UPDATING THE KNOWLEDGE ABOUT THE RELATIONSHIP BETWEEN FIBERS CHARACTERISTICS AND PULP PROPERTIES

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Antecedents

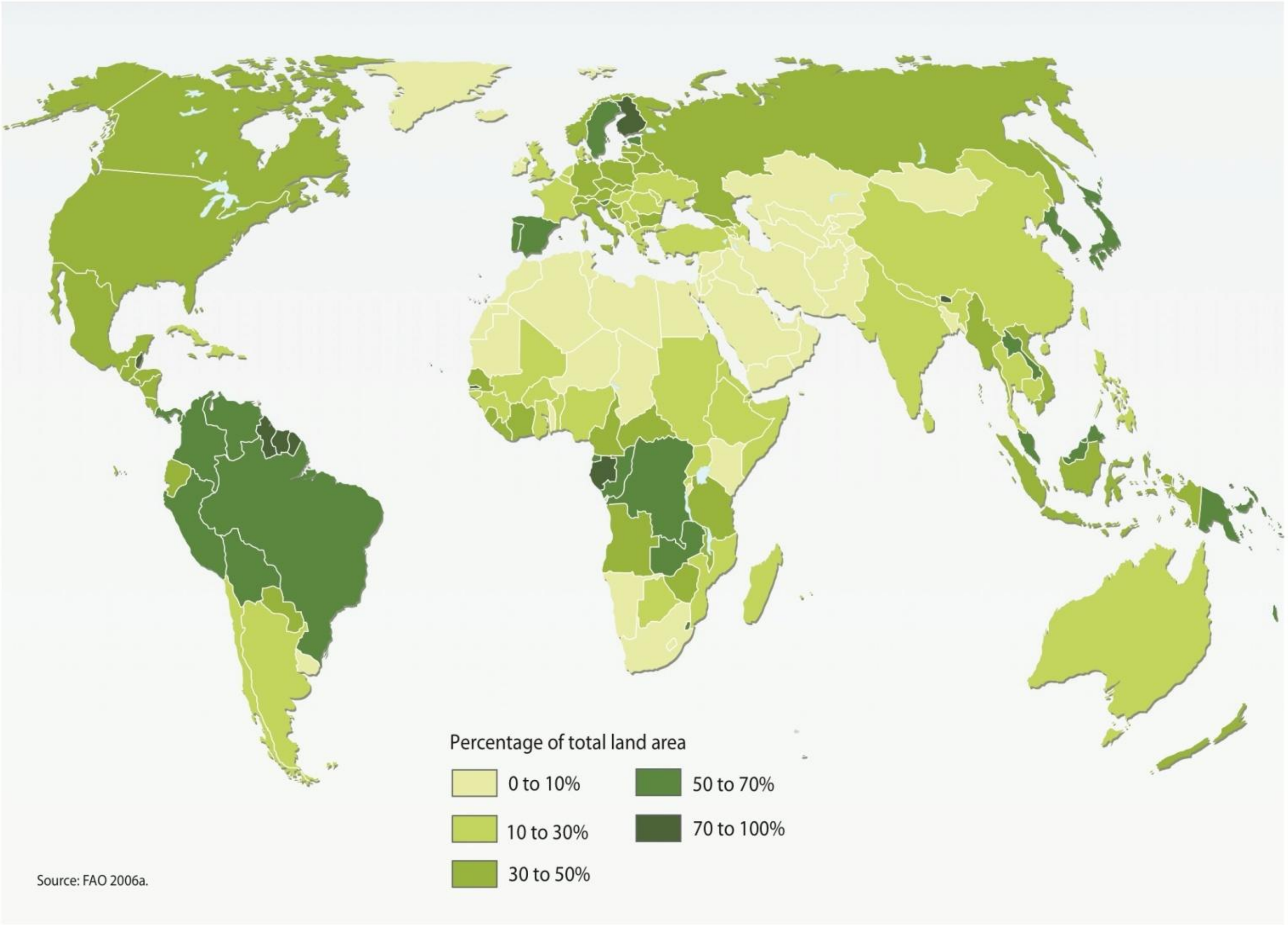
- Firs and pines dominated the global picture of the raw materials for paper industry until the '50s.
- At that time, the interest in introducing new species, mostly hardwoods, led the researchers intensify efforts to look for the fibrous characteristics and their combinations that could represent the relationship between fibers, pulp and paper.

