properties in western hemlock*.
Knowles/Shelbourne	New Zealand Forest Research Institute Ltd.	*Improving wood and stand quality of New Zealand's Douglas-fir plantations*.
Jayawickrama	Oregon State Univ.	*Tree improvement recommendations and research needs*.

Preface

A healthy, well-managed plantation of Douglas-fir or western hemlock is a joy to behold (at least for most foresters). However, more than adorning the landscape, the real purpose of growing commercial plantations is to produce trees that will be harvested and eventually turned into useful products. We should never lose sight of the impact that wood quality has on the quality of these final products.

The best approach to genetic improvement of wood quality in plantations has been debated for years. One approach recognizes that the trees will be harvested many years from now and turned into products we can't foresee using technologies we haven't imagined. According to this view (the "find them and grind them" philosophy), we should ignore wood quality, grow trees as fast as we can at the lowest possible cost, and then let future mills, chemists and technologists work their magic. At the other end of the spectrum is the view that genetic improvement is a low-cost, environmentally friendly and effective way to guarantee superior wood properties at the time of planting. Some growers are therefore willing to invest heavily in wood quality research, and carefully screen genotypes for wood quality before using their progeny in plantations. Without a crystal ball, however, some faith is needed to conclude that efforts to improve wood quality will be amply rewarded in the future. One hurdle is that many wood properties are more costly to measure than are height or diameter. In addition, perceptions vary because some growers process their own logs, whereas others only sell logs or stumpage. With all these nuances, most organizations involved in tree improvement fit in somewhere between the two views described above, paying more or less attention to the genetic improvement of wood quality as their inclinations, world-views and circumstances dictate.

The objective of our workshop was to summarize key aspects of wood quality in Douglas-fir and western hemlock — the two main species of interest to our cooperators. We tried to provide an overview of wood quality, its relevance to growers, and factors (both genetic and non-genetic) that influence wood quality. A one-day workshop cannot hope to capture all the information on such an important topic; however we hoped to at least raise the level of understanding and to stimulate thinking, debate, research and action. The workshop was attended by 49 people from Oregon, Washington, Idaho, British Columbia, New Zealand and France. We thank the 10 authors of invited presentations who generously contributed their time (travelling from afar in some cases) and shared their valuable insights, the participants, and Thimmappa Anekonda, Judy Han, Gancho Slavov, Denise Steigerwald and Igor Yakovlev, who played various roles in running the workshop.

We hope these proceedings serve as a reference and reminder of the topics covered, and that the workshop leads to better-informed decisions regarding wood quality improvement in the Pacific Northwest.

Keith Jayawickrama, Director
Northwest Tree Improvement Cooperative
Glenn Howe, Director
Pacific Northwest Tree Improvement Research Cooperative

Wood Quality Overview

Bob Megraw
Retired (Weyerhaeuser Co.)

bob megraw@aol.com

WHAT IS QUALITY WOOD (structural species) ?

- **Strong**

  High MOR (breaking strength) – doesn't fail under load

  High MOE (stiffness) – doesn't sag

- **Straight**

  No crook

  No twist

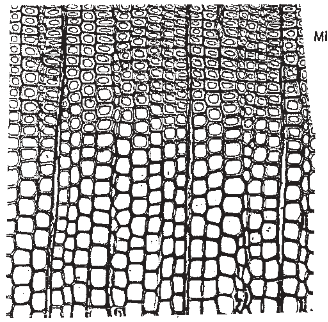
WHAT AFFECTS WOOD QUALITY ?

- **Knots**
- **Straightness of grain**
- **Compression Wood**
- **Fundamental Properties**

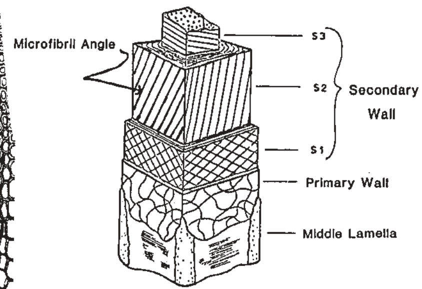
  Specific gravity

  MFA – (S2 microfibril angle)

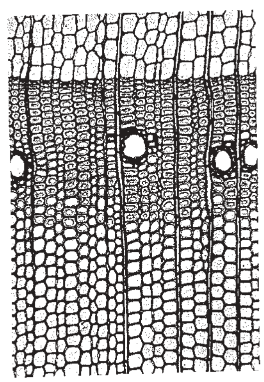
Specific Gravity



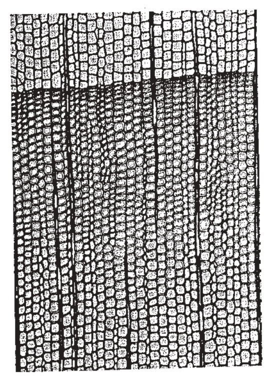
Microfibril Angle



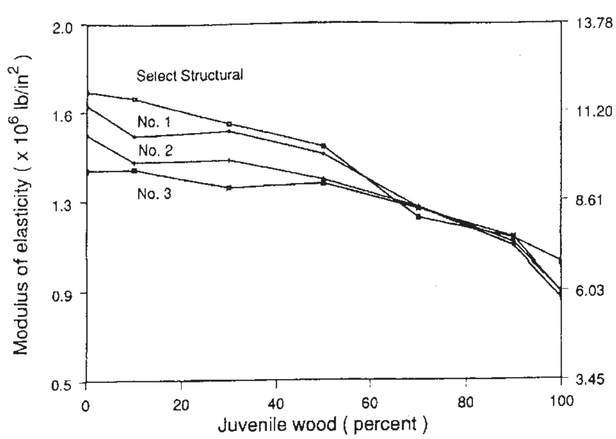
Douglas – fir



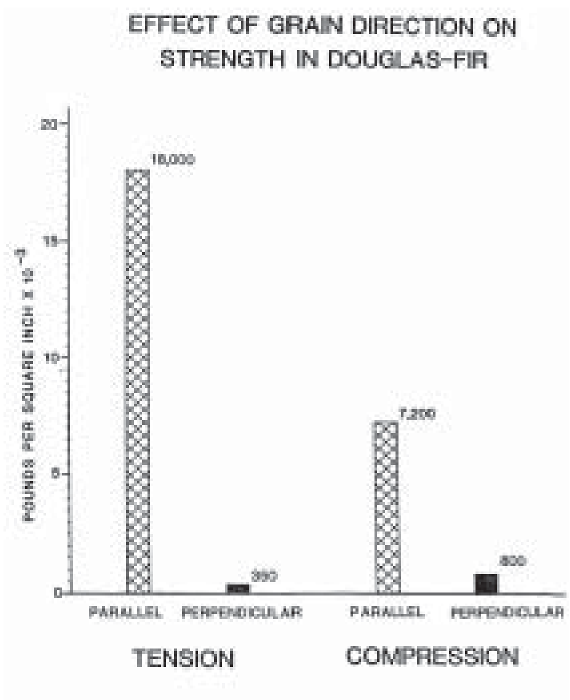
Western Hemlock



MOE vs. Juvenile Wood Percent



Source: *Kretschmann D. and Bendtsen A., 1992. "Ultimate Tensile Stress and Modulus of Elasticity of Fast-Grown Plantation Loblolly Pine Lumber." For. Prod. J., 24(2):196.*



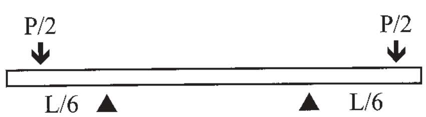
Clearwood Stiffness variation in loblolly pine and its relationship to specitic gravity and microfibril angle

24 Trees
(pamlico-4, N.C.)

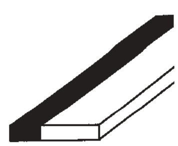
6 Heights above Stump
1 ft, 4 ft, 7 ft, 10 ft, 13 ft, 16 ft

6 Ring Positions from Pith
3, 5, 7, 10, 15, 20

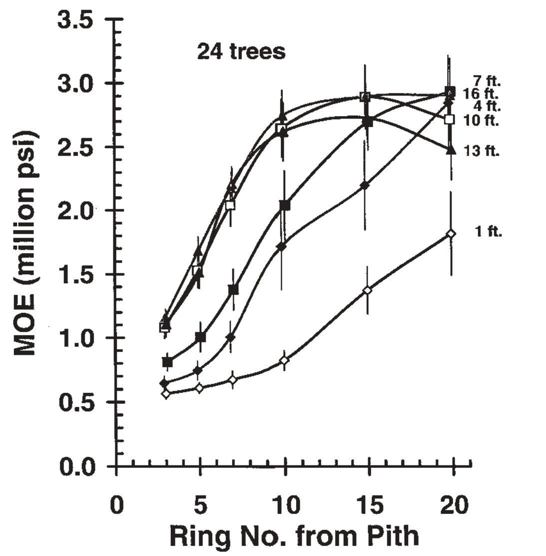
Individual-Ring Testing for MOE in Bending



$$\text{MOE} = \frac{PL^3}{(\text{def})18bd^3}$$

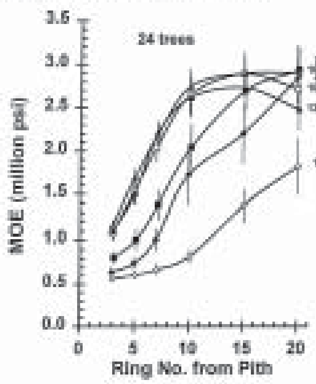


MOE by Ring No. from Pith *– Lobolly pine*

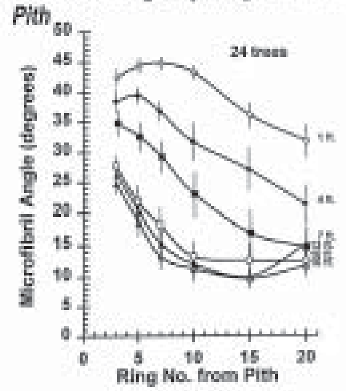


Lobolly pine

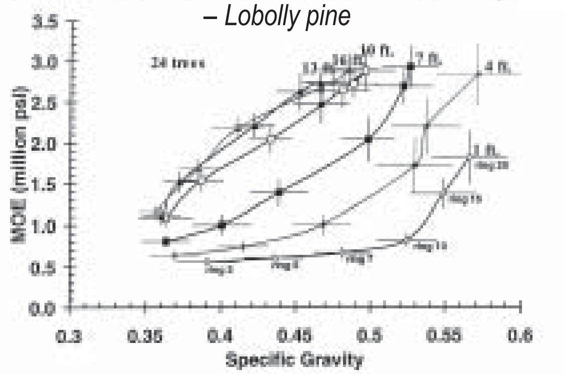
MOE by Ring No. from Pith



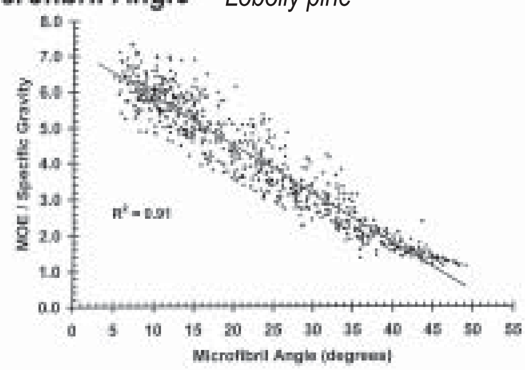
Microfibril Angle by Ring No. from Pith



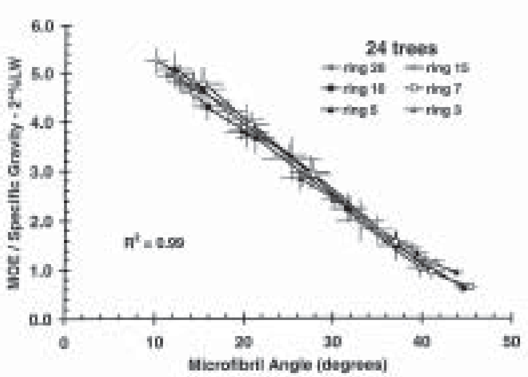
Individual-Ring MOE vs. Specific Gravity – *Lobolly pine*



(Individual-Ring MOE) / Specific Gravity vs. Microfibril Angle – *Lobolly pine*

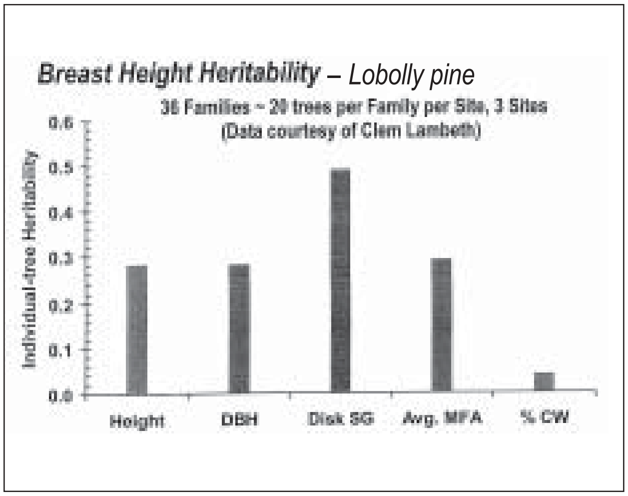


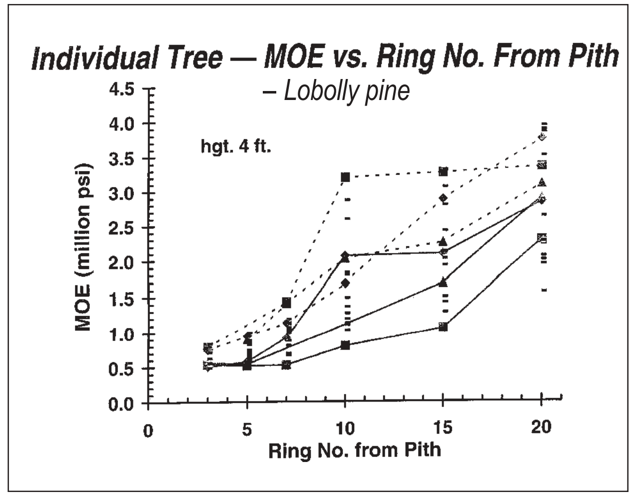
Addition of %-Latewood Factor – *Lobolly pine*

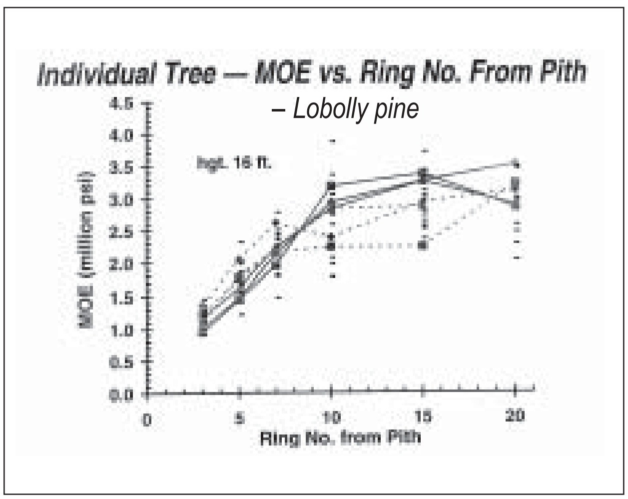


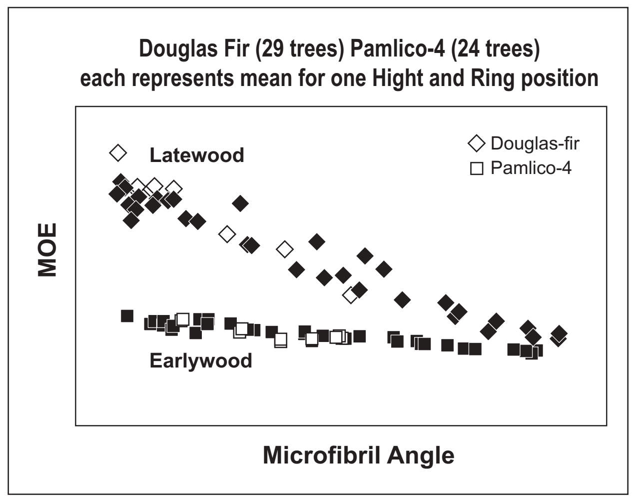
Individual-Ring MOE Regressed Against Microfibril Angle and Specific Gravity – *Lobolly pine*

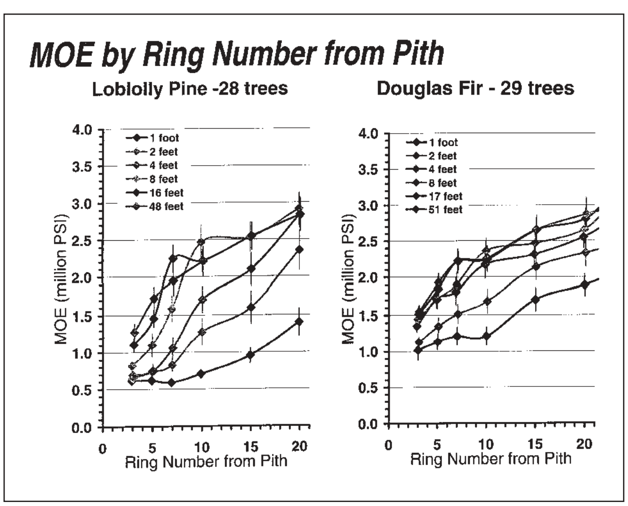
Individual-Ring Location		Multiple R^2
4 ft.	ring 3	0.76
	ring 5	0.80
	ring 7	0.78
	ring 10	0.96
	ring 15	0.89
	ring 20	0.85
16 ft.	ring 3	0.76
	ring 5	0.80
	ring 7	0.78
	ring 10	0.96
	ring 15	0.89
	ring 20	0.85

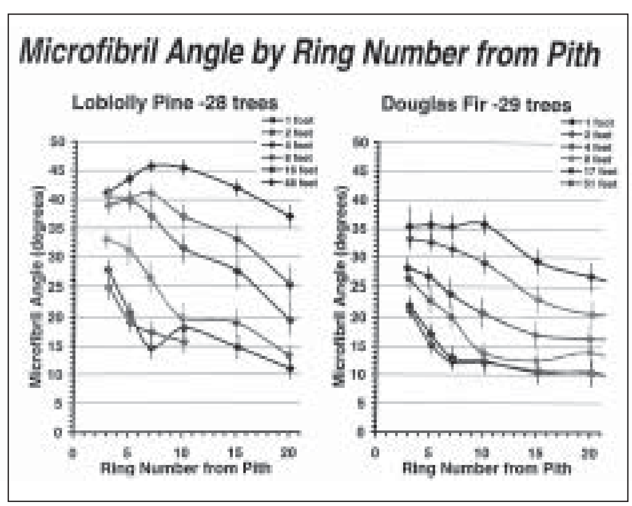

Breast Height Heritability – Lobolly pine
36 Families ~ 20 trees per Family per Site, 3 Sites
(Data courtesy of Clem Lambeth)
Individual-tree Heritability
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Height
DBH
Disk SG
Avg. MFA
% CW

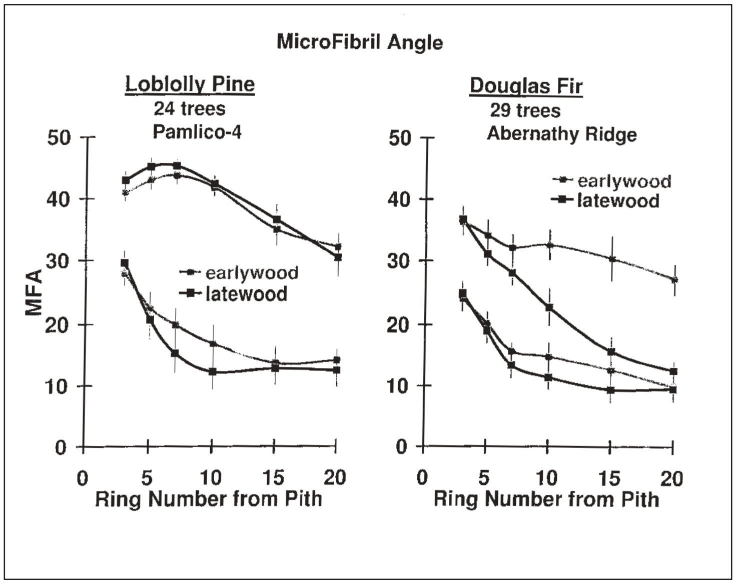

Individual Tree — MOE vs. Ring No. From Pith
– Lobolly pine
hgt. 4 ft.
MOE (million psi)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
Ring No. from Pith


Individual Tree — MOE vs. Ring No. From Pith
– Lobolly pine
hgt. 16 ft.
MOE (million psi)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
Ring No. from Pith

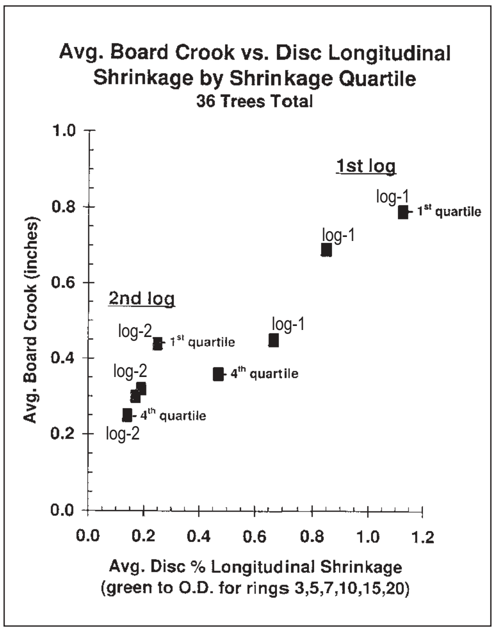

Douglas Fir (29 trees) Pamlico-4 (24 trees)
each represents mean for one Hight and Ring position
Latewood
◇ Douglas-fir
□ Pamlico-4
MOE
Earlywood
Microfibril Angle