Objectives

- This work surveys recent open access published articles (covering mostly the last decade), intending to verify:
  - which are the morphological characteristics of the fibers that nowadays are considered relevant by the authors.
  - if the old paradigms concerning the relationships between fibers characteristics and pulp properties are still valid or should be reviewed and updated.

Forest plantations and pulp and paper raw materials

Total world forest area

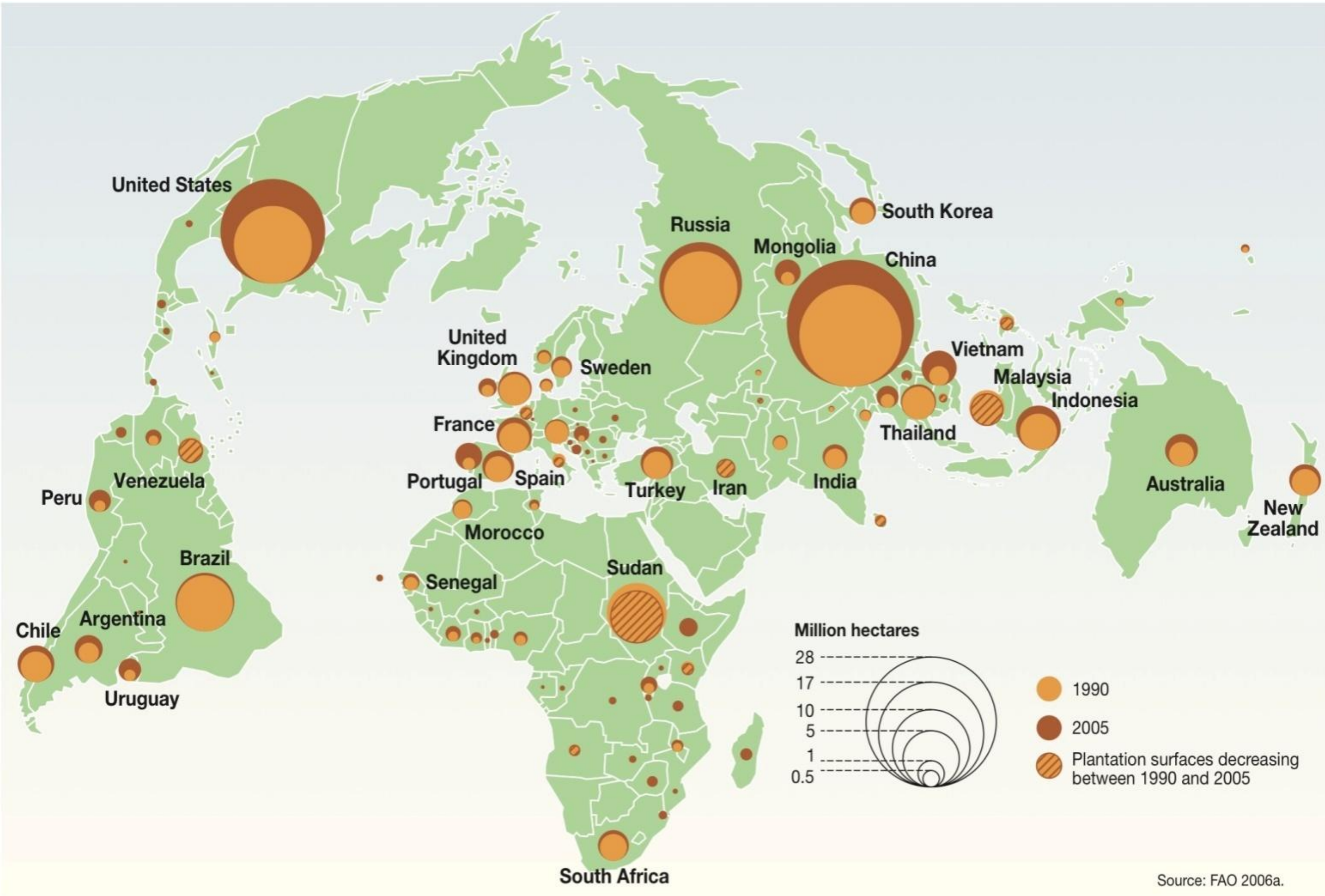


- About 4 million hectares of forests in the world
- Cover approx. 30% of the Earth's land area
- 95% native forest
- 5% forest plantations

FAO, 2006

UNEP/GRID-Arendal. Forest per Total Land Area. UNEP/GRID-Arendal Maps and Graphics Library. **2009**. Available at: http://maps.grida.no/go/graphic/forest-per-total-land-area. Accessed October 03, 2011.