MOE by Ring Number from Pith
Loblolly Pine -28 trees
Douglas Fir - 29 trees
1 foot
2 feet
4 feet
8 feet
16 feet
48 feet
17 feet
51 feet
MOE (million PSI)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
Ring Number from Pith

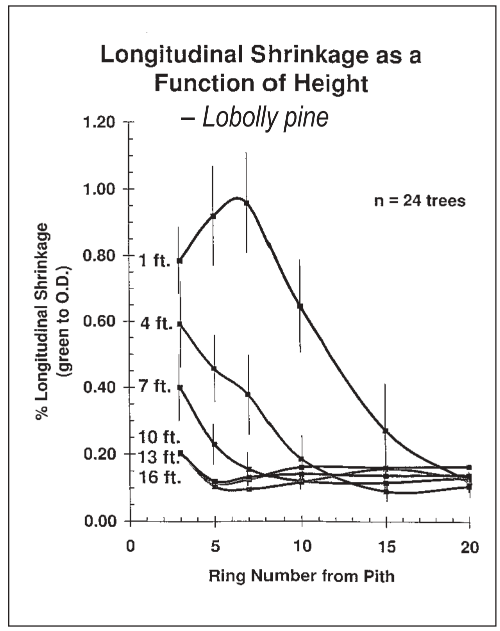

Microfibril Angle by Ring Number from Pith
Loblolly Pine -28 trees
Douglas Fir -29 trees
Microfibril Angle (degrees)
Ring Number from Pith



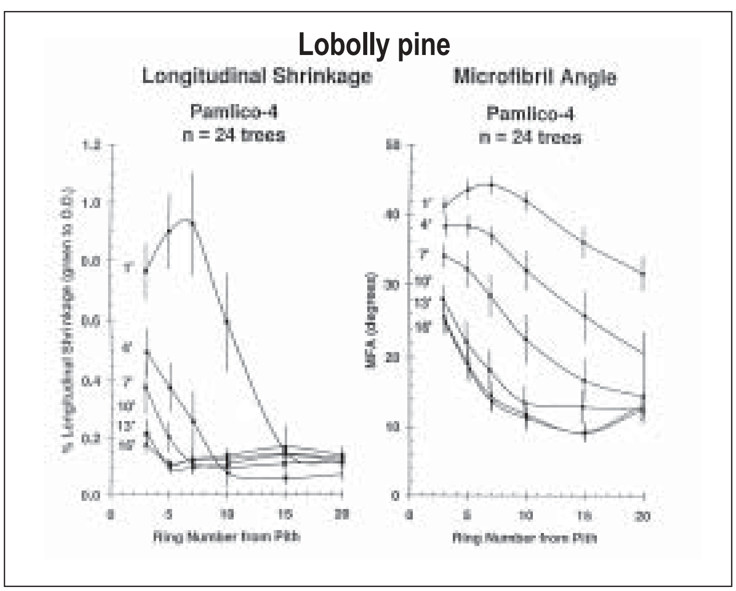
MicroFibril Angle
Loblolly Pine
24 trees
Pamlico-4
Douglas Fir
29 trees
Abernathy Ridge
earlywood
latewood
MFA
Ring Number from Pith



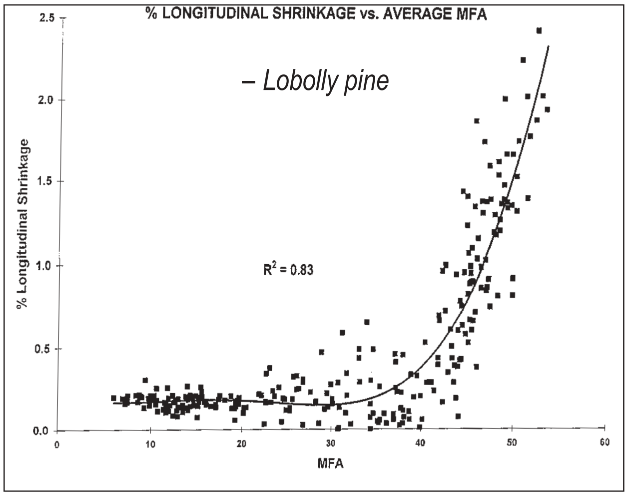
Avg. Board Crook vs. Disc Longitudinal Shrinkage by Shrinkage Quartile
36 Trees Total
1st log
2nd log
log-1
1st quartile
log-2
4th quartile
Avg. Board Crook (inches)
Avg. Disc % Longitudinal Shrinkage
(green to O.D. for rings 3,5,7,10,15,20)

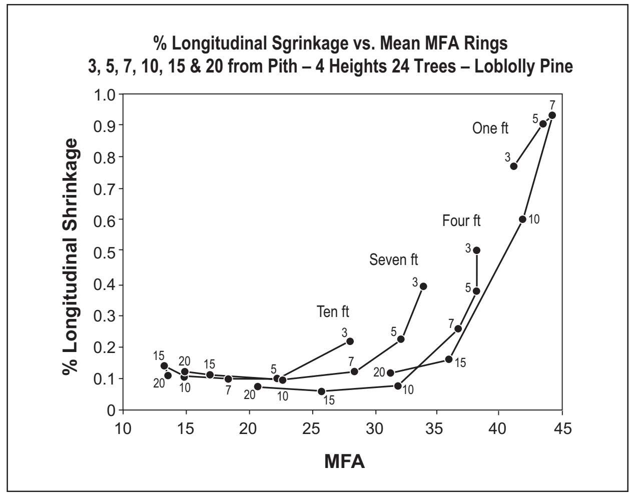


Longitudinal Shrinkage as a Function of Height
– Lobolly pine
n = 24 trees
1 ft.
4 ft.
7 ft.
10 ft.
13 ft.
16 ft.
% Longitudinal Shrinkage (green to O.D.)
Ring Number from Pith



Lobolly pine
Longitudinal Shrinkage
Microfibril Angle
Pamlico-4
n = 24 trees
Ring Number from Pith



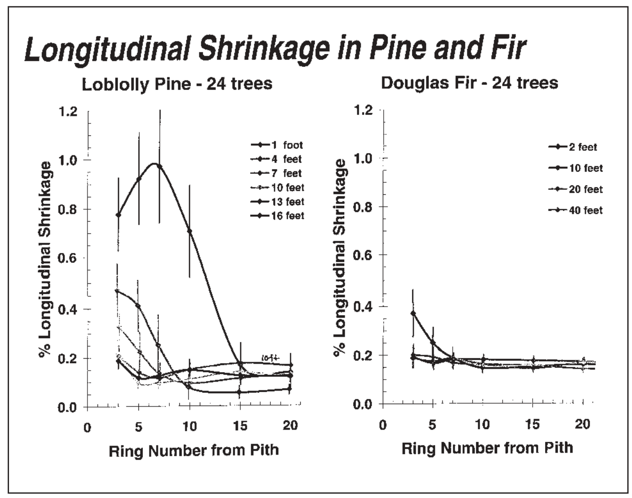


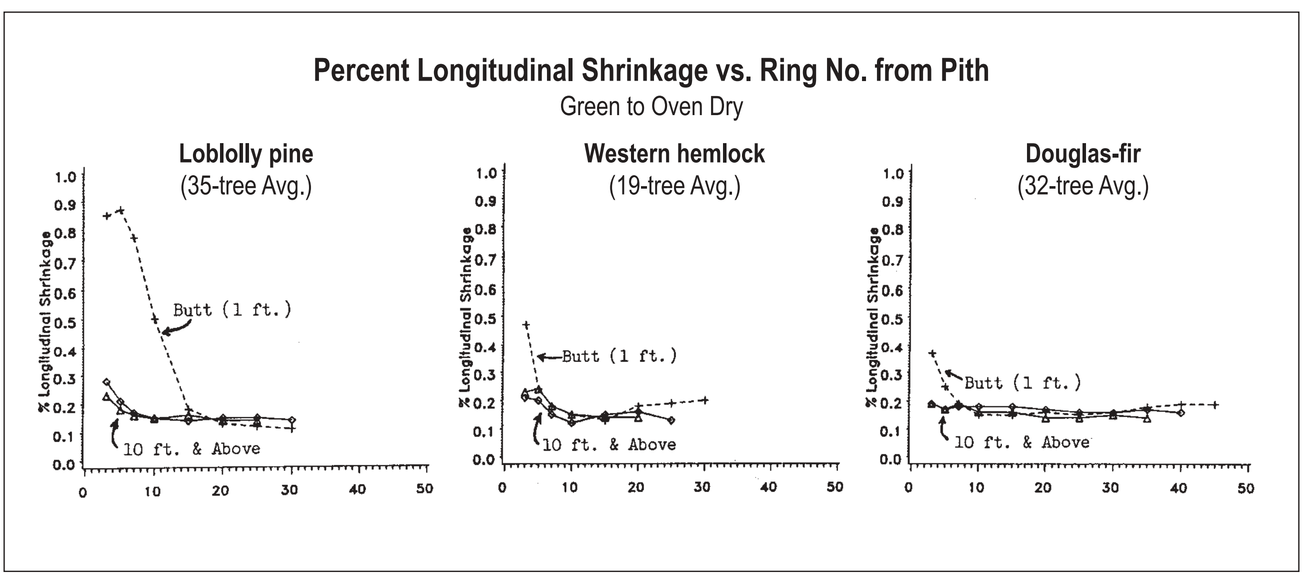
Practical Implications:

- Can we use MFA to screen out extreme longitudinal shrinkage trees? Yes

– Lobolly pine

Ranked by MFA Tree #	MFA	%LS	Ranked by %LS Tree #	MFA	%LS
13	34	0.19	13	34	0.19
17	40	0.54	3	41	0.36
3	41	0.36	23	42	0.45
23	42	0.45	15	44	0.45
6	42	0.62	9	43	0.53
22	43	1.00	17	40	0.54
25	43	0.69	6	43	0.62
9	43	0.53	25	43	0.69
14	44	0.74	14	44	0.74
15	44	0.45	24	45	0.80
7	44	0.80	7	44	0.80
5	45	1.04	16	45	0.81
18	45	1.19	22	43	1.00
16	45	0.81	8	48	1.03
24	45	0.80	5	45	1.04
20	45	1.10	20	45	1.10
12	46	1.60	4	48	1.19
21	46	1.33	18	45	1.19
2	48	1.55	11	48	1.33
11	48	1.33	21	46	1.33
4	48	1.19	2	48	1.55
8	48	1.03	12	46	1.60
10	49	2.05	10	49	2.05





Summary

- **Modulus of elasticity (MOE) varies dramatically and systematically with height in tree and ring from pith.**
- **Most variation in MOE (but not all) is due to variation in MFA and Sp. Gr.**
- **Variability (absolute) in MOE among trees is much less for inner-rings than for outer rings.**
- **Differential LS is the cause of crook. LS correlates with mfa in inner rings in the lower portion of the tree, where mfa is large. Mfa can be used to estimate which trees will rank in upper and lower brackets for LS.**

Key Recommendations:

- **Make wood property comparisons only on a very specific ring and height basis (values are very sensitive to ring position and height).**
- **Don't forget the 3rd dimension. Trees differ in height profile as well as ring-age profile.**
- **While end-use (resultant) properties (MOR, MOE, etc.) can be valuable screening tools, actual tree impr. efforts should be founded on individual basic properties (resultant properties involve more than one basic, each basic differing in heritability and influence on the resultant).**

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A joint workshop organized by the

PNW Tree Improvement Research Cooperative

and the

Northwest Tree Improvement Cooperative

Thanks to:

Organizers

Keith Jayawickrama
Thimmappa Anekonda
Cheryll Alex
Judy Han
Gancho Slavov
Denise Steigerwald

Speakers

Bob Megraw
Phil Cannon
Larry Miller
David Briggs
Randy Johnson
Barbara Gartner
Philippe Rozenberg
Charlie Cartwright
Leith Knowles
Tony Shelbourne

Why have a workshop?

- ✓ **Technology transfer –** *a lot of research has been done that could be put into practice*
- ✓ **Workshop –** *we need to develop a scientific consensus on some issues*
- ✓ **Scientists need feedback from practitioners –** *let's hear from the participants!*
- ✓ **Goal –** *provide information needed to make concrete decisions about tree improvement practices and research*

Challenges

✓ **Be careful about selecting too many traits**

- *The more traits - the less gain you get in each trait*
- *Should wood quality be included?*
- *If so, are there 1-2 key traits that should be considered?*

No. of traits selected	Selected tree is the best out of:	Per-trait superiority of selected trees	
		(i)	(%)
1	1000	3.37	100
2	31.6	2.06	61
3	10	1.54	46
4	5.62	1.23	36
5	3.98	1.03	31

Challenges

✓ **Which traits impact tree value?**

Breaking strength (MOR)
Stiffness (MOE)
Crookedness/Straightness
Sinuosity
Branch/Knot size
Branch angle
Grain straightness
Amount of compression wood
Ramicorn branching/Forking
Specific gravity
Microfibril angle (MFA)
etc

Challenges

✓ **We must predict the future**

- *Materials being bred today may not be harvested for at least 50 years*
- *What will these trees be used for?*
- *What grading criteria will be used? Visual? Mechanical?*

Challenges

✓ **Can we come up with provisional answers to these difficult questions?**

Wood Quality and Silviculture

PNWTIRC/NWTIC Workshop "Genetic Improvement of Wood Quality in Coastal Douglas-fir and Western Hemlock"
June 27, 2002, Oregon State University, Corvallis, OR

Dr. David Briggs, Director
College of Forest Resources
Box 352100
University of Washington
Seattle, WA.

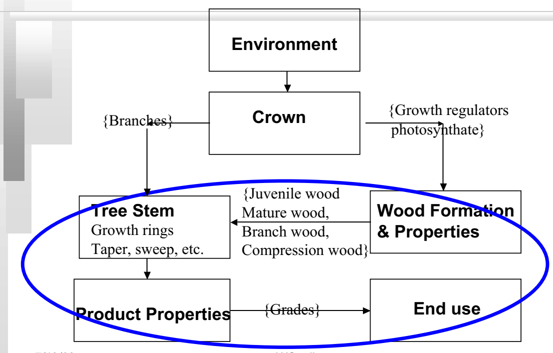
Outline

- Definitions
- Some Key Properties
- Silviculture Effects
  - Thinning & Fertilization
  - Wide Planting Spacing
  - Early (pre-commercial) Thinning
  - Pruning
- The Bottom Line
- Conclusions

I. Definitions

A. Quality: "fitness for use"

Process of Creating Quality in the Context of Wood

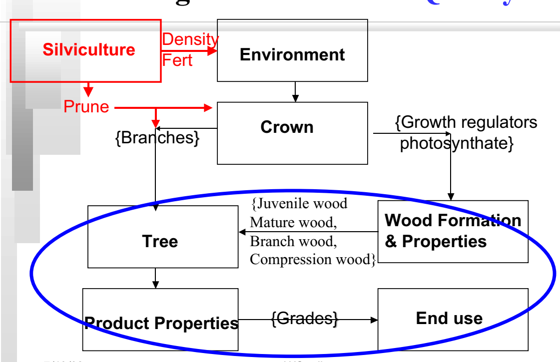


B. Silviculture:

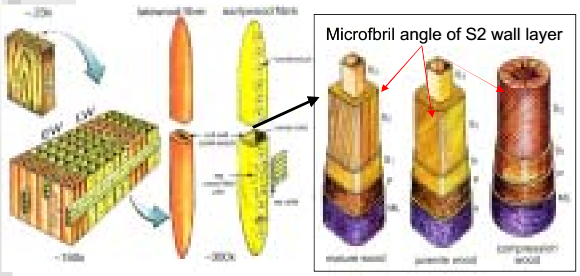
techniques to alter growth trajectories

(D. Briggs)

Relating Silviculture and Quality



II. Some Key Properties
A. Fiber: geometry, microfibril angle



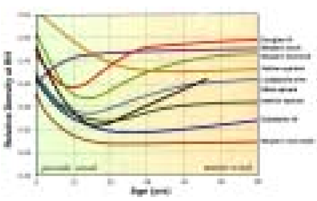
(Jozsa & Middleton 1994)

Fiber characteristics change from JW to MW

(Jozsa & Middleton 1994)

B. Wood Properties (fiber aggregates)
1. Specific gravity (relative density)

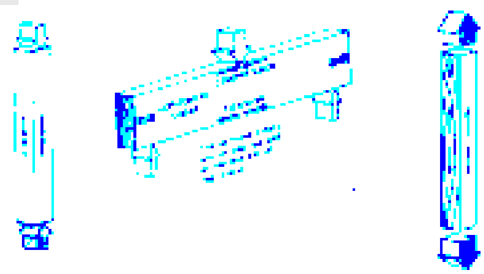
- wood substance per unit volume
- % of earlywood & latewood; related to most other properties



(Jozsa & Middleton 1994)

2. Mechanical properties (clear wood)

- baseline in absence of knots & other defects



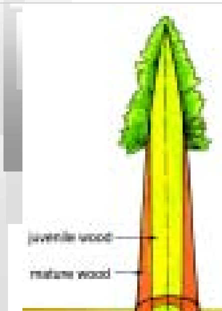
3. Growth Rings

- ring width "growth rate": wide vs narrow
- % latewood a surrogate for wood density

(D. Briggs)

C. Large Scale Aggregations
1. Juvenile and Mature Wood

- 10 ring zones painted on log ends:
- 70 year old vs 30 year old logs

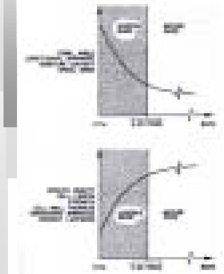


(D. Briggs)

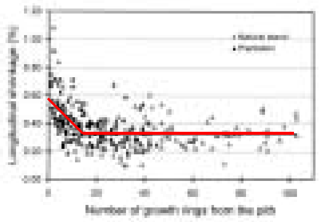
(Jozsa & Middleton 1994)

Properties do not transition from JW to MW at the same age

When is the change no longer important? Lots of variability!



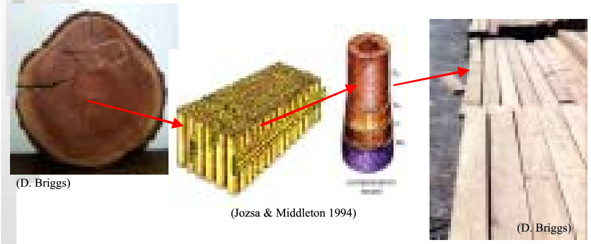
(Senft et al 1985)



(Deresse et al 2002)

2. Compression wood

- Leaning trees, branches, other de-stabilizing events

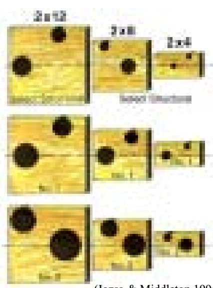


(D. Briggs) (Jozsa & Middleton 1994) (D. Briggs)

3. Branches (knots)

- Aesthetics, degrade of mechanical properties, interfere with remanufactured cuttings

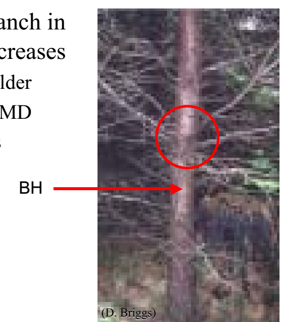
(D. Briggs)



(Jozsa & Middleton 1994)

BH Branches: an early indicator

- Diameter of largest branch in 1st whorl above BH increases
  - as the stand becomes older
  - in stands with larger QMD
  - In lower density stands
- (Briggs & Turnblom 2002)



(D. Briggs)

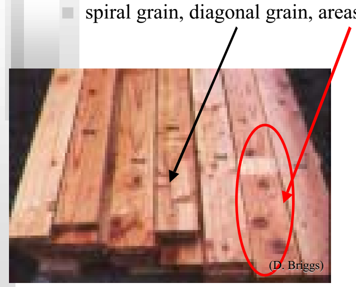
4. Stem Form (taper, sweep, crook, etc)

- Deviant grain in products, compression wood
- Reduce yield of lumber & veneer

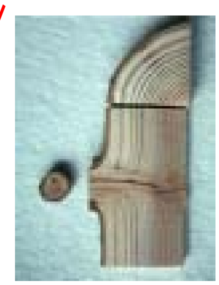
(D. Briggs)

5. Deviant grain

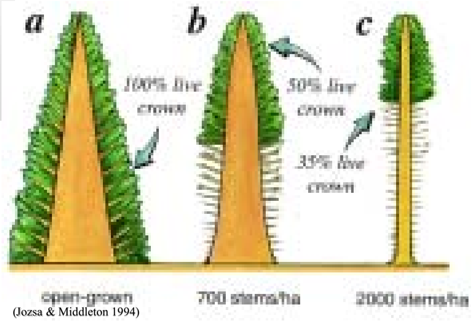
- spiral grain, diagonal grain, areas near knots



(D. Briggs)



III. Silviculture Effects



(Jozsa & Middleton 1994)

A. Thinning and Fertilization

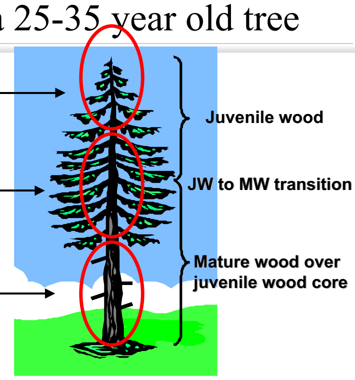
- What were pre-existing conditions?
  - Age?
  - Site?
  - Stand density?
  - Etc.
- How much do treatments alter resource availability and competition?
- How frequently are treatments repeated?

1. General Response

- If increase available resources by thinning, fertilizing, or both
- Trees respond with
  - more foliage,
  - slower crown recession (larger branches)
  - greater photosynthetic production
  - more wood formation (volume and altered properties)
- But progress toward competitive state ➔ volume & property changes are temporary

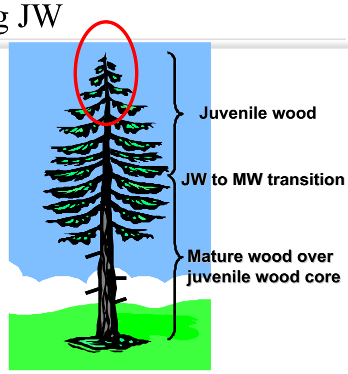
Let's T & F a 25-35 year old tree

- Top
- Middle
- Butt



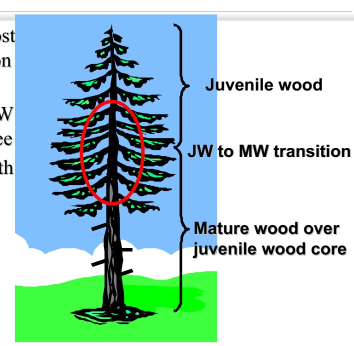
T/F effect on Top with upper live crown & young JW

- Larger knots
- Volume added: JW until transition to MW moves into this position
- 100% JW % until MW transition
- Increased ring width (?)
- Pieces small but longer
- Log/lumber grades (low)
- $



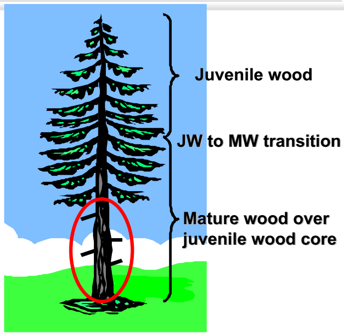
T/F effect on Middle with lower live crown & JW/MW transition

- Larger knots: growth boost & slower crown recession
- Volume added: mix of older JW followed by MW as transition moves up tree
- High JW % decreases with more MW
- Increased ring width
- Somewhat larger pieces
- Log/lumber grades (??)
- $$

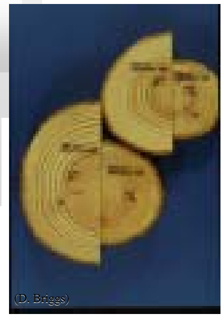


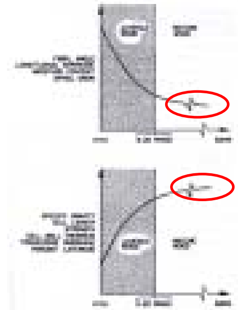
T/F effect on Butt with fixed knots & JW core diameter

- Volume added is MW
- Increased ring width
- JW % decreases
- Larger pieces
- Improved log & lumber grades
- $$$$



2. T/F Effects on Mature Wood





a. Thin only

- Fiber: shorter, larger diameter, thinner walls, larger microfibril angle (small changes; important??)
- Specific gravity: may increase or decrease; changes generally small within 5%)
- Growth rings: abrupt change from narrow to wide
- Compression wood: may form due to heavier crown & wind
- **As stand rebuilds competitive state, effects diminish**
- **Thinning can improve residual stand quality by removing poor quality trees, smaller trees, etc.; can degrade residual stand quality by removing better trees**

b. Fertilize only

- Fiber: shorter, larger diameter, thinner walls, larger microfibril angle (small changes; important??)
- Specific gravity: usually decreases; peak change 5-10% & return to normal over time (~ 5 years)
- Growth rings: abrupt change from narrow to wide
- Compression wood: may form due to heavier crown & wind
- **If fertilize dense stand competition may intensify ➔ self thinning with some effect on average quality of survivors**

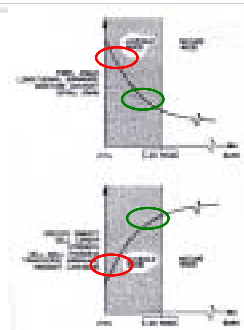
c. Combined Thin & Fertilize

- Fiber: shorter, larger diameter, thinner walls, larger microfibril angle
- Specific gravity: decreases; up to 25%; return to normal over time (~5 years); mat have lowered latewood %
- Growth rings: abrupt change from narrow to very wide
- Compression wood: may form due to heavier crown & wind

3. T/F Effects on Juvenile Wood

- Little research but effects appear to be minimal due to the strong effects of physiology on development of wood from young cambia
- What happens closer to the transition age?

Young JW
Older JW

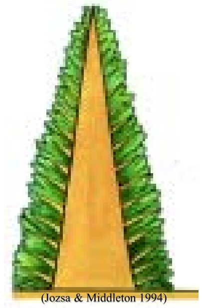


C. Wide Planting Spacing

(D. Briggs)

7/19/02 WQ_silv 31

- Large tree in short time
  ➔ short rotation
  - Wide rings
  - Large diameter JW core, high JW %
  - Slow crown recession = large branches
  - Low product value
- Initially, wide spaced trees do not grow as well = “crossover effect”
- Avoid early operation costs: a fantasy

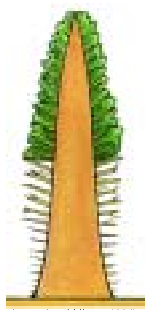


(Jozsa & Middleton 1994)

7/19/02 WQ_silv 32

D. Early Thinning

- Pre-empts competition
- Rapid growth maintained
- Large tree diameter reached more quickly
- Short rotation
- Wide growth rings
- Large JW core diameter
- Large branches

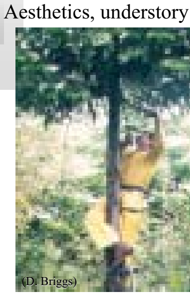


(Jozsa & Middleton 1994)

7/19/02 WQ_silv 33

E. Pruning

- Production of clear wood
- Aesthetics, understory growth enhancement, habitat,, etc.



(D. Briggs)

7/19/02 WQ_silv 34

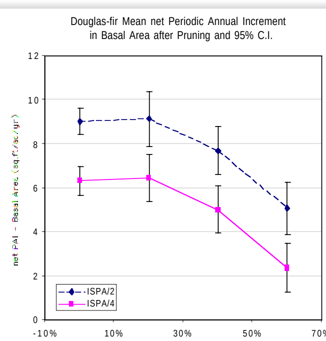
Pruning Questions and Concerns

- Stem growth & form
- Heal-over (occlusion)
- Douglas-fir pitch moth attacks
- Epicormic branches
- Branch diameter growth above the pruning lift
- Change in wood quality

7/19/02 WQ_silv 35

• Growth Basal Area Growth

- 20%, 40%, 60% crown removal
- Slight increase (?) in growth from 0-20% is not significant
- Steeper decline from 40-60%, than from 20-40%



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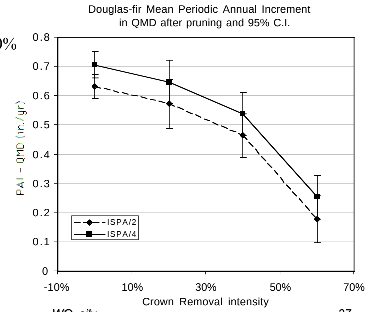
Diameter Growth

- Monotonically declining
- Steeper decline from 40-60% than from 20-40%



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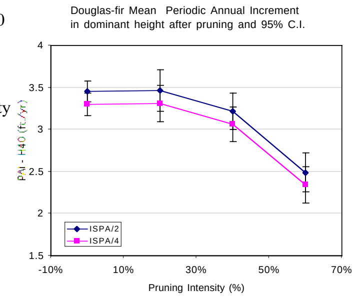
Height Growth

- Steeper decline from 40 to 60% than from 20 to 40%
- Height growth difference due to density is not significant



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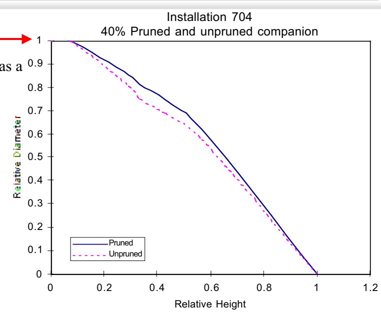
Stem Form (Taper)

- DBH = 1
  - Y-axis is diameter as a fraction of DBH
- Total Height = 1
- Manuscript in development



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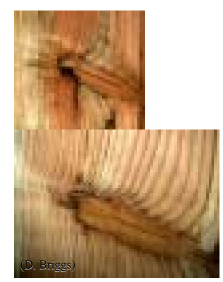
2. Heal-over (occlusion)



7/19/02 WQ_silv 40

Occlusion: (9-22 year-old Douglas-fir)

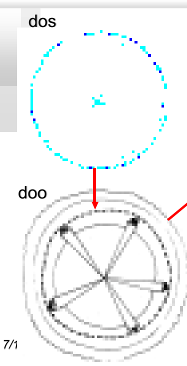
- **Time**: 1 to 14 years
- Increases if
  - •tree is larger in diameter
  - •larger distance from inside bark to stub end (bark thickness, nodal swelling, protruding stub)
  - •branch is already dead
  - •jagged splintered pruning cut
  - •tree grows slowly after pruning

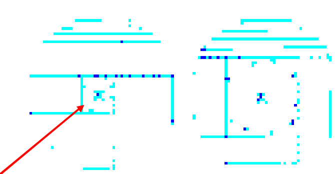
Petruncio et al 1997

- **Distance:** ROO = 28 to 266 mm (average = 110 mm)
- Width of Occlusion zone
  - 7 to 108 mm (average = 30 mm)
- ROO is larger if
  - prune a larger tree
  - distance from inside bark to stub end is larger
  - branch is larger in diameter
  - branch is already dead
  - accelerated growth rate after pruning

7/19/02 WQ_silv 41

Diameter over stubs, Diameter over occlusion, defect core & clear wood yield





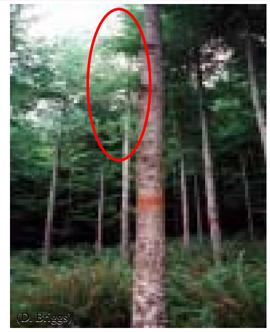
Prune small diameter, vigorous trees to minimize defect core in the final log!

7/1 WQ_silv 42

3. Douglas-fir pitch moth

4. Epicormic Branches

- Few form in Douglas fir if
  - Remove no more than 40% of live crown
  - And stand has at least 200 trees per acre
- Collier & Turnblom, 2001

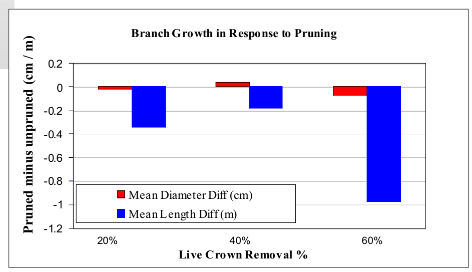


5. Growth of remaining branches above pruning lift

- 18 Douglas-fir installations with 3 plots in each installation, 56 plots total
  - Plot densities range from 85 to 270 SPA
  - There is one plot each of 20, 40, and 60% green crown removal intensity - every tree pruned
  - Pruning triggered by attainment of 30-ft height
- Turnblom & Collier 2002

Growth of Remaining Branches

None of the branch diameter differences are significant
Branches in trees with 60% crown removal are significantly sho

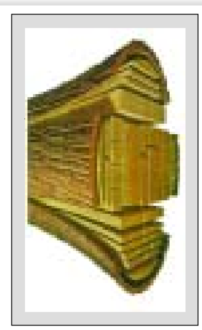


6. Pruning Effect on Wood Properties

- Little research
- An immediate temporary increase in specific gravity may occur
  - Relatively severe pruning
  - A reduction of earlywood relative to latewood due to loss of foliar biomass
  - Mitigated as the tree builds new crown and restores balance of EW & LW

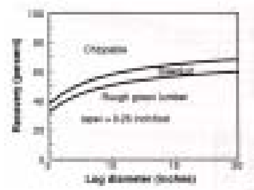
IV. The Bottom Line

- Effects on Product Yield and Grade Recovery
- $ Value



• Lumber
1. Material Balance

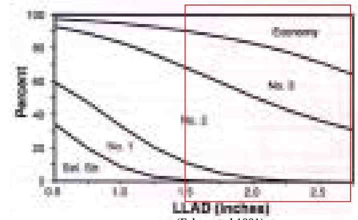
- % lumber
  - increases with increasing diameter
  - decreases with increasing taper



(Fahey et al 1991)

2. Visual Lumber Grade

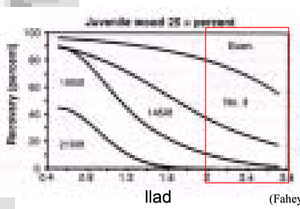
- Select Structural disappears with 1.5 inch LLAD
- No. 1 disappears with 2.0 inch LLAD
- LLAD = average of largest limb in each log quadrant



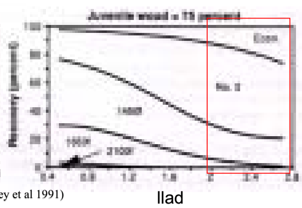
(Fahey et al 1991)

3. Machine Stress Rated Lumber Grade

- 2100f & better disappears with 75% Juvenile wood
- If knots are >=2 inches > 60% is No 3 & Economy

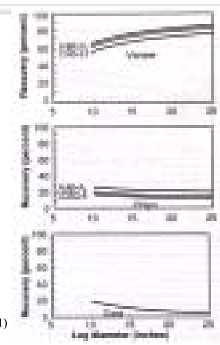


(Fahey et al 1991)



B. Veneer
1. Veneer Material Balance

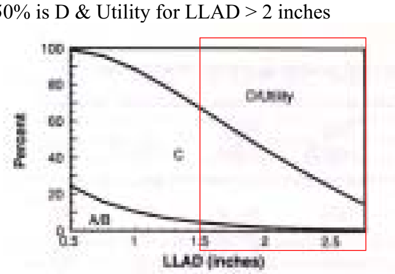
- % Veneer
  - increases with increasing diameter
  - decreases with increasing taper
  - Decreases with larger LLAD



(Fahey et al 1991)

2. Visual Veneer Grade

- A/B disappears with 1.5-2.0 inch LLAD
- >50% is D & Utility for LLAD > 2 inches



(Fahey et al 1991)

C. $/A Gain of T/F After 22 Years

Age 55 Site index 85, 1000 trees/acre before treatment
Harvest @ age 77

Treatment	*Log Value*	*Visual Grade Lumber Value*
Thin Only	*$3,625*	*$5,683*
Biosolids Only	*$1,142*	*$2,107*
Thin & Biosolids	*$9,069*	*$10,708*

Value impacts are not additive!

(Sonne 2001)

V. Conclusions

- Quality can have a variety of contexts: be sure you know what is important for the specific product of interest
- To evaluate silviculture effects be sure you are aware of
  - What were pre-existing conditions?
    - Age?, Site?, Stand density?, Etc.
  - How much do treatments alter resource availability and competition?
  - How frequently are treatments repeated?
  - Effects of combinations may not be additive!

Recommendations

- Research is needed on the effects of silvicultural treatments and regimes during the early stages of development especially
  - Properties of JW
  - How long a tree produces JW
- Can differences between JW and MW be made more uniform via genetic selection?
- Research is needed on early branch development and number/size of knots. Genetic selection?
- Need to improve integration of silviculture/quality/ product value effects in growth models.

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The End

- **http://www.standmgt.org**

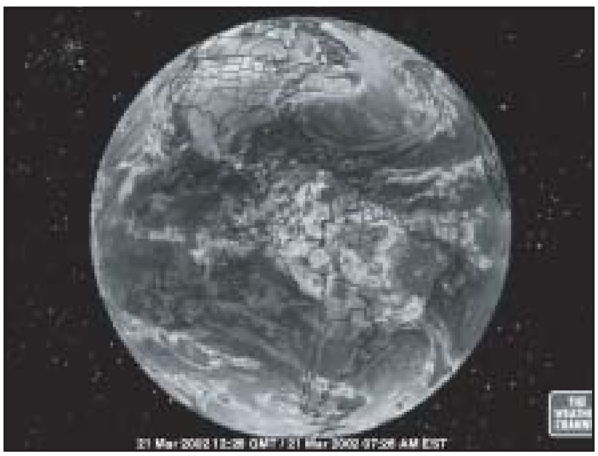
Stand Management Cooperative

An Industrial View of Douglas-fir Wood Quality

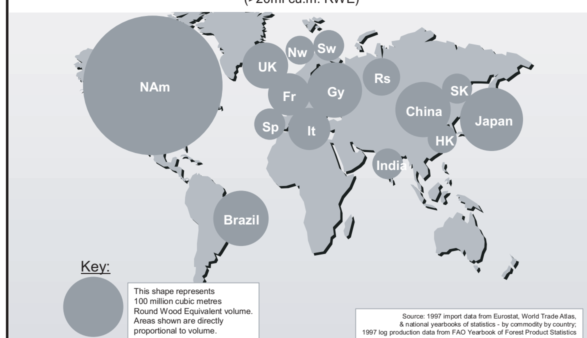
Phil Cannon & Larry Miller
Boise Cascade Corporation

Recipe for Successful Research

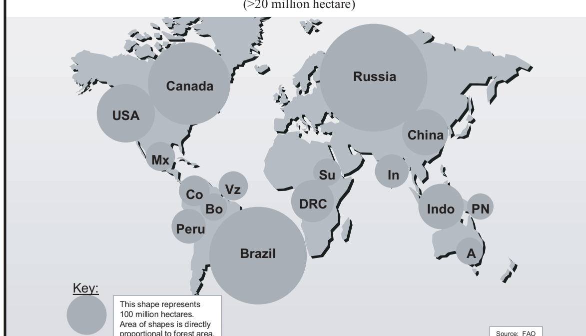
ï 1) Know what you want
ï 2) Figure out what is possible
ï 3) Develop a plan to achieve what is possible
ï 4) Go for it
ñ A rough paraphrase of Scott Wallinger, VP for Forest Research at Mead-Westvaco



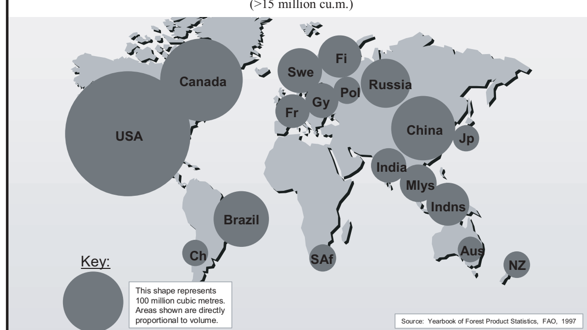
Consumption timber, pulp & paper 1997
(>20mi cu.m. RWE)



ìF orestî area 1997
(>20 million hectare)



Production industrial round wood 1997
(>15 million cu.m.)



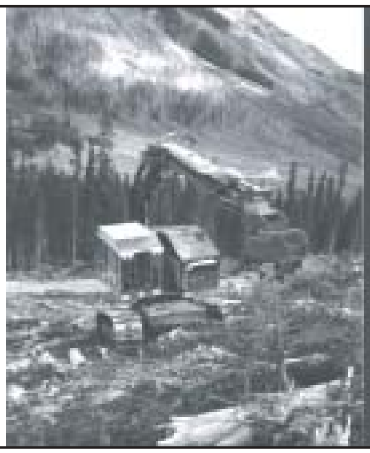
Forest Industry Faces Two Major Challenges:

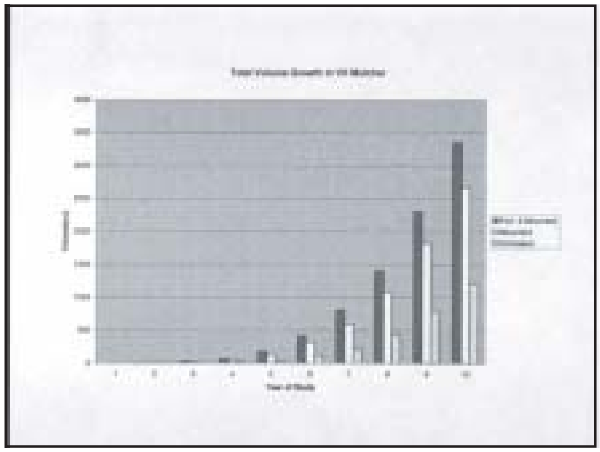
- To meet the demands and aspirations of people for wood and fiber from a world population that will approach 9-10 billion people by 2050
- To manage forests at high intensity on fewer acres in a world that values biodiversity and nontimber forest values

Scott Wallinger
VP for Mead-Westvaco

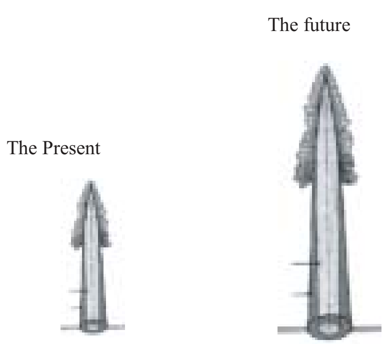
Things that Make Trees Grow Faster

- Choice of site
- Site preparation
- Genetic improvement
- Use of vigorous containerized stock
- Weed control (herbicides)
- Fertilization (several times)
- Thinning
- Maintenance of forest health

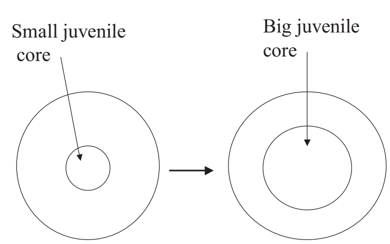


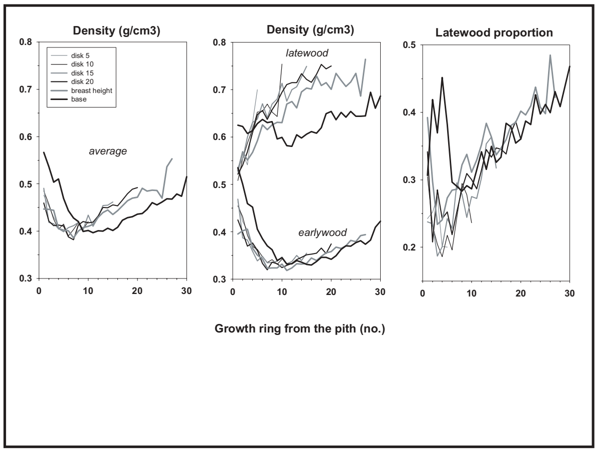


HOW FAST CAN TREES BE EXPECTED TO GROW

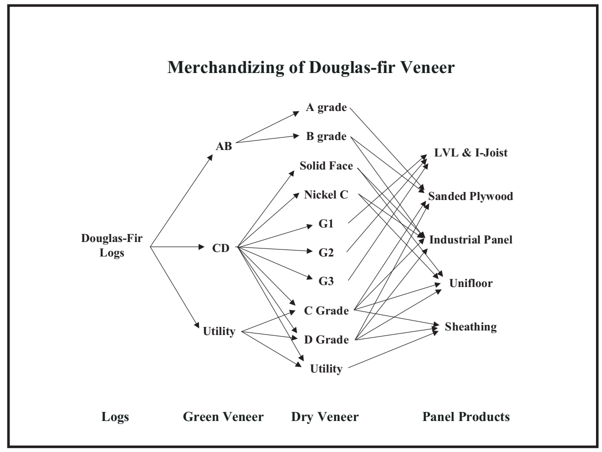


One Effect of Growing Douglas-fir faster





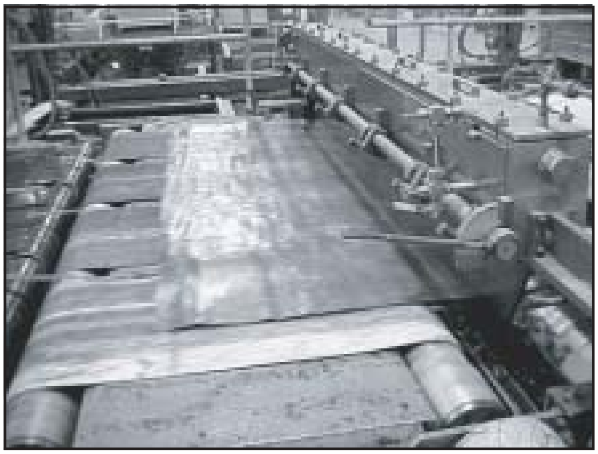
Density (g/cm3)
Density (g/cm3)
Latewood proportion
disk 5
disk 10
disk 15
disk 20
breast height
base
average
latewood
earlywood
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
10
20
30
Growth ring from the pith (no.)