Trends in productive forest plantations



- 1990-2005: increase of 40% in productive plantation area
- This growth will continue
  - FAO

UNEP/GRID-Arendal. Trends in Area of Productive Forest Plantations. UNEP/GRID-Arendal Maps and Graphics Library. 2009. Available at: http://maps.grida.no/go/graphic/trends-in-area-of-productive-forest-plantations. Accessed October 03, 2011.

Current raw materials in the pulp and paper industry

- 85% of the wood fiber used to make cellulose pulp is derived from sustainable forests
  - 37% from plantations (29% in 1993)
  - 49% from natural forests managed productively

Relevance of forests plantations

- Renewable resource essential to human needs
- Decrease pressure on native forests
  - Substitution of native woods less noble purpose
  - Sustainable source of raw materials
  - Provide more than 80% of industry needs
- Substitution of non-renewable products with high environmental impact
  - Capture and storage of CO_2
  - Soil remediation
  - Adaptation to mixed productions
- Their social and environmental sustainability can be certified

Changes in the six largest producers of wood pulp for paper and paperboard 1999-2010 (billion tons)

	USA	Canada	Finland	Sweden	Japan	Brazil
1999	57053	25371	11579	10694	10904	7121
2010	49300	18536	10508	11878	9387	14064
% of change	-13.6	-26.9	-9.2	11.1	-13.9	97.5

FAO statistics

Facts

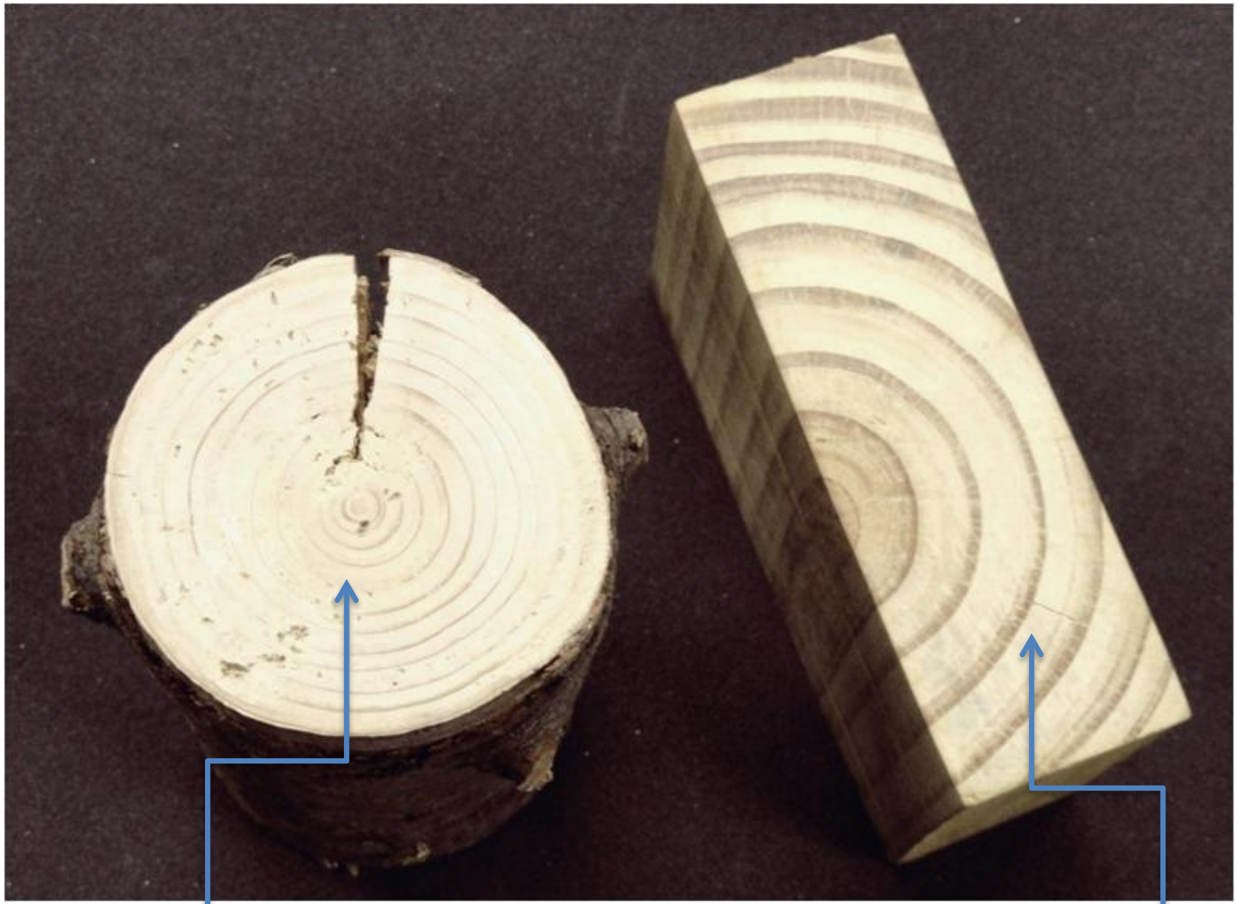
- The pulp and paper industry has shown, mainly in the last two decades, a strong North-South displacement.
- This is to a large extent due to the favourable climate, which promote the development of trees.

Rotation and Yield Comparison
Softwood Pulp Species

Species	Country	Rotation (years)	Yield m^3/ha.year
Pinus spp	Brazil	15	35
Pinus radiata	Chile	25	22
Pinus radiata	New Zealand	25	22
Pinus elliottii / taeda	United States	25	10
Douglas Fir	Canada (coast)	45	7
Picea abies	Sweden	70-80	4
Picea abies	Finland	70-80	4
Picea glauca	Canada (inland)	55	3
Picea mariana	Canada (east)	90	2

Source: Pöyry

Bracepa, Brazilian pulp and paper industry, BCP-RM17/DEST, March 2009, http://www.bracelpa.org.br/eng/estatisticas/pdf/booklet/march2009.pdf



Spruce (approx. the same age, natural forest, Canada)

Pine (plantation, 10 years old, Argentina)

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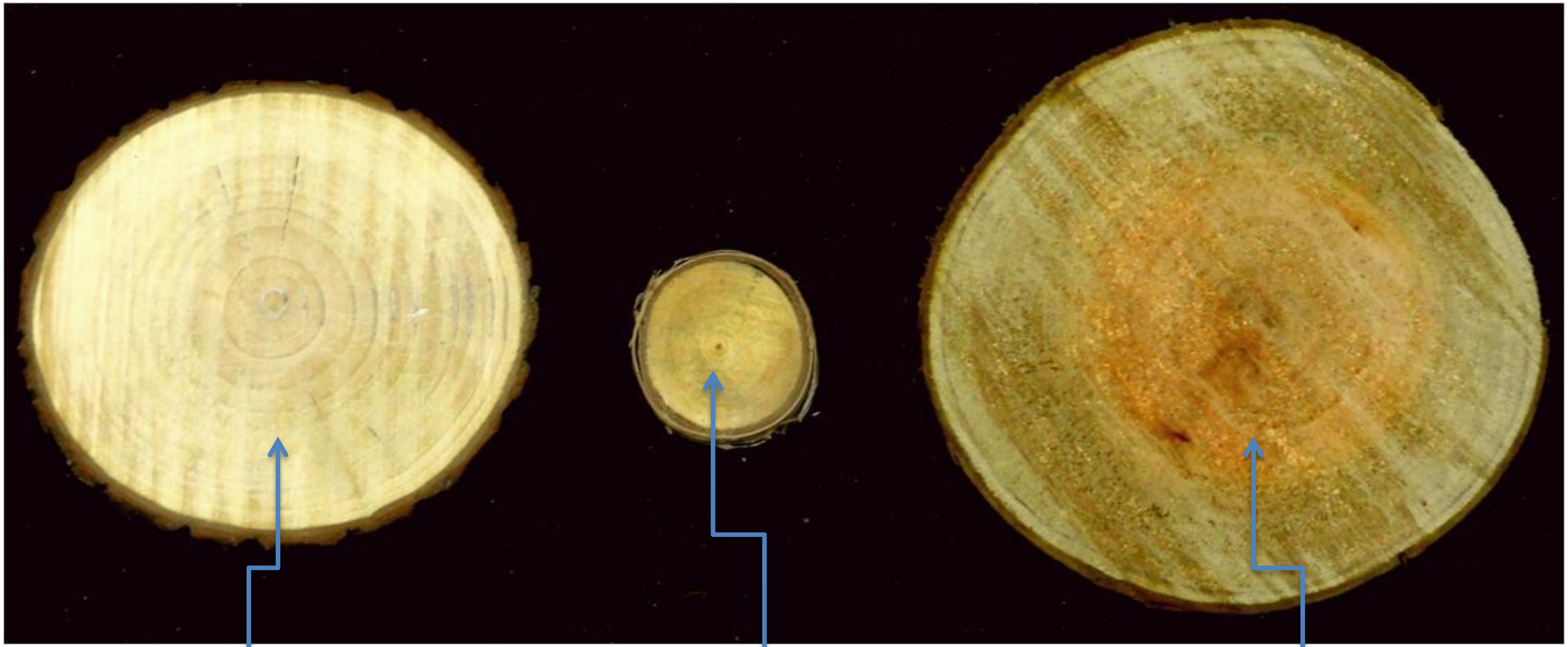
Rotation and Yield Comparison
Hardwood Pulp Species