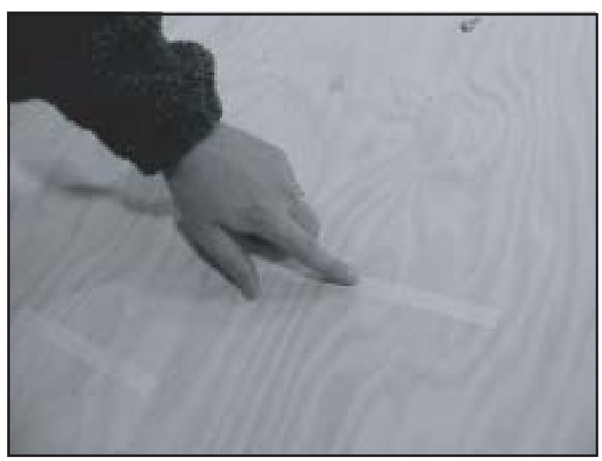
Merchandizing of Douglas-fir Veneer
Douglas-Fir Logs
AB
CD
Utility
A grade
B grade
Solid Face
Nickel C
G1
G2
G3
C Grade
D Grade
Utility
LVL & I-Joist
Sanded Plywood
Industrial Panel
Unifloor
Sheathing
Logs
Green Veneer
Dry Veneer
Panel Products

Metriguard

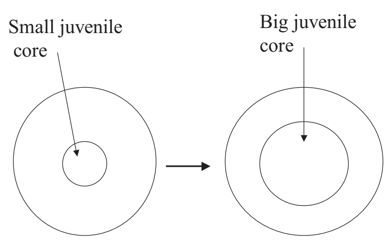
432




DANGER



One Effect of Growing Douglas-fir faster



An Implied Mandate

- ìUnless you get the wood strength issue sorted out, I am not going to get very excited about moving Doug-fir to a short rotation (eg 32 years).î
  - Russ McKinley
  - Western Oregon Timberlands Manager
  - Boise Corp.

Alternatives for Meeting Wood Strength Needs

- Re-design the product
- Modify the silviculture
- Find and sort the strong wood better
  - Radar, NIR (sp), Hitman, Philippeís approach
- Go off-shore
- Traditional tree breeding
- Biotechnology

Modify the silviculture

- Start with vegetatively propagated material that is ontogenically five years old
- Favor silvicultural practices that promote late growing-season growth
- Wait to supe up the silviculture until the plantation is 15 years old

Biotechnology

- Identify genes that confer a propensity to transition to mature wood faster, increase ratio of latewood to earlywood, increase density of earlywood, latewood, or overall within-ring density, reduce microfibril angle
- Transfer these genes into somatic embryos of elite clones for mass propagation

Genetic Differences in Veneer Quality

Douglas-fir Wood Quality and Veneer Study

- Objectives:

  Develop correlations between indirect methods of wood quality estimation and veneer strength

  Develop correlations between wood specific gravity measured by non-destructive means and veneer strength

Douglas-fir Wood Quality and Veneer Study

- Objectives

  Develop correlations between direct and indirect measures of wood quality, and strength of engineered wood products

  Develop a better understanding of how changes in wood specific gravity veneer strength

Douglas-fir Wood Quality and Veneer Study

- **Old field sites; vegetation control only; no fertilization**
- **Spacing 9 x 9 feet; no thinning**
- **DBH (ob): 9.9-14.0î with mean of 12.1î**
- **Height: 57-95í with mean of 79**

Douglas-fir Wood Quality and Veneer Study

- Two half-sibs from each of 18 families ñ 36 trees total
- Families selected based on range of breast height specific gravity known to exist at age 15 (0.341-0.461)

Douglas-fir Wood Quality and Veneer Study

- **Standing trees**
  - Increment cores taken at breast height, bark to pith
  - NIR spectra captured in bore holes
  - Pilodyn penetration at 4 cardinal directions

Douglas-fir Wood Quality and Veneer Study

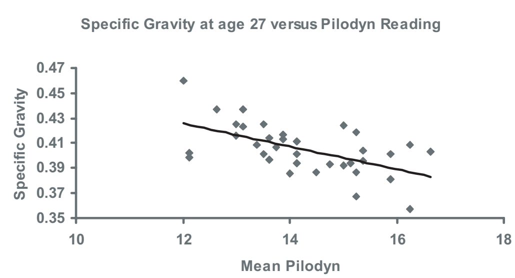
- **Cut logs**
  - Each 108î peeler block was individually labeled
  - Sonic wave readings taken on each block
  - Blocks debarked, steamed, and peeled in early December, 2001
  - Recovered ~ 850 sheets, 54î wide

Douglas-fir Wood Quality and Veneer Study

- **Veneer**
  - Intact 54ís were individually labeled and shipped to Medford plywood mill
  - Veneer was dried and graded by Metriguard

Douglas-fir Wood Quality and Veneer Study

- **Preliminary Results:**
  - Mean Pilodyn penetration moderately well correlated with breast height specific gravity



r^2 = -0.57

Preliminary Results (continued)

Genetic differences between trees

Tree A

Specific Gravity Age 27	Mean Pilodyn	DBH (in.)	Total Height (ft.)	Block	G2	G1	wet	xd	c
0.425	13.5	12.8	81	A	X				
				A					X
				A	X				
				A	X				
				A					X
				B		X			
				B					X
				B		X			
				B		X			
				B	X				
				B	X				
				B	X				
				B					X
				C			X		
				C				X	
				D	X				
				D					X
				D					X
				E					X

Tree B

Specific Gravity Age 27	Mean Pilodyn	DBH (in.)	Total Height (ft.)	Block	G2	G1	wet	xd	c
0.425	13.0	12.6	77	A			X		
				A				X	
				B			X		
				B					X
				C			X		
				C					X
				C					X
				D			X		
				D					X
				D			X		
				D			X		
				D					X
				D					X
				E			X		
				E			X		

Where to from here?

- Lay up test panels with sub-set of sheets covering range of grades
- Determine ability of Metriguard to accurately identify strong veneer
- Data analyses of direct and indirect methods of measuring and estimating wood quality and veneer strength
- Investigate potential for assessing trees in genetic tests for wood quality and veneer strength

Variation in Wood Density in Coastal Douglas-fir

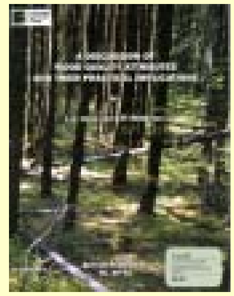
(and the relationship of growth and wood density)

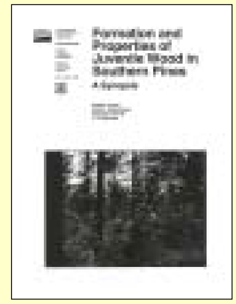
Randy Johnson

and

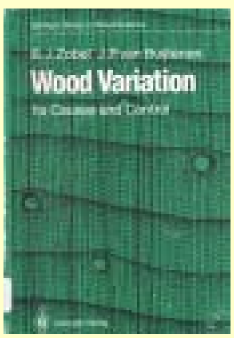
Barbara Gartner

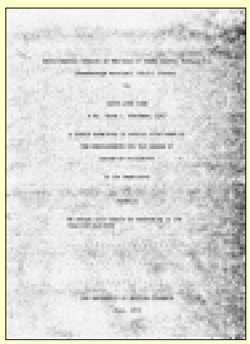
In addition to Megraw 1985, check out the following for variation with trees:





Where to find information on variation patterns





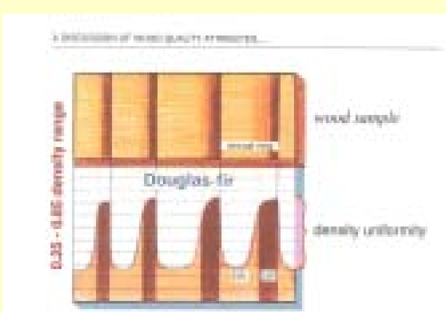
Dave Cown's PhDThesis

Variation must be examined with regard to scale:

- Within ring
- Within tree
- Within a stand
- Among stands and regions

Wood density of earlywood and latewood

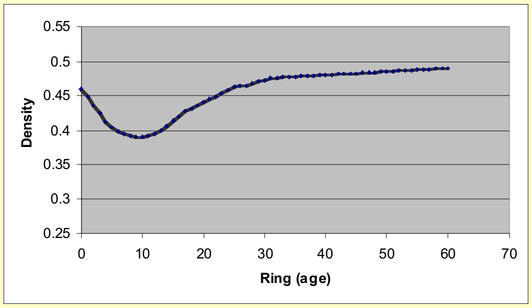
(Josza and Middleton 1995)

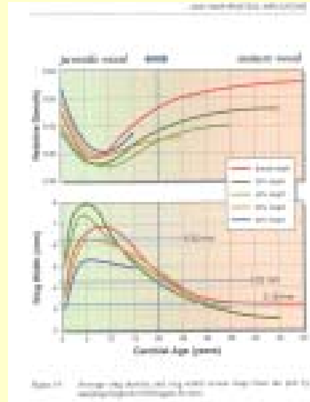


Earlywood and Latewood Densities

Site	Earlywood	Latewood	ratio
McDonald	0.272	0.550	0.49
Beaver Crk	0.380	0.824	0.46
ODF study	0.329	0.688	0.48
Vargus-Hernandez	0.347	0.768	0.45
Nimpkish	0.292	0.674	0.43
Haney	0.284	0.637	0.45
Molalla	0.319	0.662	0.48
Valley	0.271	0.671	0.40
Dorena	0.293	0.702	0.42
MEAN	0.310	0.686	0.45

Within-tree ring density pattern





Within-tree correlation between ring width and density

What do you say in coastal Oregon when you see:

- Decreasing ring width
- Increasing proportion of latewood

What do you say in coastal Oregon when you see:

- Decreasing ring width
- Increasing proportion of latewood

Swiss Needle Cast!

What do you say in coastal Oregon when you see:

- Decreasing ring width
- Increasing proportion of latewood

Swiss Needle Cast!

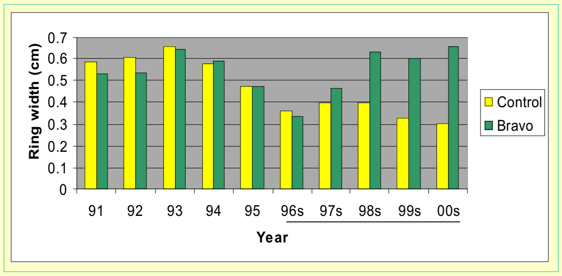
or

Normal growth?

History of ODF Bravo Plots

- 1995- Severely infected stand identified
- 1996-2000 – Three 5-acre plots sprayed with Bravo (adjacent control plots established too)
- 2000/2001 – Growth plots established and felled
- 2001 – X-ray densitometry on disks (20 trees in each of 6 plots)
- 2001 – Moisture contents sampled in May and September (20 trees in each of 6 plots)

Ring width



Sapwood Properties of Infected Trees

Ring Width	**1.02**	**1.88**	**Ring density**	**0.599**	**0.568**
EW width	**0.49**	**1.13**	EW density	0.380	0.360
LW width	**0.53**	**0.75**	LW density	0.772	0.778
LW %	**56.2%**	**50.1%**	**% Water**	**41%**	**48%**
			% Air	**27%**	**21%**
			% Wood	32%	31%

Why less water and more air?

- Air embolisms occur daily
- Tree can repair the plumbing
- Girdled tree studies (Salleo *et al*. 1996, Zwieniecki and Holbrook 1998) show more moisture above girdle
- Need energy to fix the embolisms
- Less energy in the sick trees

Implications:

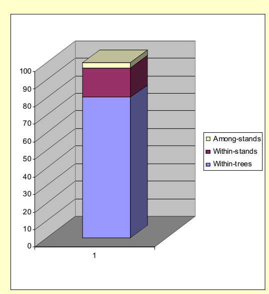
- Poor plumbing system in SNC infected trees (controls): less sapwood, less moisture content, and more air
- This is probably a function of less crown and lower energy supply
- Fresh weight of an equal volume of logs is 7.4% greater for Bravo-sprayed logs:
  - Control wet density = 0.79
  - Bravo wet density = 0.85

Within-Stand Variation Patterns

Wood density variation sources

<u>Last 3 rings</u>

- 11% among trees, 89% within trees (Gartner et al. 2002)
- 15% among stands, 85% among trees



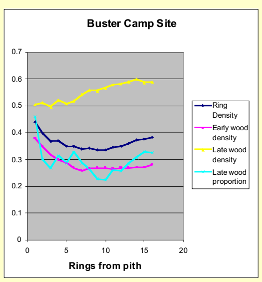
Proportion of density variation attributed to genetics

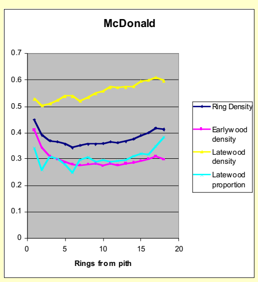
Citation	Heritability
St. Clair 1994	0.54
King et al. 1988	0.90
Bastion et al. 1985	> 0.8
Loo-Dinkins and Gonzalez 1991	0.54 – 0.71
Vargas-Hernandez and Adams 1991	0.59
Johnson and Jayawickrama (next)	0.72

Ring Density

- Function of:
  - Latewood density
  - Earlywood density
  - Latewood proportion
- These functions vary with ring age

Components of Wood Density





Density increases mostly as a function of increasing latewood proportion and latewood density

Impact of Density Components
(Vargas-Hernadez and Adams)

	h^2	r_a	Selection response
Overall density	0.55	1.0	5.7 %
Earlywood density	0.51	0.97	5.3 %
Latewood density	0.46	0.74	3.8 %
Latewood proportion	0.39	0.95	4.5 %

Relationship between growth and density

Don’t confound within-tree variation with among-tree variation

- Developmental changes
- Annual climate effects
- Must account for both when comparing among trees or among stands

Relationship between width and density

Negative relationship
- Harris and Orman 1958
- McKimmy 1959
- Haigh 1961
- Smith et al 1961
- Knigge 1962
- Cown 1976
- Bower 1998

Mixed or no relationship
- McKimmy 1959
- Mozina 1960
- Littleford 1961
- Wellwood and Smith 1962
- Polge 1969
- Smith and Kennedy 1983
- Abdel-Gadir et al. 1993

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Negative relationship
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Mixed or no relationship
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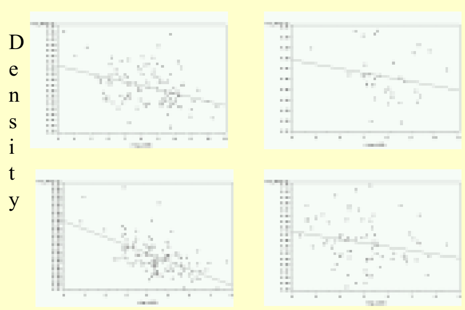
Relationship between ring density and ring width for rings 10-12 at four Oregon coast range sites



Ring width-density correlations

	All data	> 5 mm
Buster Camp	**-0.38**	**-0.26**
MacDonald	-0.20	-0.11
McKee	**-0.57**	-0.24
Univ. Falls	**-0.23**	+0.06

Reasons for adverse correlations

- Genetics – genes which increase growth decrease density
  - Faster growing trees have more earlywood
  - Less dense earlywood and/or latewood
- Environmental factors which increase growth decrease density
- Environmental factors affecting earlywood and latewood can operate independently

Stand to stand variation

Mostly studied in the 50's and 60's, before X-ray densitometry

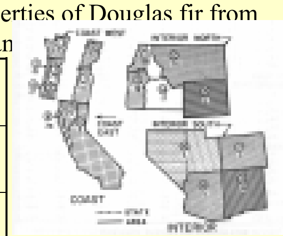
Drow, J.T. 1957. Relationship of locality and rate of growth to density and strength in Douglas-fir.

Region	Specific Gravity	Std. Dev.
Interior North	0.415	0.041
Coast	0.428	0.050
Interior West (Cascade East slopes)	0.433	0.052

(A mill study)

Snodgrass, J.D. and A.F. Noskowiak. 1968. Strength and related properties of Douglas fir from mill san

Region	Specific Gravity	MOE
Coast – west	0.445	1546
Coast – east	0.443	1499
Interior – North	0.437	1396
Interior – South	0.442	1482



Western Wood Density Survey (1965)

-Cored 9,133 trees

Regression analysis of the Cascades plots

-· Density = , Latitude

- · Density = , Elevation

- r^2 not very large

- Same trend found in pines

Knigge 1962

- 51 stands in OR and WA
  4 trees per stand (dom. – int.)
- Density increased with
  - · yield class
  - , elevation
  - To a minor degree
    - , growing season precipitation
    - · growing season temperature
- r^2 not overly impressive

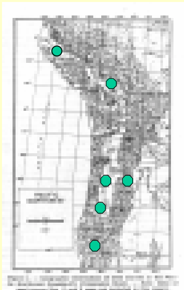
Lassen and Okkomen 1969

- 45 stands in OR and WA Cascades
- · Density = , Summer precip
- · Density = , Elevation

- $r^2 = 0.53$

Are any of these location differences because of genetics?

Cown and Parker (1979) used Kim Ching's trials



- 17-year-old trials
- No provenance differences
- Indication of site*provenance interaction

McKimmy's crew used Munger and Morris 1916 Douglas-fir heredity trial

-10 OR and WA provenances

-2 or 4 test sites

- Significant provenance variation

- Significant family x site and provenance x site interactions

Wilcox in New Zealand

- 45 provenances on 3 sites
- Significant provenance variation
- Significant provenance * site interaction

Thoby in France

(quoted from Cown 1976)

- (25 provs on 1 site)
- Significant provenance variation

Typical Ranges in Provenance Differences

Study	Range
Cown & Parker 1979	No differences
McKimmy 1966	0.414 to 0.449
Abdel-Gadir, Krahmer, McKimmy 1993	0.459 to 0.500
Wilcox 1974	0.360 to 0.410
Thoby 1975 (from Cown 1976)	range = 0.035

Summary - Provenance Variation

- Range in provenance means is about 10%, i.e., about 0.05 g/cc range and mean 0.45 g/cc
- Provenances do not consistently rank the same across sites
- Most of the genetic variation is associated with families within provenance
- Little opportunity to increase density with provenance selection (must also consider provenance effect on growth / adaptability)

Environment and Density

- Patterns observed are probably a function of environment, not genetics
- Consistent pattern of increasing density with lower elevation and more southerly latitude
- N fertilization decreases density (short term)
- Summer moisture decreased density in 2 or 3 studies

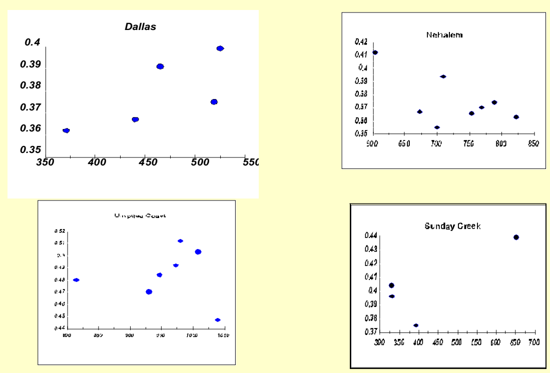
Conclusions – Growth-Density

- ▪ temp or ▪ growing season = ▪ density
- Improved soil factors = , density
- Therefore, improved growth can have a mixed effect on wood density, must know the reason for improved growth rates.

NWTIC data

(an example)

Height and Density for 4 Local Breeding Cooperatives



How can we improve density now that we know something about its variation patterns?