Species	Country	Rotation (years)	Yield m^3/ha.year
Eucalyptus	Brazil	7	41
Eucalyptus	South Africa	8-10	20
Eucalyptus	Chile	10-12	25
Eucalyptus	Portugal	12-15	12
Eucalyptus	Spain	12-15	10
Birch	Sweden	35-40	6
Birch	Finland	35-40	4

Source: Pöyry

Bracepa, Brazilian pulp and paper industry, BCP-RM17/DEST, March 2009, http://www.bracelpa.org.br/eng/estatisticas/pdf/booklet/march2009.pdf



10 years old
willow
(*Salix* sp,
Delta Argentina)

10 years old
birch
(*Betula* sp,
Quebec, Canada

7 years old
Eucalyptus grandis
(NE Argentina)

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Raw materials in the pulp and paper industry

- The total production of pulp in 1960 was 60 millon tons, including:
  - 78% of softwoods
    - Mostly *Pinaceae* family, genera: *Larix, Picea, Pseudotsuga, Thuga,* and *Abies* from natural forest and *Pinus* from plantations
  - 16% of hardwoods
    - Mostly *Betula, Populus* and mixed hardwoods
  - 6% of others

Raw materials in the pulp and paper industry

- Nowadays the fiber supply has changed:
  - from being almost exclusively softwoods (such as spruce) from natural forests of the Northern Hemisphere cold regions
  - to fast growing species of short fibers, such as eucalyptus, and willow and poplar hybrids from plantations.

Main genres planted for productive purposes in Argentina

a  b  c 

a) *Eucalyptus grandis (*Entre Ríos*)*
b) *Populus sp.* (Buenos Aires)
c) *Salix sp.* (Delta of the Paraná River)

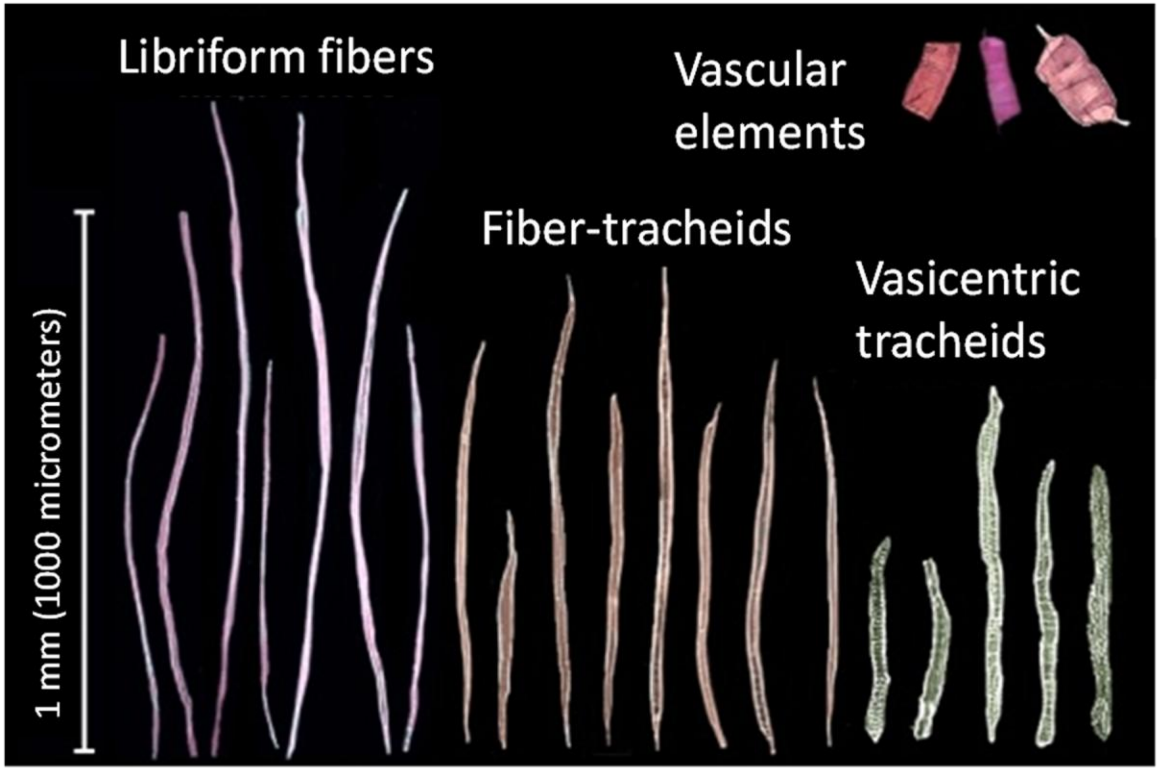
from INTA website

Basic characteristics of wood fibers

Wood fibers

- Wood in conifers consists for more than 90% of longitudinal tracheids
- In hardwoods fiber content varies between species, but generally ranges between 40 - 80%.
  - As a result of greater specialization, they have cells responsible for mechanical support, other kind of cells to transport the liquids, and several intermediate forms of transition elements whose function is both, transport and support.

Different kinds of cells present in *Eucalyptus grandis*



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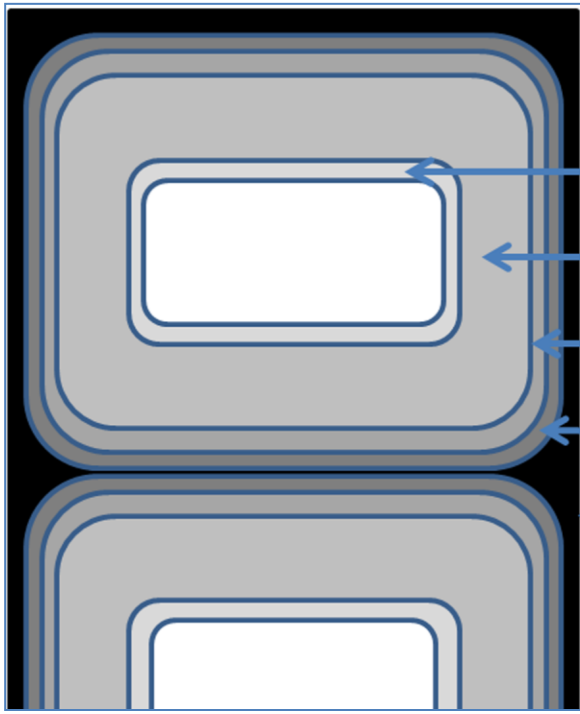
Demonstrative scheme of the percentages of major components of the cell wall layers



Cell wall layer	Relative oven-dry mass %
S3	20% lignin + 40% hemicelluloses + 40% cellulose
S2	20% lignin + 30% hemicelluloses + 50% cellulose
S1	40% lignin + 20% hemicelluloses + 30% cellulose
P	70% lignin + 20% hemicelluloses + 10% cellulose
ML	100% lignin + pectin