Genetics

- Provenance variation will provide little improvement
- Breeding programs using family variation
  - Density vs growth
    - (can't have your cake and eat it too)
  - 7% increase max
    - 0% is the goal for most programs

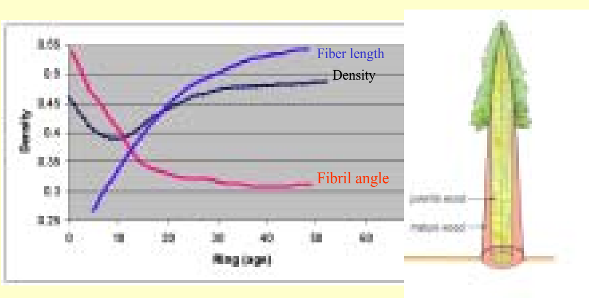
Stand location variation

- Not usually an option for altering density (but seems to becoming more common)
- Trends of increasing density with lower elevation and more southerly latitude (but not a very reliable predictor)

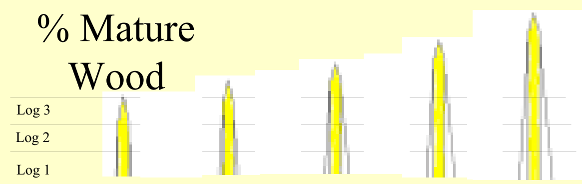
To increase wood quality…

INCREASE ROTATION LENGTH

Spend more time out of the juvenile core



% Mature Wood



Log	Rotation Age				
	30 yr	35 yr	40 yr	45 yr	50 yr
Butt	38%	55%	65 %	71 %	75%
2nd	2 %	9%	38%	55 %	65%
3rd	0%	0%	2%	9 %	38%

Genetics of wood specific gravity in coastal Douglas-fir

Randy Johnson
and
Keith Jayawickrama

PNWTIRC / NWTIC workshop on ìGenetic Improvement of Wood Quality in coastal Douglas-fir and western hemlockî

June 27, 2002
Oregon State University, Corvallis, OR

Conclusions

- Wood specific gravity is highly heritable.
- Probably need to sample more trees per family than we do at present.
- There is a negative genetic correlation between core length and wood specific gravity.
- The losses in specific gravity are less than expected, and about 1/10 the gain in height growth.
- Need to continue assessing the SPG of selections, and use as a culling factor in breeding and orchards
- Within BUs, no consistent relationship found with parent tree origin (elevation, latitude, longitude)

Two Specific Objectives

- Document genetic variation patterns in NWTIC programs.
- Examine the relationship between wood specific gravity and growth

Background

- Wood specific gravity considered an important predictor of wood quality
- Inheritance of wood specific gravity has been reported
- Selected first for height, diameter and stem form in 1st-generation co-op programs
- Co-operators also wished to prevent losses in specific gravity

Background

- For each selection, (usually) went to a single progeny test site and cored trees
  - ñ 6 progeny per parent selection ***
  - ñ Any individual forward selection
  - ñ 30 random trees to get stand average ***
- Standard water displacement technique
  - ñ Measured volume and dry weight of last 5 rings
  - ñ Specific gravity = dry weight / volume

Available Co-op Data

- 21 Test Sites (EPs)
- 15 Breeding Units (6 BUís sampled 2 sites)
- 658 Families

Site	Breeding Unit	Families Cored	Total Families
Cedar Cr	BLM 11	21	261
Rye Mtn	BLM 11	53	261
Black Rock	BLM 12	6	219
S-3	BLM 12	68	219
Gershman	Burnt Wds 1	44	158
Religion	Burnt Wds 1	5	158
Steep Row	Burnt Wds 2	13	329
Steep Row 2	Burnt Wds 2	8	329
Elk Creek	Coquille	133	371
Bishop	Cowlitz 4	41	289
Feather	Cowlitz 5	31	201

Site	Breeding Unit	Selected Families	Total Families
Pheasant	Dallas Add	5	94
Fanno Mt	Dallas High	12	181
Peedee	Dallas Val	11	193
Pomeroy	Dallas Val	5	193
Cole Mt	Nehalem	40	400
Vesper	Nehalem	7	400
West Gil	Skagit	79	345
Walta	Sunday Ck	19	120
Walta (2)	Sunday Ck	10	120
Scaponia	Vern SE	47	200
Totals		**658**	**5041**

Data Limitations

- Truncated data (families highly-ranked for growth and form)
  - ñ Not all variation will be observed
  - ñ Slightly bias correlations between traits (downward)
- Can only examine the correlated response in specific gravity when selecting for growth, not vice-versa.

Genetic parameter estimates

- Use the data from the 6 progeny at a site
- Estimate heritability (proportion of variation under genetic control)
- Estimate correlations of core specific gravity with diameter increment (as a function of core volume)

Correlations between parent tree location (within BU) and specific gravity

- Variables examined:
  - ñ Elevation
  - ñ Latitude
  - ñ Longitude
- Regression using differences from mean of selections
- **NO CONSISTENT RELATIONSHIPS FOUND**

Estimates of Realized Gain (Specific Gravity)

- Looked at the difference between wood specific gravity for the cored families and the 30 random trees at that site.
  - ñ For all the cored families, and
  - ñ For the tallest 10 families (based on multiple test sites) per set

Estimates of Realized Gain (growth)

- Looked at difference in growth between selected families and:
  - Trial mean
    - ï Using data from all progeny test sites
    - ï Using data for the individual site-set combination
- Selected families:
  - All selections
  - Best 10% in the set based on age-10 height

Proportion of specific gravity variation attributed to genetics

Study	Heritability
King et al. 1988	0.90
Bastion et al. 1985	> 0.8
NWTIC Data	**0.72**
Loo-Dinkins and Gonzalez 1991	0.54 ñ 0.71
Vargas-Hernandez and Adams 1991	0.59
St. Clair 1994	0.54

Some NWTIC age-10 height heritabilities

Local Co-op	Mean	Minimum	Maximum
Vernonia	0.13	0.00	0.25
Umpqua Coast	0.20	0.12	0.25
Burnt Woods I	0.18	0.00	0.30
Snow Peak	0.22	0.10	0.38
Gold Beach	0.17	0.03	0.32
Medford	0.11	0.05	0.20
Nehalem	0.30	0.12	0.38

Correlations between growth and wood specific gravity

Correlations between core specific gravity and core length
(only apples with apples available)

Correlation	Mean	Min	Max
Individual tree	**-0.36**	-0.50	-0.03
Family mean	**-0.37**	-0.94	0.58
Genetic	**-0.77**		

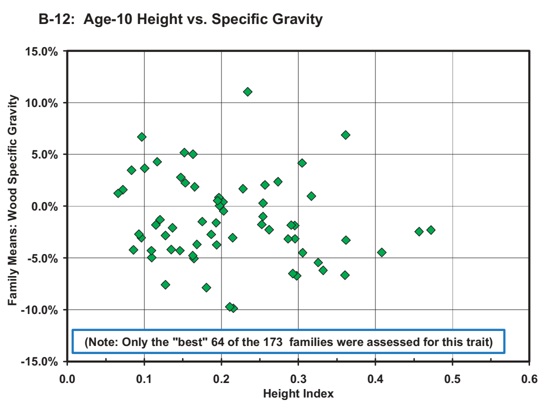
Correlations between specific gravity and core length
(>40 families in bold)

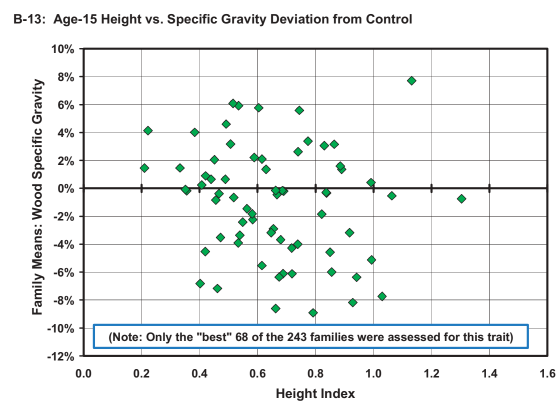
Site	Ind. Tree	Fam Mean		Site	Ind. Tree	Fam Mean
B	**-0.44**	**-0.67**		**G**	**-0.03**	**-0.23**
CC	**-0.41**	**-0.34**		**Ry**	**-0.44**	**-0.43**
EC	**-0.45**	**-0.45**		**Sc**	**-0.34**	**-0.51**
WG	**-0.48**	**-0.31**		**S-3**	**-0.34**	**-0.24**
CM	-0.36	-0.13		SR	-0.26	-0.48
FM	-0.10	0.36		SR2	-0.24	-0.46
F	-0.15	-0.20		V	-0.18	-0.51
Po	-0.28	-0.70		W	-0.50	-0.64
Pe	-0.40	-0.82		W2	-0.37	-0.09
Ph	-0.24	0.58		BR	-0.21	-0.06
Re	-0.44	-0.94		**Mean**	**-0.36**	**-0.37**

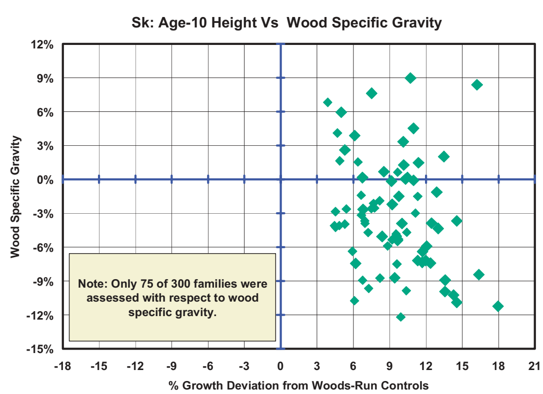
Family-Mean Correlations for Height and Diameter with Specific Gravity

Trait	Mean across sites	Mean for site at which cores were taken
Height (age-5)	-0.06	-0.11
Height (age-10)	-0.07	-0.11
Height (age-15)	-0.07	-0.07
DBH (age-15)	-0.15	-0.13

Example Plots: Family Means for Height vs. Specific Gravity







Genetic Correlations

Study	Height	Diameter
Bastien et al. 1985	-0.57 (0.15 to -1.0)	
King et al. 1988		-0.53
Vargas-Hernandez and Adams 1991	-0.19	-0.63
OUR STUDY		**-0.77 (core length)**
St. Clair 1994	-1.02	-0.99

Overall Selection Differentials (all selections, all sites)

Site	Density	Ht-10	DBH-15
Bishop	2.3%	8.4%	
Black Roc	0.0%	7.4%	6.5%
Cedar Cr	-1.8%	12.0%	8.7%
Cole Mt	4.4%	5.3%	
Elk Creek	-3.0%	5.5%	4.7%
Fanno Mt	0.7%	5.5%	
Feather	0.9%	7.9%	
Gershman	-0.8%	3.1%	4.5%
Peedee	-1.3%	5.6%	2.8%
Pheasant	-0.6%	7.9%	8.1%
Pomeroy	2.0%	5.5%	2.7%
Religion	1.1%	7.2%	0.5%
Rye ounM	-0.3%	1.9%	2.3%
S-3	-1.4%	5.3%	3.5%
Steep Row	0.1%	7.6%	7.1%
Scaponia	-1.1%	4.5%	
Steep Row	-1.1%	4.5%	3.9%
Vesper	2.2%	8.9%	
Walta (2)	-0.3%	5.8%	5.5%
Walta	-1.5%	2.5%	3.1%
West Gil	-3.0%	17.6%	
MEAN	-0.9%	6.9%	3.6%

	Sample or Population	Selections	% diff
Specific Gravity	0.397 g/cc	0.393 g/cc	-0.9 %
Height	484 cm	517 cm	+6.9 %
DBH	139 mm	144 mm	+3.6 %

Overall Selection Differentials (all 658 selections, single set/site means)

Site	Density	Ht-10	DBH-15
Bishop	2.3%	10.1%	
Black Roc	0.0%		
Cedar Cr	-1.8%	4.0%	12.8%
Cole Mt	4.4%	4.7%	
Elk Creek	-3.0%	5.9%	5.1%
Fanno Mt	0.7%	7.3%	
Feather	0.9%	4.9%	
Gershman	-0.8%	2.8%	4.3%
Peedee	-1.3%	8.7%	6.0%
Pheasant	-0.6%	1.9%	4.6%
Pomeroy	2.0%	7.6%	5.3%
Religion	1.1%	12.5%	4.8%
Rye ounM	-0.3%	0.3%	2.5%
S-3	-1.4%	7.0%	4.4%
Steep Row	0.1%	8.3%	6.6%
Scaponia	-1.1%	4.5%	
Steep Row	-1.1%	6.8%	5.9%
Vesper	2.2%	7.7%	
Walta (2)	-0.3%	4.6%	6.3%
Walta	-1.5%	2.2%	2.0%
West Gil	-3.0%	11.8%	
MEAN	-0.9%	6.0%	3.0%

	Sample or Population	Selections	% diff
specific gravity	0.397 g/cc	0.393 g/cc	-0.9 %
Height	558 cm	591 cm	+6.0 %
DBH	153 mm	158 mm	+3.0 %

Overall Selection Differentials (top 10% for height growth, single set / site means)

Site	Density	Ht-10	DBH-15
Bishop	3.1%	9.9%	
Black Roc	-0.1%		
Cedar Cr	-1.8%	6.8%	
Cole Mt	2.8%	6.1%	
Elk Creek	-2.4%	8.9%	
Fanno Mt	0.3%	15.9%	
Feather	1.3%	4.5%	
Gershman	-2.1%	7.7%	
Peedee	-2.3%	7.2%	5.6%
Pheasant	-1.5%	6.3%	8.1%
Pomeroy	-0.8%	8.2%	6.9%
Religion	-3.3%	12.6%	4.3%
Rye Moun	-2.0%	9.7%	10.4%
S-3	-0.2%	5.0%	9.2%
Steep Row	0.4%	9.1%	2.6%
Scaponia	-2.3%	5.2%	
Steep Row	1.1%	8.2%	
Vesper	2.5%	8.8%	
Walta (2)	-1.2%	6.0%	
Walta	-1.9%	5.2%	6.6%
West Gil	-3.2%	8.1%	5.6%
MEAN	-0.4%	7.9%	2.9%

	Sample or Population	Selections	% diff
specific gravity	0.397 g/cc	0.395 g/cc	-0.4 %
Height	561 cm	605 cm	+7.9 %
DBH	154 mm	158 mm	+2.9 %

191 families selected

Growth was increased about 10 times as much as the decrease in wood specific gravity

Reported estimates of specific gravity loss when selecting best 10% on growth

- - 4.1 % (Bastien et al. 1985)
- - 1.1 % (Vargas-Hernandez and Adams 1991)
- - 0.6 % Our study

Reasons for such little loss

- All family means are estimated with error (fewer trees and sites, greater error)
  - $h^2_{\text{family mean}}$ for specific gravity 0.56 with 6 trees
  - $h^2_{\text{family mean}}$ for growth usually > 0.6
- Selection for growth is good but not perfect (some error), resulting in imperfect correlated responses
- Rethink our specific gravity sampling???

Estimated family mean heritabilities

(correlation of what you see with what youíll get)

	Growth	Specific Gravity
1 site, 6 trees/site (specific gravity sample)	0.19	**0.53**
2 sites, 8 trees/site	0.38	**0.71**
3 sites, 8 trees/site	0.47	0.82
6 sites, 12 trees/site (growth sample)	**0.72**	0.91

Reasons for such little loss

- All family means are estimated with error
- **We select for growth based on all sites, measure specific gravity only on one (cannot estimate or account for G x E)**

Average genetic correlation among sites

- $r_{growth} = 0.7$
  - Examined over many locations
- $r_{specific\ gravity} = 0.71, 0.86, 1.00$
  - Examined in only 3 pairs of sites
  - Much lower correlations observed when families come from a wide range of locations and tested over a broad range of sites (see Cown and McKimmy papers)

Reasons for such little loss

- All family means are estimated with error
- We select for growth based on many sites, measure specific gravity only on one (cannot estimate or account for G x E)
- **There appears to be less genetic variation in wood specific gravity than for growth rate**

Coefficient of family variation

$$CV = \frac{\text{(standard deviation of family means)}}{\text{Overall Mean}} \times 100$$

Core volume: CV = 20.1%

Core specific gravity: CV = 7.8%

Reasons for such little loss

- All family means are estimated with error
- We select for growth based on many sites, measure specific gravity only on one (cannot estimate or account for G x E)
- There appears to be less genetic variation in wood specific gravity than for growth rate
- **Non-random sample of 30 control trees?**

"Warning…. Gains at rotation will be different from those in the tables "

- Gain = 2 h^2_{fm} (Selection differential)…..
  - Tables present selection differentials, not gain
- Correlation of age-10 height / dbh and rotation-age volume is less than 1.0
- Correlation of age-15 specific gravity and SG of later rings is less than 1.0
- Correlation of core specific gravity with stem specific gravity is less than 1.0
  - Estimated at 0.727 in the Western Wood Density Survey (1965)
- Correlation of SG on 1 site with target deployment sites is less than 1.0

Conclusions

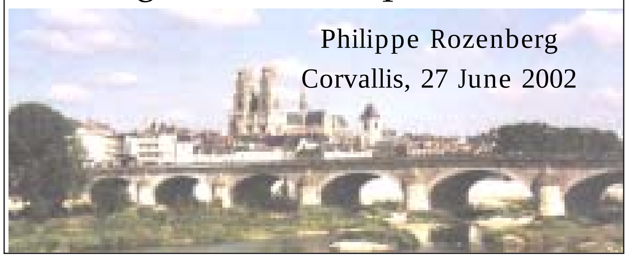
- Wood specific gravity is highly heritable.
- Probably need to sample more trees per family than we do at present.
- There is a negative genetic correlation between core length and wood specific gravity.
- The losses in specific gravity are less than expected, and about 1/10 the gain in height growth.
- Need to continue assessing the SPG of selections, and use as a culling factor in breeding and orchards
- Within BUs, no consistent relationship found with parent tree origin (elevation, latitude, longitude)

Acknowledgments

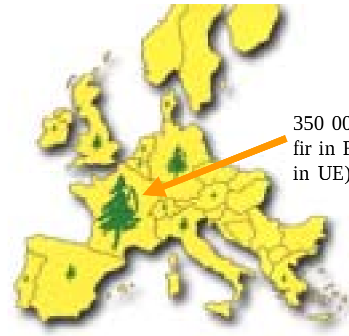
- NWTIC co-operators for data
- Dan Cress generated the three charts

Wood quality research at INRA: implications for Douglas-fir tree improvement

Philippe Rozenberg
Corvallis, 27 June 2002



France, the country of Douglas-fir in Europe



Douglas-fir in France

- Douglas-fir plantation in France (2nd planted species after maritime pine)
- Growth and wood quality
- Solid wood products
- Near future: plywood, pulping (TMP)

Douglas-fir wood research at INRA

- History of Douglas-fir wood research at INRA (from 1960 to 1996)
- EUDIREC project (1996-2000)
- INRA Orléans today (2000+)

60's: Microdensity at INRA Nancy

- Comparison of 2 Douglas-fir provenances using X-ray microdensity profiles (Polge)
- Study of cracks using X-ray pictures in Douglas-fir (Polge)
- Estimation of density components in Douglas-fir (Keller)

70's and 80's in Nancy

- Pruning and wood quality (Polge, Keller, Riou-Nivert)
- End-product quality: surface roughness (Nepveu), radial cracks (Polge), peeled veneer (Keller), rotary cutting (Mothe)
- Synthesis of Douglas-fir genetic variation of wood quality (Nepveu)

60's: Microdensity at INRA Nancy

- Comparison of 2 Douglas-fir provenances using X-ray microdensity profiles (Polge)
- Study of cracks using X-ray pictures in Douglas-fir (Polge)
- Estimation of density components in Douglas-fir (Keller)

70's and 80's: the first genetic studies at INRA Orléans

- Age-age correlation of microdensity variables in 24 Douglas-fir provenances (Thoby)
- Genetic variation of stem form and branching in Douglas-fir (Jarret)
- Genetic variation of microdensity traits (Vonnet, J.C. Bastien)

Main Trends for the Genetics of Wood Density

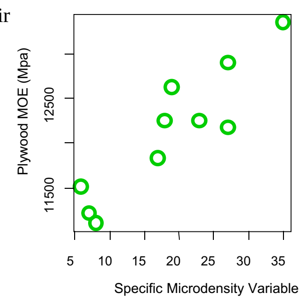
- High heritability, low genetic variation
- Little genotype-by-environment interaction
- Unfavourable genetic correlations with flushing, height growth, within-ring heterogeneity, shrinkage... and, to some extent, radial growth

Eudirec Research Project (1995-1999)

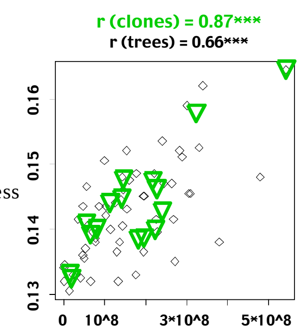
- EU funded research project
- Germany (NFV), Spain (INIA-CIFOR), Italy (CNR), France (INRA)
- Isoroy, Stora-Corbehem
- Solid wood products, plywood and thermo-mechanical pulp
- Direct and indirect Douglas-fir variation for end-products quality

Plywood Mechanical Properties

10 Douglas-fir trees



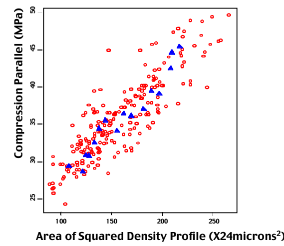
TMP Properties



Stiffness and Density

- Up to 70% of stiffness variation
- …adding information about the genetic composition of the tree population: up to 90% (without information on MFA)
- …genetic variation of the stiffness-density relationship?

Compression and Density



A very strong relationship

R^2 (samples) = 0.77

R^2 (clones) = 0.94

Eudirec Conclusions

- Douglas-fir for plywood
- Douglas-fir for TMP
  - pulp strength
  - brightness
  - extractive contents (effluents)
- Heterogeneity and stiffness
- Coarseness and stiffness

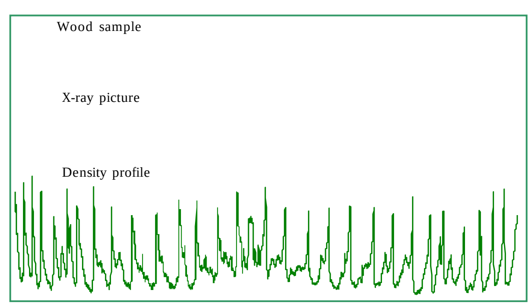
Objectives at INRA Orléans

- Avoid any Douglas-fir wood quality decrease
- Monitor the evolution of wood quality
- Genetic and environmental determinism of wood formation

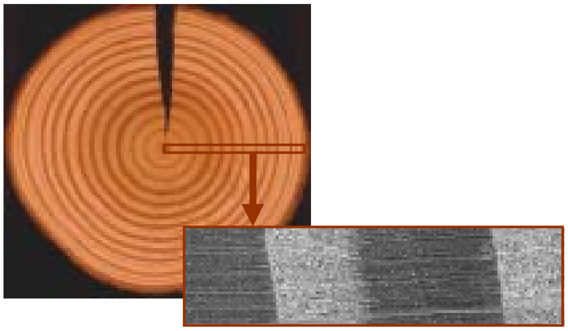
Main Wood Characters of Interest

- Today: microdensity, stiffness… shrinkage
- Tomorrow: quantitative anatomy, heartwood formation
- Traits we'd really like to add: MFA and grain angle

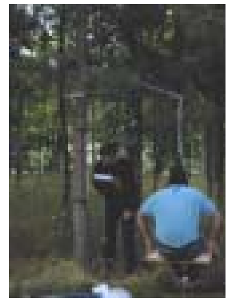
Microdensity



Wood anatomy profile



Rigidimeter

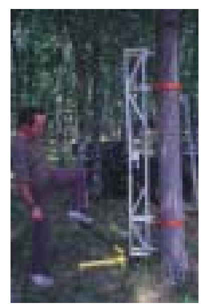


Koizumi's
Bending machine
(copy) 1995

Rigidimeter

First Prototype
1998

Rigidimeter

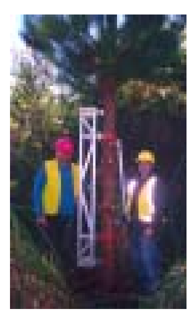


Second Prototype
Orléans
1999

Rigidimeter

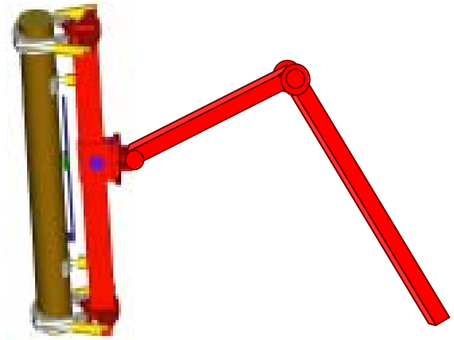
Second Prototype
(squared tubes)
Chili
October 2000

Rigidimeter



Second Prototype
(squared tubes)
New-Zealand
July 2001

A Rigidimeter for Big Trees?



Recent Results: Wood Heterogeneity

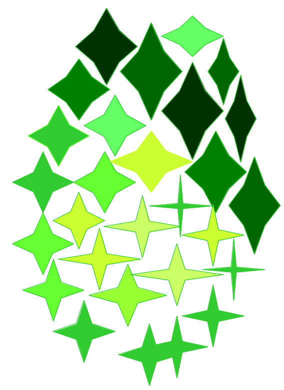
- Observation Scale
- Genetic Control
- Coefficient of Variation
- Relationship with Density

Recent Results: Consequences on Wood Density

- of increased radial growth
- of genetic variation of cambium reaction to climate

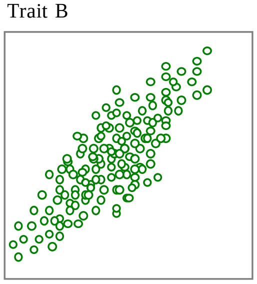
Genetic Variability

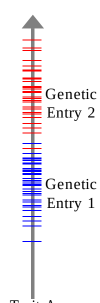
- Traits: populations and individuals

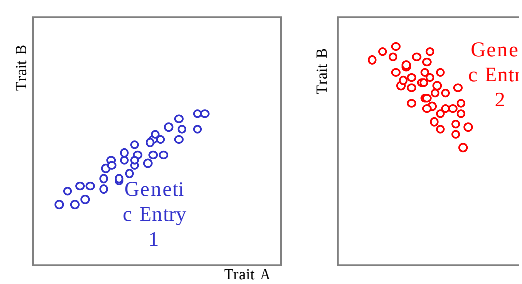


Relationship between 2 traits

Genetic variability of a given trait

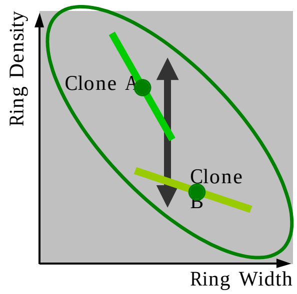




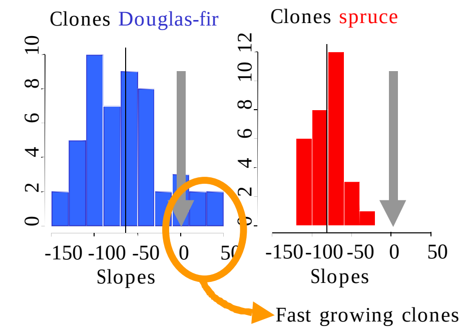


Genetic variation of relationships bet traits

Radial Growth and Density

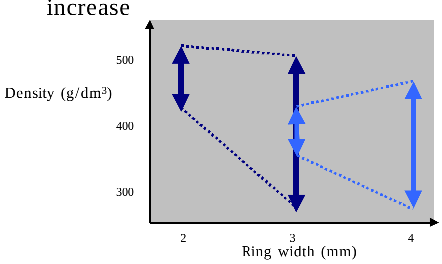


Genetic variation of the slope of the ring width - ring density relationship



Consequences

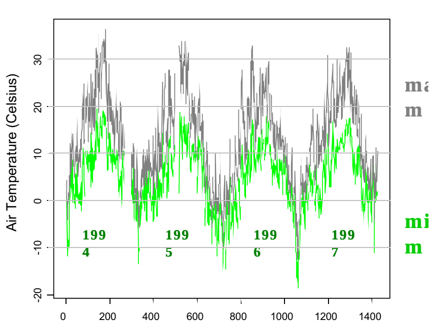
- Possible consequences of an increased ring width: from a density decrease to a density increase



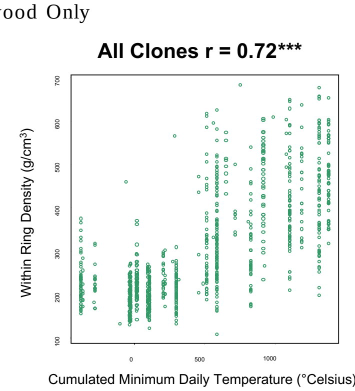
Cambium Reaction to Climate

- Wood as a record of cambium reaction to climate
- Example: relationship between within-ring density variation and within-growing season minimum temperature

Minimum Temperature

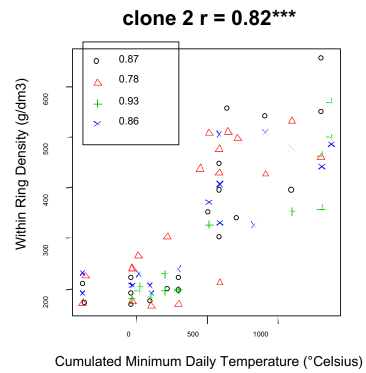


In Earlywood Only



Simila
trends
other
softw
(marit
pine)

In Earlywood Only



Clone Effect

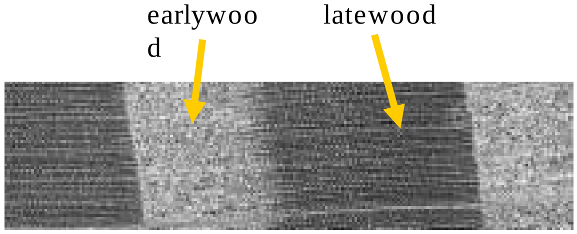
- Slopes at tree level;
- Significant clone effect

	H^2	Standard Error
Slope	0.53	0.06
Overall Density	0.36	0.05
Radial Growth	0.04	0.01

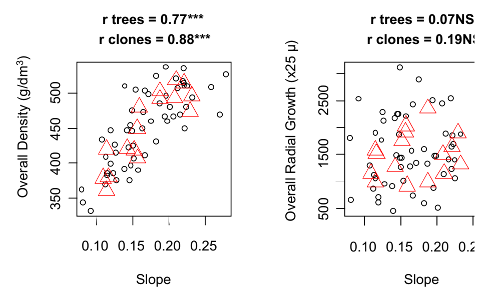
Genetic Control of Cambium Reaction

Strong in earlywoo d

Weak in latewood



Consequences



Conclusion: Implications for Douglas-fir breeding

- There are still needs for methodological improvements
  - MFA, Grain Angle
  - standing trees
- Simultaneous studies of multiple traits
- Component traits:
  - within tree: from ring to ring
  - within ring, within early- and latewood (cell group)

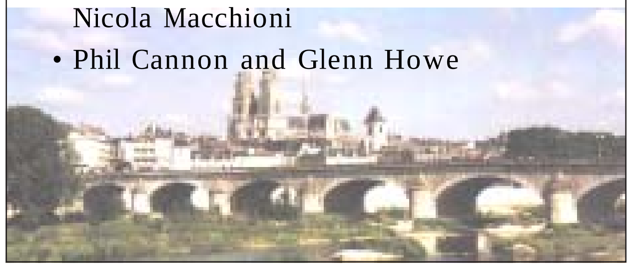
- Large scale studies of genetic variation of end-product value
- Relationships between basic wood properties and end-products value
- Wood heterogeneity

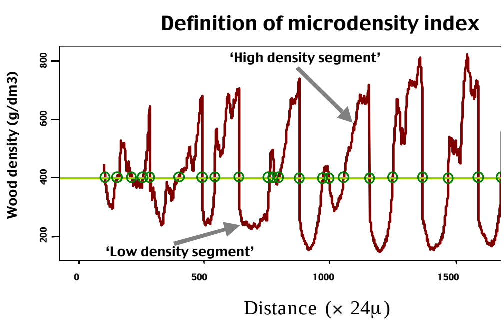
Recommendations

- Douglas-fir breeding programs *must* take wood quality into account
- Wood quality *may* or *may not* be defined according to end-product quality
- Genetic variation of end-product *value* (requires a highly motivated private company)
- Wood *heterogeneity* as a consensus character (consensus in the literature, encouraging results in Douglas-fir, maritime pine, Norway spruce,

Special Acknowledgements

- Frédéric Millier
- Catherine Bastien, Milosh Ivkovich, Gunnar Schüte, Jean-Charles Bastien,
- Guillaume Chantre, Victoria Baonza, Nicola Macchioni
- Phil Cannon and Glenn Howe





Genetic Improvement of Conifer Lumber Stiffness and Strength

Keith Jayawickrama

PNWTIRC / NWTIC workshop on iGenetic Improvement of Wood Quality in coastal Douglas-fir and western hemlockî

June 27, 2002
Oregon State University, Corvallis, OR

Take-Home Messages

- Stiffness (MOE) and strength (MOR) are heritable
  - We know very little about genetic control for DF and WH
- Juvenile wood in conifers (including DF and WH) is weaker & less stiff; shortening rotations therefore reduces average stiffness & strength
- Whether the reduced stiffness and strength affects $$ return will depend on many factors
  - rotation length, product, grading procedure, log segregation procedure, where the trees are grown, market demand etc

Take-Home Messages (contd)

- Would be very helpful if tree improvers (breeders) get good feedback from industry if & when they find lumber stiffness & strength to be deficient
- Improving wood density should help maintain stiffness and strength, butÖ
- Reported relationships between density & stiffness / density & strength may exaggerate the true relationships at the family level
  - We donít know what the relationships are at the family level

Take-Home Messages (contd)

- Smaller, fewer knots lead to higher stiffness and strength
  - Can select / breed for fewer ramicorns and forks
  - Ramicorns and forks less of a problem on slow-growth sites
  - Knot size best managed by spacing
- Fibril angle may be as important in controlling stiffness / strength in juvenile wood as density,
  - Harder (more expensive) to measure
  - Very little knowledge on its variation for DF and WH in PNW region (genetic, geographic)

Take-Home Messages (contd)

- New tools are being developed to measure stiffness on logs and standing trees
- Stiffness / strength are being researched actively in France (D-fir), Japan (sugi), New Zealand (radiata pine) and Queensland (slash x Caribbean hybrid)
  - In at least two of above, research is being translated to practice
  - Very little recent published work in the PNW in the USA.
  - Lots of research done in the southeastern USA over a long period, only a few of the findings have been used

Background

Bending stiffness and strength are two important mechanical properties

- resistance to force perpendicular to the long axis of a beam

Bending stiffness - *how easily does the beam bend?*

- Fibre Stress at Proportional Limit
  - expressed in Mega Pascals = MPa (10^6), or 10^6 psi
- Modulus of Elasticity= MoE (Youngís Modulus)
  - expressed in Giga Pascals = GPa (10^9)

Bending strength - *at what point does the beam break?*

- Modulus of Rupture = MoR (expressed in MPa)

Stiffness testing (MoE) of boards

Douglas-fir is billed as a high-wood-quality species:

– "When architects and engineers look for the best in structural lumber, their first choice repeatedly is Douglas-fir…. dimensionally stable and universally recognized for its superior strength-to-weight ratio…. high specific gravity provides excellent nail and plate-holding ability. ….. a documented superior performance from natural phenomena such as winds, storms… truly the ideal structural and general purpose wood for framing lumber……. "

(From WWPA ì Douglas-fir and western larch species factsî , 1996)

Several factors discourage long rotations:

- Interest rates: E.g. At 8%, $100 cost carried for:
  - 25 years, grows to $ 685, 50 years, grows to $ 4,690
- Carrying lots of mature timber makes a corporation more attractive for a hostile takeover
- No price premium for large logs (opposite may apply)
- To keep trees growing, may need frequent thinnings cost associated with multiple entries
- Mature timber can become a political battleground (spotted owls, anti-logging activism)

• **Conifers produce lower-quality juvenile wood during their first 10-20 years**

DF lumber does command a price premium, but it may not match big cost differentials compared to some fast-growing pines

Good News..

- Douglas-fir juvenile wood is better than pine juvenile wood in some respects
  - Denser, stronger, stiffer
- Modern mills in Oregon and Washington can run very efficiently on small logs

Factors Controlling Lumber Stiffness and Strength

- Species
- Provenance / seed source (probably)
- Family within provenance
- Geographic area where trees were grown?
- Silviculture (spacing, thinning, pruning etc)
- Size and frequency of knots
- Distance from pith (linked to % juvenile wood)
- Distance from base of tree (again linked to % juvenile wood)
- Intrinsic clearwood properties (density, fibril angle, % latewood)

Species:
- Reasonable understanding of species differences
- Made complicated by lumber grading rules which lump species together

Provenance / seed source:
- Almost zero knowledge on between-source differences for DF and WH
- New 2nd-generation progeny tests the place to look

Family within provenance:
- Little knowledge on genetic control of MOE or MOR
- Some knowledge on genetic control of specific gravity

Geographic area where trees were grown?
- Very little knowledge on geographic variation in stiffness & strength for D-f and WH in PNW

Silviculture (spacing, thinning, pruning etc)
- David Briggs presentation in this workshop

Size and frequency of knots
- Size affected by spacing, frequency of ramicorns & forks
- Genetics of ramicorns & forks, ability to select against, discussed by Glenn Howe in this workshop
- Ramicorns and forks routinely assessed in progeny tests

Number of rings from pith (linked to % juvenile wood)
- A very important variable
- "Specific gravity, fiber length and fibril angle less desirable near pith for most purposes" – Megraw 1985

Distance from base of tree (again linked to % juvenile wood)

DF: Bending stiffness (MOE) decreases with increasing juvenile wood %

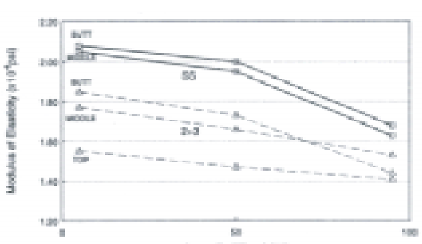
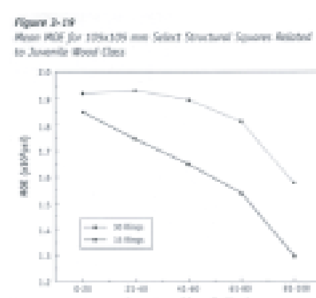


Figure 2. — Mean MOE versus juvenile wood percent by log position and visual grade.

Source: Barrett, J.D. and Kellogg, R.M. Forest Products Journal 41:35-43

WH: Bending stiffness (MOE) decreases with increasing juvenile wood %



Source: FORINTEK Special Publication SP-41 September 2001

DF: Bending strength (MOR) decreases with increasing juvenile wood %

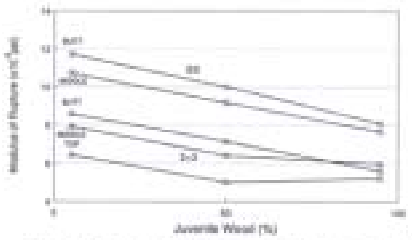
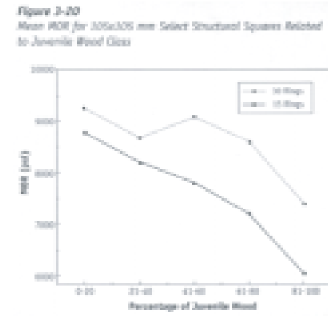


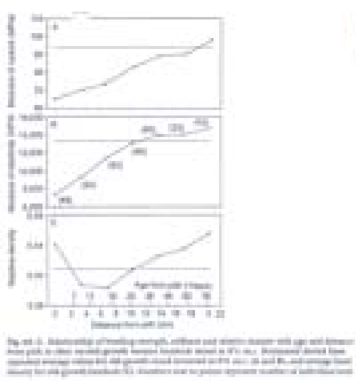
Figure 3. — Mean MOR versus juvenile wood percent by log position and visual grade.

Source: Barrett, J.D. and Kellogg, R.M. Forest Products Journal 41:35-43

WH: Bending strength (MOR) decreases with increasing juvenile wood %



Source: FORINTEK Special Publication SP-41 September 2001



WH: MOE and MOR increase much faster with age from pith than density

Source:

Kennedy, R.W. 1995: Wood Science and Technology 29: 321-338

Intrinsic clearwood properties - Fibril angle:

- Fibril angle decreases dramatically with age from pith in DF
- Fibril angle recently shown to have as much effect on stiffness and strength as density in radiata pine
- Expensive to measure
- We have practically zero information on variation in DF and WH in the PNW
  - Geographic variation
  - Genetic control

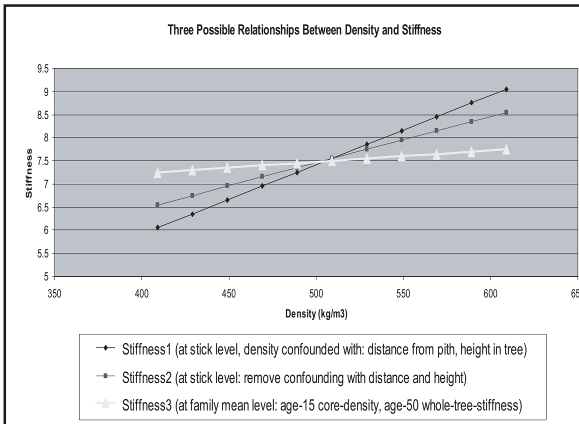
Intrinsic clearwood properties - Density:

- Generally considered to be an important trait
- Some research on inheritance
  - Johnson & Gartner summary
  - Several publications (PNWTIRC, BC etc)
- Thousands of progeny test trees assessed in co-op programs
  - Johnson and Jayawickrama presentation on inferences

Density : stiffness & strength relationships have sometimes been overestimated, by "*Stack-of-boards-in-lumberyard*" syndrome, confounding :

- Relationship of stiffness / strength with
  - Density
  - Number of rings from pith
  - Height from ground
  - Site of lumber origin

– As mentioned, other properties change dramatically pith to bark (e.g. fibril angle) and could affect stiffness
– For example, Keoki Carter (OSU M.S. thesis, 1993) estimated that specific gravity (removing effect of distance from pith etc) only explained the following proportion of variation in juvenile wood:
  – 28% of variation in MOR (strength)
  – 25% of variation in MOE (stiffness)



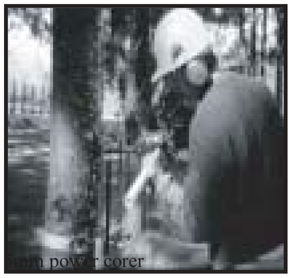
Examples of techniques to assess stiffness and strength

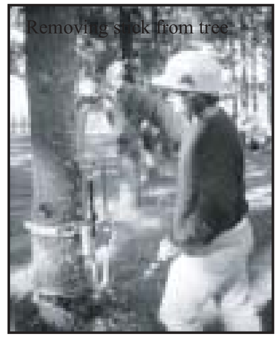
Taking wood cores - by hand

Taking Wood Cores – Power Drill

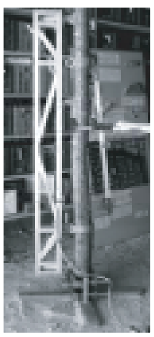
Stiffness testing (MoE) of boards

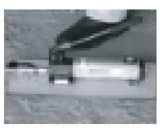
Non-destructive Sampling: Taking Clearwood Sticks
(tool developed by Forest Research, New Zealand)





Non-destructive measure of stem stiffness: Rigidimeter tool, under development by INRA (France)





Log segregation based on wood stiffness: "Hitman" tool, developed by Industrial Research and Carter Holt Harvy (New Zealand)

What have we done in co-operative programs to genetically improve stiffness and strength?

All our efforts (in operational programs) to date have been directed toward:

- Assessing forking, ramicorns and specific gravity in progeny tests
- Culling some proportion of parents from orchards and from use in 2nd generation programs based on these three (two) traits

- The objectives:
  - Improving age-15 breast-height core density to improve age-40 (or age-50) whole tree lumber stiffness (and therefore value).
    - Improving juvenile wood stiffness & strength might be enough, since mature wood stiffness & strength are OK
  - Reducing forks and ramicorns to improve the log class
    - Stiffness and strength not usually the main objective

So Where To From Here Re. Stiffness and Strength?

1. First, establish if & when lumber stiffness & strength are limiting factors for DF and WH
   - Stiffness and strength are problems in other species, does it apply for our species in our conditions too?
   - Breeders need feedback from industry, mills

2. If there is enough reason to make lumber stiffness and strength a priority, need to develop a strategy to improve these traits:
   - A. Estimate level of genetic control (between, within provenances) and relationship with other traits
   - B. Set a Breeding Goal
   - C. Choose most appropriate selection traits, strategies & techniques
   - D. Screen populations (trials), identify best genotypes
   - E. Process and interpret information, predict gains
   - F. Use in deployment / breeding decisions

Snapshots of efforts for some important conifer species

Southeastern USA (southern pines):
- Massive investment in wood quality research (including genetic studies)
- Applications in genetic improvement programs:
  - Improve stem straightness (selecting for straight trees)
  - Reduce branch size (selecting for smaller, flatter branches)
  - Screen plus trees & forward selections for wood density
  - Wood Quality Elite Breeding Population (Texas co-op)

France (DF and other species):

- Very active basic research program currently underway (Rozenberg presentation in this workshop)

New Zealand (radiata pine):

- Breeding values for density, branch cluster frequency
- Ranking families for stiffness
- Indirect testing, log segregation tools

Queensland (slash x Caribbean pine hybrid)

- Research and selection aimed at producing high-quality sawlogs on a 20-year rotation
- Emphasis on improving stiffness and strength via selection of clones

Japan:

- Work on selecting sugi (Cryptomeria japonica) clones for high wood stiffness and strength

Genetics of Stem Quality in Coastal Douglas-fir

Glenn Howe
Pacific Northwest Tree Improvement Research Cooperative

Keith Jayawickrama
Northwest Tree Improvement Cooperative

What are stem quality traits?

Branch traits

- ✓ Branch size
- ✓ Branch number
- ✓ Branch angle

Stem defects

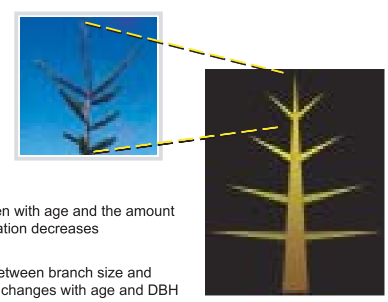
- ✓ Excessive taper
- ✓ Sinuosity
- ✓ Crookedness/Straightness
- ✓ Ramicorn branching and forking

Branch traits

Biology

- Low to moderate genetic control *(PNWTIRC, King et al 1992, St. Clair 1994)*
- There may be a genetic tradeoff between branch number and branch size
  - Few large branches
  - Many small branches
- Genetic relationships between branch traits and growth are unclear *(King et al 1992 , St. Clair 1994)*
  - Absolute or relative branch diameters have been analyzed
  - Results differ according to the age of the trees

Branch traits



Biology

- Branches flatten with age and the amount of genetic variation decreases
- Relationship between branch size and stem diameter changes with age and DBH

Branch traits

Measurement

- Quantitative measures are known to work well, but are costly
- Visual scores are much cheaper – how good are they?
- Uniform (sophisticated) analytical techniques should be used

Impact

- Large, steep branches = visual degrade, loss of strength (MOE), etc
- Potential genetic gains in relative branch size are limited:

Selection of top 10% of parents to put into a seed orchard		
Gain	Change in branch size	Citation
9.2%	1.94 to 1.76 cm	*King et al (1992)*
8.3%	1.90 to 1.74 cm	*St. Clair (1994)*

Branch size

Will this have an economic impact?

Branch no. = 6 - 9
Branch size = 2.5 – 3.5

Branching index (no. class x dia. class)	Value ($/m^3)	Number of trees
2	$34.51	4
3	$26.49	2
4	$26.22	12
6	$25.61	20
8	$25.83	4

- ✓ If 1 cm (33%) reduction in size = $0.61/m^3
- ✓ Then 8.7% reduction in size might = $0.16/m^3
- ✓ Volume gains may produce 25X more value?

Branch traits

Recommendations

- Determine the relative efficiency of low-cost, visual scoring techniques
- Measure branch traits if low-cost measuring techniques are useful
- Do not use branch traits as selection criteria at the present time – probably best managed through control of stand density
- Study the genetics of "final" branch size using older trees
- Study the genetics of self-pruning

PNWTIRC

Branch traits

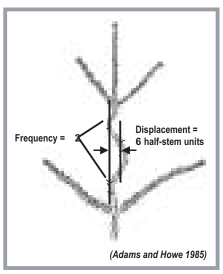
Recommendations

- Integrate existing information on tree value and genetics to explore multi-trait selection options using continuous value functions
  - ✓ *Bridgwater and Stonecypher (1979) among mean tree total values for 6 straightness classes…" "most of the variation in value was related to size."*
  - ✓ *Busby (1983) "the impact of quality-related improvements in stem knottiness on dollar value of a tree was insignificant in comparison to the impact of tree size."*

Sinuosity

Biology

- "Sinuosity is any stem crookedness or displacement from the vertical that is confined within an interwhorl stem segment" (*Campbell 1965*)
- Cause is unknown
  Nutrition, excessive growth, other?
- Low to moderate genetic control
  $h^2_i = 0.13$ and $h^2_f = 0.41$
  (*Temel and Adams 2000*)
- Weak genetic correlation with growth
  $r_A = 0.01$ (*Temel and Adams 2000*)



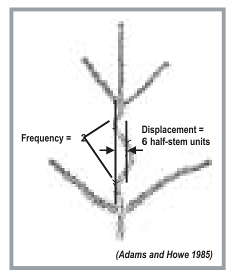
(Adams and Howe 1985)

PNWTIRC

Sinuosity

Measurement

- First, second and third third interwhorls at the top of the tree (*Campbell 1965; Adams and Howe 1985; Spicer et al 2000)*
- NWTIC measures as % deflection and "ignores the often wildly sinuous terminal"
- Measurements much below the 3rd interwhorl should be called something else
  Crookedness? Straightness?



(Adams and Howe 1985)

PNWTIRC

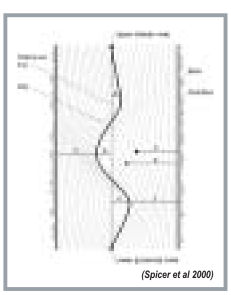
Sinuosity

Impact

- Affects a narrow core of wood near the center of the tree
- Increases compression wood
- Causes slope of grain defect
- Only a concern for highly sinuous trees

Recommendations

- Measure before crown closure according to Adams and Howe (1985)
- Select against the most highly sinuous genotypes using independent culling


(Spicer et al 2000)

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Crookedness/Straightness

Biology

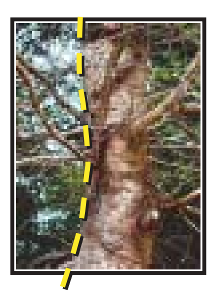
- Crookedness much below the 3rd interwhorl
- A crook is a "departure of the main stem… (that) originates in a branch whorl, rather than on the interwhorl" (
  Associated with ramicorns?
- Sinuosity scores "lack consistency between ages 12 and 24" (*Temel and Adams 2000*)

Impact

- Yield loss and association with large knots?

Recommendations

- Measure separately from "sinuosity"



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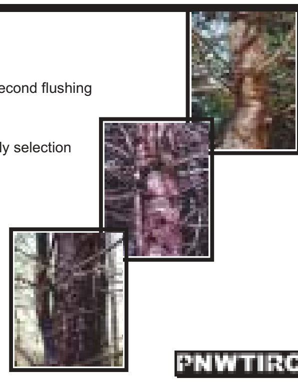
Ramicorn branching & forking

Biology

- Most frequent cause is aberrant second flushing
  Adams and Bastien 1994
- More frequent at early ages – Early selection should work well
- Low to moderate genetic control
- Large genetic gains are possible
- Correlated with growth rate
- More frequent on productive sites



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Second flushing may lead to:

No defect | **Ramicorn branch** | **Forking defect**

PNWTIRC

Stem defects are genetically controlled

Heritabilities of growth and stem form traits in a NWTIC first-generation progeny test in the Nehalem breeding zone.

Trait	Age	Individual h^2	Family h^2
Growth traits			
Height	5	0.25	0.86
Height	11	0.27	0.87
Height growth	5 -11	0.23	0.84
Diameter	11	0.23	0.84
Volume	11	0.25	0.84
Stem form traits			
Ramicorns	11	0.20	0.81
Crookedness	11	0.16	0.78

PNWTIRC

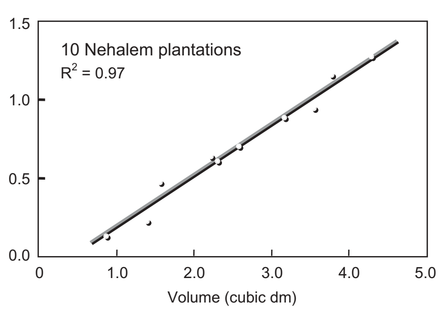
Stem defects are correlated with growth

Correlations between growth and stem form traits in a NWTIC first-generation progeny test in the Nehalem breeding zone.

		Genetic correlation		Site correlation	
Growth trait	Age	Ramicorns	Crookedness	Ramicorns	Crookedness
Height	5	0.36	0.44	0.98	0.77
Height	11	0.36	0.45	0.95	0.86
Height growth	5 -11	0.33	0.42	0.88	0.87
Diameter	11	0.43	0.37	0.97	0.84
Volume	11	0.45	0.41	0.99	0.79

PNWTIRC

Ramicorns and forks are correlated with plantation growth



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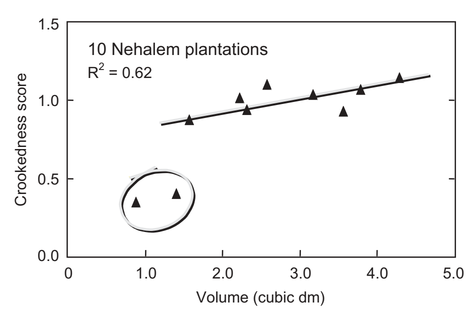
Crookedness is correlated with plantation growth



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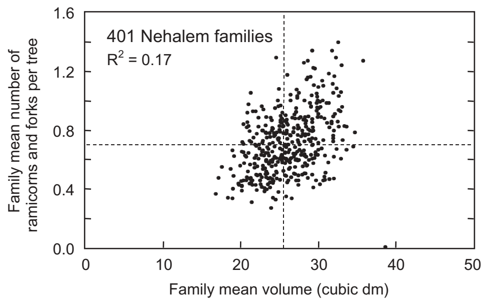
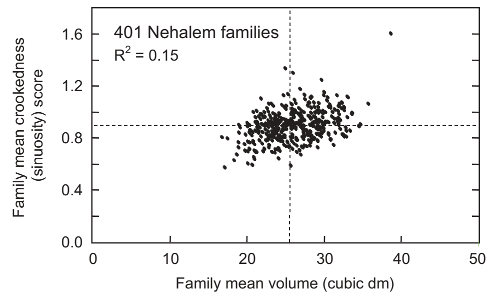
Ramicorns and forks have much lower correlations with growth at the family level



PNWTIRC

Crookedness is much less correlated with growth at the family level



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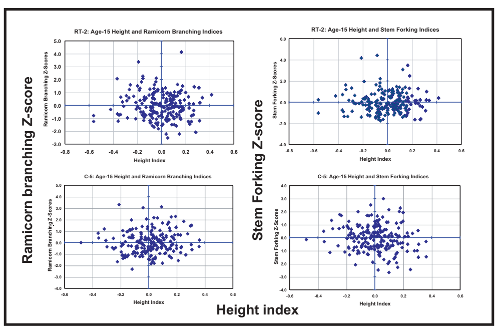
Ramicorn branching and forking has been scored in many NWTIC co-ops



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Selection for increased growth will increase ramicorns and forks

Potential for reducing ramicorns and forks is large			Selecting only for increased growth will increase ramicorns and forks			
Direct selection to reduce ramicorns and forks			Correlated increase in ramicorns and forks by selecting only for increased growth			
	Absolute change when:				Absolute change when:	
Response (%)	Mean 0.13	Mean 1.3	Trait selected	Response (%)	Mean 0.13	Mean 1.3
–	–	–	Height (age 13)	+12	+0.02	+0.16
−47	−0.06	−0.61	DBH (age 9)	+28	+0.04	+0.36
−19	−0.02	−0.24	DBH (age 12)	+9	+0.01	+0.12
−84	−0.11	−1.08	Volume (age 11)	+38	+0.05	+0.49

(Adams & Bastien 1994; Schermann et al 1997; Temel & Adams 2000; Nehalem data)

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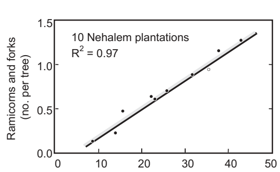
Ramicorn branching & forking

Measurement

- Logical to analyze ramicorns and forks as a single trait because they are highly genetically correlated

Impact

- Ramicorns and forks affect knot size and yield
- Ramicorns and forks may increase dramatically under high-yield forestry



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Stem quality

Conclusions

- For most stem traits, there seems to be little opportunity to increase tree value via genetic improvement
  Ramicorns and forks could be an important exception
- Ramicorns and forks could increase dramatically under high-yield forestry
- Second flushing is an important underlying problem
  - ✓ Ramicorns and forks are associated with increased second flushing
  - ✓ Second flushing also associated with increased susceptibility to fall cold and summer drought
- Stem crookedness may be a secondary concern?

Stem quality

Key recommendations

- Track ramicorns and forks in progeny tests and operational plantations
- Determine the economic value of reducing ramicorns and forks
- Use ramicorn branching as a selection criterion
- Cull genotypes with very high propensity for sinuosity
- Measure other stem quality traits using proven, low-cost visual scoring techniques
- Presently, there seems to be little reason to use other stem quality traits as selection criteria

PNWTIRC

Acknowledgements

✓ NWTIC co-operators for permission to analyze and report Nehalem data

✓ Randy Johnson and Bryan Nelson for helpful discussions

✓ Dan Cress for scatterplots from two breeding units

PNWTIRC

Improving Wood and Stand Quality of New Zealandís Douglas-fir Plantations

Leith Knowles

Forest Research, Rotorua, NZ

Contributors

- Forest Research
  - Tony Shelbourne, Mark Kimberley, John Lee, Charlie Low, John Roper, Doug Gaunt, Russell McKinley, Brad Barr, Mark Dean, Mina Van der Colff, Luis Gea
- Geoff Downes, CSIRO, Hobart, Tasmania
- Graeme Young, Fletcher Challenge Forests
- Ian Whiteside (retired)
- Lars Wichmann Hansen, Royal Veterinary and Agricultural University, Denmark

History and management of D-fir in NZ

- Oldest plantings: 1865
- 1910-1985: 70,000 ha planted with Washington seed sources
- 1996-2002: 24,000 ha planted with 'fog belt' Oregon/ Californian seed, in the South Island
- Thinned to waste to 500-800 stems/ha MTH 14-16m; Production thinned to 250-400 stems/ha age 26-34 years.
- Pruning: limited areas only
- Main product: structural lumber
- Market: NZ, Australia, and Japan.

Growth and yield

- Mean site index (MTH @ 40 yrs) 32 m
- Clearfell yields at age 45-60 yrs vary between 500m^3/ha and 1500 m^3/ha. Some sites produce up to 2000m^3/ha.
- Seed from the Californian/Oregon coastal fog belt produces significantly more growth than Washington, or inland seed

Goal of tree improvement in NZ Douglas-fir

- Increase merchantable yield by at least 50% over traditional Washington seed sources
- Increase quality (as represented by MoE of clearwood) from 9.2GPa to 10.5GPa
  - increase BH outerwood basic density from 418 kg/m^3 at age 30yrs to 450kg/m^3
  - reduce BH MFA from 12∫ to 10.5∫

Growth of best 7 provenances in NZ (versus Washington provenance)

Seed Source in US	MAI age 39 yrs (m^3/ha)	% advantage over control
Jackson S. F., CA	23.4	34
Santa Cruz, CA	22.9	31
Stewart Point, CA	22.0	26
Florence, OR.	21.9	25
Berteleda, CA	21.8	25
Mad River, CA	21.3	22
Mt Talmalpeus, CA	20.7	18
Control (ex WA)	17.5	-

Wood density of best 7 provenances in NZ (versus Washington provenance)

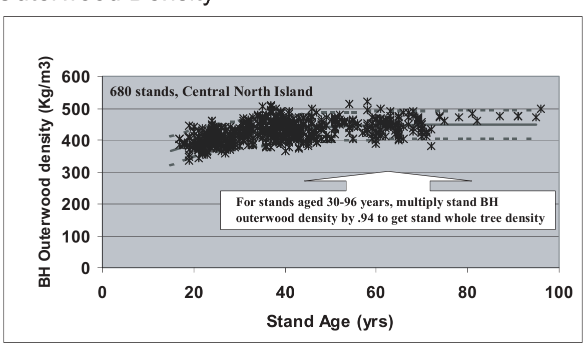
Seed Source in US	Pith to bark density @ 34 yrs	Difference to control	Significance	Range at the tree level	
	Stand mean (kg/m^3)	%		Min	Max
Jackson S. F., CA	413	-2	*	341	483
Santa Cruz, CA	421	0	NS	361	501
Stewart Point, CA	411	-3	**	351	467
Florence, OR.	425	+1	NS	377	486
Berteleda, CA	392	-7	**	349	449
Mad River, CA	426	+1	NS	359	485
Mt Talmalpeus S.P., CA	434	+3	**	380	503
Control (ex WA)	422	-	-	366	476

Mean range 120 kg/m3

Conclusions re breeding for wood density

- Variation in density **between** provenances is small (max of +16 kg/m^3)
- Variation between trees **within** a provenance is very large (mean of +60 kg/m^3)

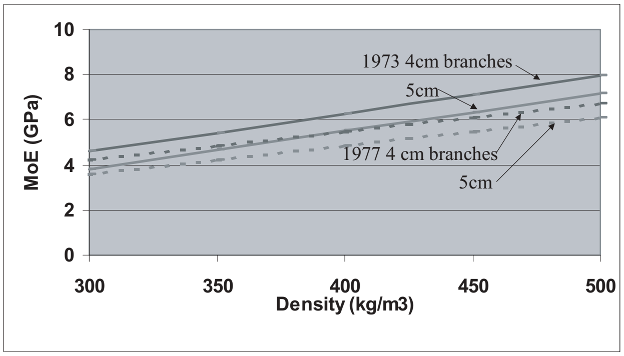
Effect of Stand Age (17-96 years) on BH Outerwood Density



Prediction of timber stiffness (MoE) in NZ D-fir

- 1973 study linked branch and stem morphology, and wood properties, to MoE
  - 32 trees, 132 logs (aged 45 yrs) chosen for extremes
  - density and branch size explained 63-72% of variation in MoE of butt and second logs
- 1977 study measured branch size and density in 100 trees (aged 51 yrs)
  - a subset of 23 second logs were selected to cover the range, and sawn
  - density and branch size explained 80% of variation in MoE

Effect of Density and Branch Size on MoE



Prediction of timber stiffness (MoE) in NZ D-fir

- 1994 study sampled 100 trees for density, branch size and DBH in 4 stands, two aged 33 years, and 2 aged 59 years.
- 60 trees contributed 195 logs, which were sawn to timber of 42mm thickness and various widths
- The timber was graded to NZ MSG, Australian and WWPA grades.
  - Regressions linked density, branch size and log height class to NZ MSG.
  - Compared to the earlier studies, the predicted timber grades were significantly better
  - the relationships with log variables were weaker

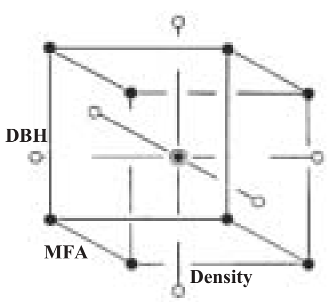
Export grade Douglas-fir logs

- 300mm min. SED
- 12m length
- small branches
- straight

Plan of Current (2002) Study

- 50 trees, aged 42 years, screened for BH density and MFA, by SilviScan
- Subset of 18 trees selected for range of MFA, density, and DBH, using response surface central composite design
- 18 trees (54 x 16ft sawlogs), sawn to 2x4 timber, MS graded
- MoE from small clears (at 5.3m height intervals) related to SilviScan density, MFA, and predicted MoE from pith to bark strips
- Relate whole-tree wood property and MSG results to BH core, sonic MoE, and branch size assessments
- SilviScan assessments done by CSIRO, Melbourne

Response surface central composite design



Small DBH, high density, low MFA, very high MoE (+20%)

Small DBH, high density, low MFA, very high MoE (+20%)

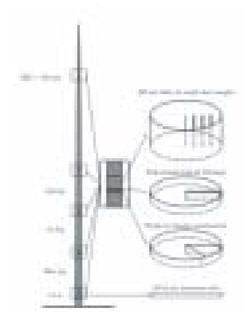
Large DBH, high density, high MFA, medium MoE (0%)

Large DBH, low density, high MFA, low MoE (-6%)

Large DBH, low density, high MFA, low MoE (-6%)

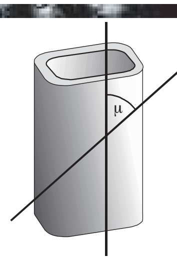
Large DBH, high density, low MFA, high MoE (+11%)

Sampling plan for SilviScan and small clear mechanical testing

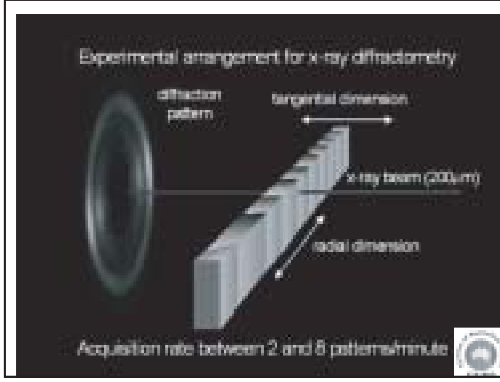


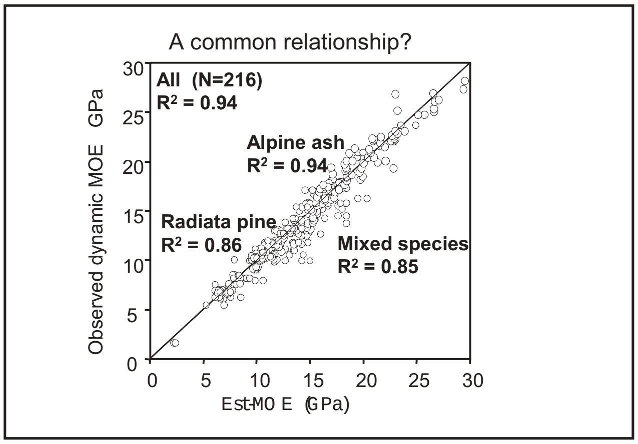
Microfibril angle

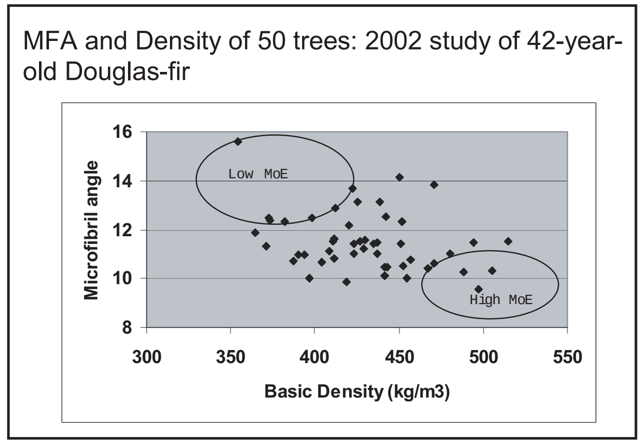
Average angle of the cellulose molecules in the S2 layer of the cell wall relative to the axis of the cell

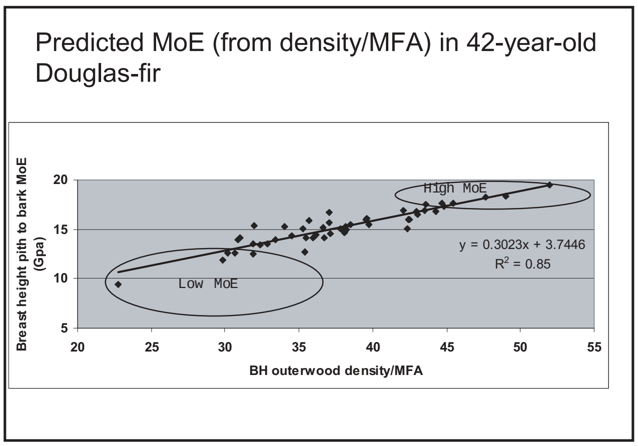


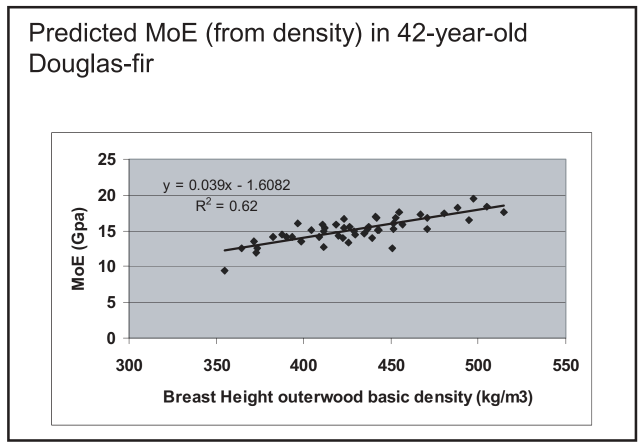
Forestry and Forest Products

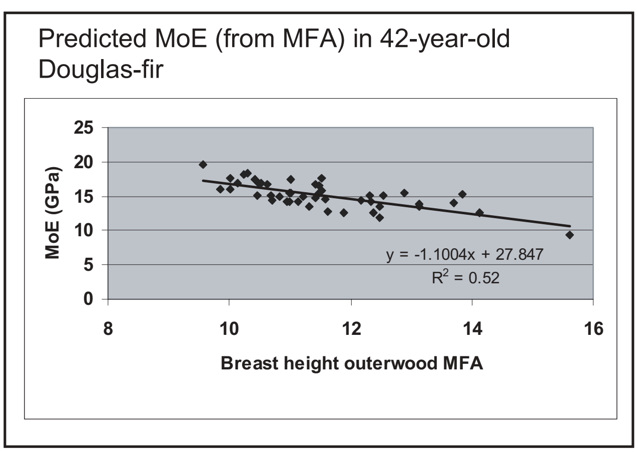


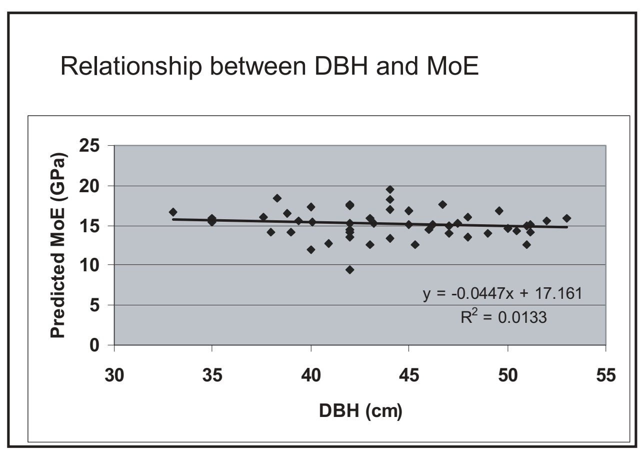

A common relationship?
All (N=216)
R^2 = 0.94
Alpine ash
R^2 = 0.94
Radiata pine
R^2 = 0.86
Mixed species
R^2 = 0.85
Observed dynamic MOE GPa
Est-MOE (GPa)
0
5
10
15
20
25
30


MFA and Density of 50 trees: 2002 study of 42-year-old Douglas-fir
Low MoE
High MoE
Microfibril angle
Basic Density (kg/m3)
8
10
12
14
16
300
350
400
450
500
550


Predicted MoE (from density/MFA) in 42-year-old Douglas-fir
High MoE
Low MoE
y = 0.3023x + 3.7446
R^2 = 0.85
Breast height pith to bark MoE (Gpa)
BH outerwood density/MFA
5
10
15
20
25
30
35
40
45
50
55


Predicted MoE (from density) in 42-year-old Douglas-fir
y = 0.039x - 1.6082
R^2 = 0.62
MoE (Gpa)
Breast Height outerwood basic density (kg/m3)
0
5
10
15
20
25
300
350
400
450
500
550


Predicted MoE (from MFA) in 42-year-old Douglas-fir
y = -1.1004x + 27.847
R^2 = 0.52
MoE (GPa)
Breast height outerwood MFA
0
5
10
15
20
25
8
10
12
14
16


Relationship between DBH and MoE
y = -0.0447x + 17.161
R^2 = 0.0133
Predicted MoE (GPa)
DBH (cm)
0
5
10
15
20
25
30
35
40
45
50
55

Simplified Decision Support System for NZ Douglas-fir Growers

Green Solution Software *Douglas-fir*

Input Variable	Mean	±
Livestock Carrying Capacity (LSU/ha)	5	
Establishment costs (cents/tree)	70.88	
Annual fixed costs ($/ha)	80	
Land Value ($/ha)	0	
Clearfell Logging Cost ($/m^3)	35	
Production Thin Logging Cost ($/m^3)	40	
Livestock capital value ($/LSU)	70	
SBAP	2.1	
SI (m)	32	
B.H. Outerwood Density (kg/m^3)	420	
Outerwood Measurement Age (yrs)	30	
Rotation (yrs)	45	10
FCS (stems/ha)	500	
Clearfell Conversion (%)	85	
Thinning Conversion Reduction (%)	10	
Log Prices (%±standard)	0	
Labour Cost ($/hr)	22	
Labour Supervision (%)	15	
Ht waste thin (m)	14	
Ht prod. thin (m)	24	
Waste thin : Total thin stems (%)		
Prune ? (Y/N)	N	
Discount rate (%)	7	
Log Grade Prices ($/m^3)	**Standard**	**Reset**
P1 (price for PLI = 6)	190	
S1	225	
M1a	200	
M1b	200	
S2	160	
L1	140	
L2a	83	
L2b	83	
Ari	60	

* Value outside recommended range

Rotation	EFGM $/LSU	IRR %	NPV $/ha	Cost $/m^3	Value $/m^3	Labour hr/ha	BIX cm	Juv. %	SED mm	PLI	Density kg/m^3	MOE
35	14.6	7.71	762	43.3	90.0	32.5	2.8	26.1	230	0.0	406	6.3
40	19.2	7.89	1,116	42.4	104.2	32.5	2.9	22.1	250	0.0	412	6.3
45	21.0	7.88	1,252	41.7	119.4	32.5	2.9	18.8	268	0.0	416	6.3
50	20.0	7.76	1,175	41.1	134.9	32.5	3.0	16.3	283	0.0	419	6.4
55	16.5	7.56	911	40.6	150.6	32.5	2.9	14.6	297	0.0	421	6.4

Rotation	Initial	Waste thin				Production thin				Clearfell		
	SPH	Age	SPH1	SPH2	DBH	Age	SPH1	SPH2	DBH	DBH	MTH	Vol
35	1,650	17.8	1,521	1,521	16.9	29.9	1,228	516	28.2	37.3	28.4	556
40	1,650	17.8	1,521	1,521	16.9	29.9	1,234	534	28.2	40.7	32.0	727
45	1,650	17.8	1,521	1,521	16.9	29.9	1,240	560	28.1	43.7	35.4	917
50	1,650	17.8	1,521	1,521	16.9	29.9	1,245	595	28.0	46.4	38.5	1,117
55	1,650	17.8	1,521	1,521	16.9	29.9	1,251	630	27.8	48.8	41.3	1,314

Rotation	Clearfell Log Grade Volumes (m^3/ha)										
	P1	S1	M1a	M1b	S2	L1	L2a	L2b	Ari	Pulp	Total
35	0	12	69	36	4	13	101	164	43	30	473
40	0	33	133	63	6	15	128	172	43	26	618
45	0	79	204	104	5	17	141	165	43	23	780
50	0	172	256	160	2	18	135	145	41	20	950
55	0	326	260	226	0	18	110	117	39	19	1,117

Rotation	Production Thining Log Grade Volumes (m^3/ha)										
	P1	S1	M1a	M1b	S2	L1	L2a	L2b	Ari	Pulp	Total
35	0	0	0	0	1	0	54	68	90	38	253
40	0	0	0	0	1	0	53	66	88	38	246
45	0	0	0	0	1	0	51	64	85	37	238
50	0	0	0	0	1	0	49	62	82	36	231
55	0	0	0	0	1	0	48	60	79	35	224

last updated 17-June-2002

Conclusions- wood quality improvement in Douglas-fir

- Breeding and management objectives: yield and MoE
- Define relationships between MoE and tree size, branch size, density, and MFA. SilviScan is clearly a key tool
- Develop cheap screening method for MoE
- Select provenance for growth rate, and select and breed for MoE and yield
- CP seed + vegetative propagation for deployment of improved stock
- Develop and use simplified DSS to integrate all this knowledge

Preferred South Island site for new planting of Douglas-fir.

Low growing cost, high productivity, easy logging, few restrictions.

Genetics of Wood Properties in Western Hemlock

Charlie Cartwright

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Canada V0R 2N0
Charlie.cartwright@gems1.gov.bc.ca

Western hemlock though not particularly prized for its wood properties is a large part of inventories on the West Coast of North America. It is a climax species that maintains its dominance through shade tolerance, acidic litter detrimental to other species, and fecundity. Due to its ability to seed in, many hemlock cut-blocks are regenerated naturally. As a result tree improvement is not so concerned with wood quality as focused on volume gain in order to provide an incentive for silviculturalists to plant. Due to shade tolerance many branches and stems are retained often leading to smaller diameter logs which translates to a larger portion of the stems being chipped. As well, low fibre coarseness and limited levels of chromophoric or toxic extractives result in wood that is not durable, or attractive to Western tastes; it is however suitable for Asian markets or pulp. Wood density is slightly lower than for Douglas-fir but much higher than in red cedar, and this combined with a better ability to absorb wood preservatives than either, contributes to hemlock being the preferred species for pressure treated wood products. To summarise its wood qualities, coastal western hemlock is desirable for pulp, treated wood and where uniformity is valued.

Studies of the genetics of hemlock wood properties in BC have so far included pilodyne tests to rank families for relative density, immersion method to estimate specific gravity, x-ray densitometry, and image analysis to ascertain micro-fibril angle of the S2 layer (MFA). Most recently x-ray diffractometry / optical scanning (Silviscan) to determine MFA, plus estimate density in order to derive wood stiffness has been done for some families. For pulp properties, fibre length (FL) and coarseness were measured through optical fibre analysis. Later cell morphology was studied by confocal microscopy and by image analysis allowing ratios of cell wall thickness to cell size to be determined. Significance of the measurements for solid wood was checked by mechanical testing of small clear pieces and for pulp by testing hand sheets from selected families sampled from progeny tests. A summary of the investigations carried out and the number of families checked follows (Table 1: Hemlock families analyzed by various methods).

As expected, family heritabilities for wood properties were almost twice as high as for growth traits for the corresponding samples. However, variability in the wood traits was limited and in general less than half that for growth. As with many other wood density studies there were strong (- 0.4 to - 0.5) negative phenotypic correlations with growth measures. MFA was positively correlated with growth and FL was close to neutral but depended on how FL was adjusted for breakage of fibres. Despite some difficulty in selecting for both wood and volume improvement, this was possible through use of correlation breakers. Because there are a considerable number of tested first generation hemlock parents it would not be difficult to construct seedlots that show gains in both growth and wood traits and yet meet BC requirements for diversity (effective population size = 10).

Ongoing investigations in the genetics of wood properties of western hemlock at the BC Forest Service will include analysis of extractive content, realized gain trials for wood properties, and selection of parents superior in wood or pulp quality for sub-lines of the breeding population. It is hoped that through this activity and better silviculture, hemlock can maintain its position in the marketplace.

Recommendations:

1. Screening of hemlock parent trees for pulp traits.

2. Screening of hemlock parent trees for density and MFA.

3. Inclusion of parents selected for wood and fibre quality in breeding populations.

Table 1: Hemlock Families Analyzed by Various Methods

		Solid Wood				**Pulp**				
Series	**Site**	Pilodyne	Relative Density	X-Ray Densit.	Mechanical Testing	Silvi-scan	Fibre Analyzer	Confocal Imaging	Cell Morpho.	Hand Sheets
MM1	Mission	29	29	29	5	6	29	4 & 29	5	5
1979	Adam	29	29						5	
MM2	Carman		33				27		30	5
1980	Jrd Hi		39				12			
MM3	Bonanza		76				40		40	5
1981	Quatse	76	76							
	Naka		76							

Summary, Tree Improvement Recommendations and Research Needs

Keith Jayawickrama

PNWTIRC / NWTIC workshop on ìG enetic Improvement of Wood Quality in coastal Douglas-fir and western hemlockî

June 27, 2002
Oregon State University, Corvallis, OR

Wood Quality Overview: Megraw

- Stiffness varies dramatically with height in tree and ring from pith
- Most (but not all) variation in stiffness is due to variation in fibril angle and specific gravity
- Wood properties differ going up the stem as well as pith to bark
  - Make comparisons only on a very specific ring and height basis
- While end-use properties such as stiffness can be valuable screening tools, tree improvement efforts should be founded on individual basic properties

Wood Quality and Silviculture: Briggs

- Be sure of what is being referred to by "wood quality"
- Thinning, fertilization, pruning, rotation age all affect quality
  - Fiber properties, specific gravity, compression wood
- Knot size is strongly affected by spacing
  - Wide spacing leads to low quality, not a good management alternative
- Thinning & fertilization affect the quality of top logs *vs.* middle logs *vs.* butt logs in different ways
  - improves quality in butt log, makes quality worse in top log
- Need research on effect of silviculture on the juvenile wood phase

Improving Wood Quality : Cannon & Miller

- Their company is interested in faster growth, shorter rotations and stronger wood (all at the same time)

Overview on Specific Gravity: Johnson & Gartner

Most of the variation is within a tree

Within tree variation >> within stand > among stands

Within a stand ñ mild adverse association with tree dbh

No clear evidence that fast-growing stands produce lower specific gravity

Specific gravity increases with:

ñ decreasing elevation, decreasing latitude

Improved specific gravity with:

ñ Longer rotations

ñ Genetic Improvement?

Genetics of Specific Gravity: Johnson & Jayawickrama

Brief summary of data from 3,900 trees from 658 families (protocol recommended to date ñ 6 trees/family on 1 site)

Narrow-sense heritability estimated at around 0.7

Data are not well suited for estimating genetic correlations with growth traits, but family-mean correlations appear weak

From selecting the best 10% per set for height, a selection differential of +6.0 % for height, -0.6% for specific gravity (10 :1 height : specific gravity)

Probably need to sample more trees / family than current protocol

DF Wood Quality Research at INRA: Rozenberg

- Over 750,000 acres DF plantations in France
- Extensive wood quality research on DF since 1960
  - Provenances, form & branching, density, microdensity, stiffness, pruning, peeling, thermomechanical pulping, plywood
- DF breeding programs must take wood quality into account
- A highly motivated industrial landowner could make use of genetic variation of end-product value

Improving lumber stiffness & strength: Jayawickrama

- Stiffness and strength likely to be heritable in DF & WH
- Need feedback if & when stiffness & strength are deficient
- We donít have a good estimate of the density: stiffness relationship at the family level
- Conifer lumber stiffness & strength are being actively researched in several regions / countries, in some cases information is being used in operational tree improvement

Genetics of Stem Form: Howe & Jayawickrama

- Probably not worth trying to breed for small, flat branches
- In some datasets, sinuosity, ramicorns/forking are almost as strongly inherited as height / dbh / volume
- Ramicorns + forking has low-to-moderate, adverse genetic correlation with growth rate (research papers + Nehalem data)
  - Could use more NWTIC data (hundreds of thousands of observations) to confirm these trends
- Ramicorns + forking strongly correlated with growth rate at plantation level (I.e. more defect at fast-growing sites)
- Keep assessing ramicorns + forking, use in selection

  Could select low-ramicorn families to deploy in high-growth conditions (fertile soils, low elevation, weed control etc.)

Genetics of WH wood properties: Cartwright

- Points of difference between DF and WH
- Ten yearís work in BC on genetics of WH wood properties, including studies on
  - Between-provenance differences
  - Within-provenance (family) differences
- Genetic parameter estimates obtained for some traits
- Advocates screening top WH parents for pulp properties (fiber length and collapsability)

New Zealand Douglas-fir: Knowles et al.

Log size, branch size, specific gravity and fibril angle all influence lumber grade

Have established clear goals for improving yield and lumber stiffness through breeding and silviculture

Have selected provenances for growth rate, are selecting and breeding within provenances for stiffness and growth rate

Planning to use control-pollinated seed + vegetative propagation for deployment of improved stock

Some Research Questions to Answer for Douglas-fir and western hemlock

1. What are the log + wood quality traits we should emphasize in breeding & deployment?
2. How much weight should we put on wood quality vs. growth rate (e.g. is it worth losing x % gain in growth rate to get y % gain in stiffness)
3. Nature of genetic control:
   - Differences between provenances (seed sources)
   - Differences between families within provenances

4. How can we translate data from progeny test to operational plantation:
   – I.e. How much gain can be obtained by:
     Measuring the selection trait (e.g. specific gravity) on part of a tree, at a given age, on a given site, and extrapolating to:
     – Target properties (e.g. stiffness)
     – Target sites + operational conditions
     – Whole trees
     – Rotation age

5. What is the most efficient, cost-effective way to predict stiffness and strength?
   - Review, test non-destructive tools and techniques
6. Is it possible to develop a breed of western hemlock with wood ìqualityî equal to Douglas-fir, what would it take, is it worth the effort?
7. What are the regional trends in wood properties (effects of latitude, elevation, precipitation)?
   - Need to know these for efficient deployment ñ if certain site conditions favor certain wood properties, may not need to emphasize them when selecting parents

How to Proceed Regarding Genetic Improvement of wood quality

Existing PNW research on wood quality has been fairly well implemented in the operational tree improvement programs

NWTIC role: Need to be sure stem form is being assessed correctly and uniformly across co-ops

– Differentiate sinuosity and crook
– Assess the same part of the tree from co-op to co-op
– Use the same scoring system / scale from co-op to co-op
– Update test measurement guidelines
– Cant fix any existing inconsistencies in first-gen. data, but be prepared before 2nd gen tests are ready for measurement

If there is need for, and interest in, improving a particular wood property :

A. Set a Breeding Goal
B. Choose most appropriate selection traits, strategies & techniques
C. Screen appropriate populations (trials), identify best genotypes
D. Process and interpret information, predict gains
E. Use in deployment / breeding decisions

Existing 1st – generation tests can be used right now to fill out any gaps in wood property information

- Rank 1st-generation seed orchard parents, now with emphasis on log + wood properties
- Predict breeding values.
- Choose orchard parents with desired level of gain for wood properties
- Translate information immediately to gain in plantations

Next option would be to assess 2nd – generation tests:

- Advantages:
  - Can assess between-provenance differences as well as within-provenance differences
  - Tests should be more uniform and successful than 1st gen tests
  - At some point in the future, can establish new orchards with more gain than 1st ñ generation orchards
- Disadvantages:
  - Trees are still too young to measure most wood properties

We donít need to improve every wood trait for every cooperator / co-operative / plantation. Examples:

- Some evidence that density increases going southward, thus density may be OK in south OR / north CA
- Ramicorns and forking may be less important on slow-growing sites
- Forest growers processing their own wood likely to be more interested than those selling logs
- Wood quality less of an issue if planning longer rotations

If we have the right data, could tailor orchard seedlots to co-operator need and site (mix and match)

Controlled crosses would provide a further level of control