Changes in fiber supply

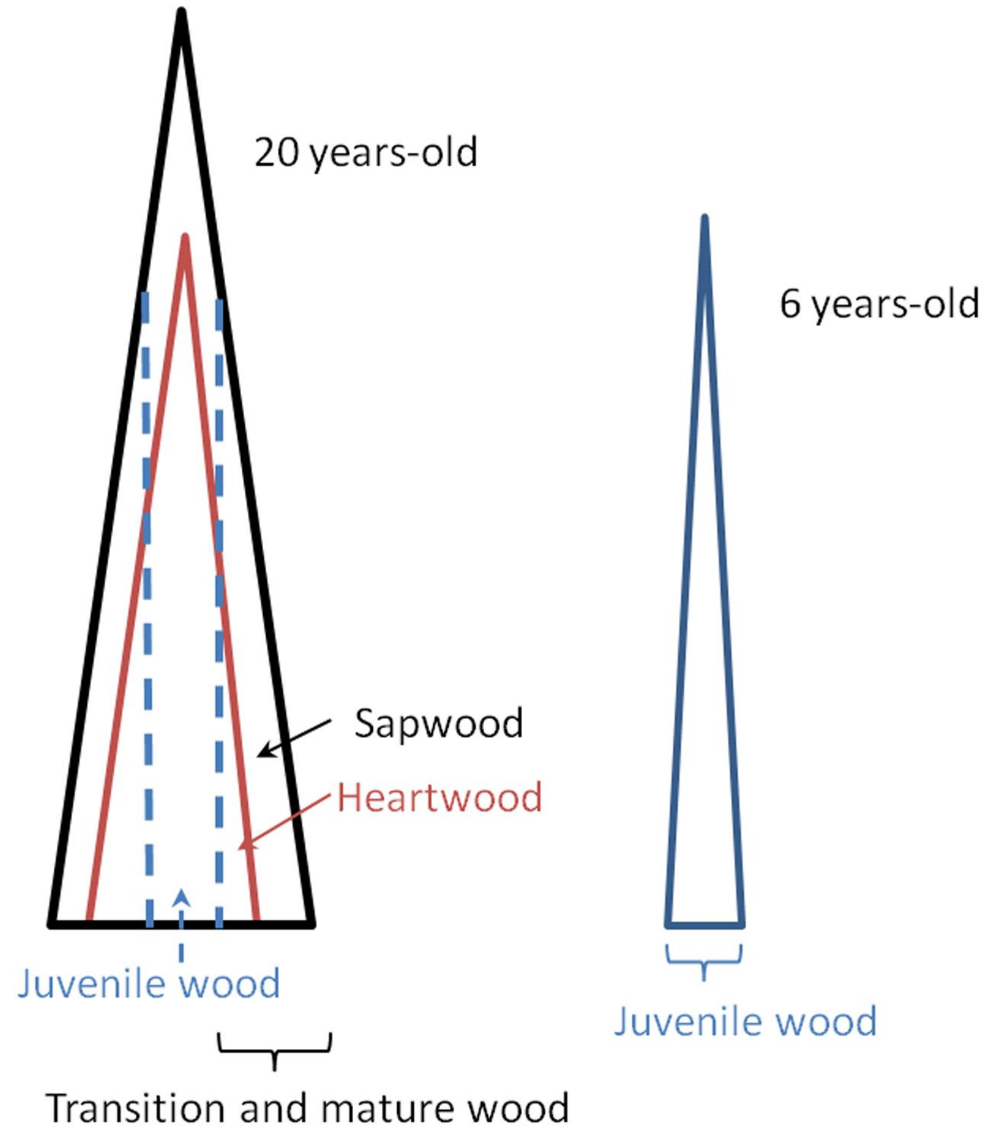
- Trees are used increasingly at younger age.
- These new species, that begin to dominate the paper panorama, not only differ from classic ones in fiber length, but they present particular characteristics, like large amounts of juvenile wood, different fibrillar angle, etc.

Juvenile wood

- To satisfy the increased demand for forest products, much of the future timber supply will come from plantations of species that grow relatively fast, such as *Pinus* and *Eucalyptus*.
- This resource will tend to be harvested in short rotation cycles and will consequently contain higher proportions of juvenile wood than currently has the harvested lumber.

Little importance was given to the distinction between different zones of the tree stem in the past, as most of the wood used industrially came from adult trees from natural forests.

Juvenile and mature wood at two ages in trees from plantations

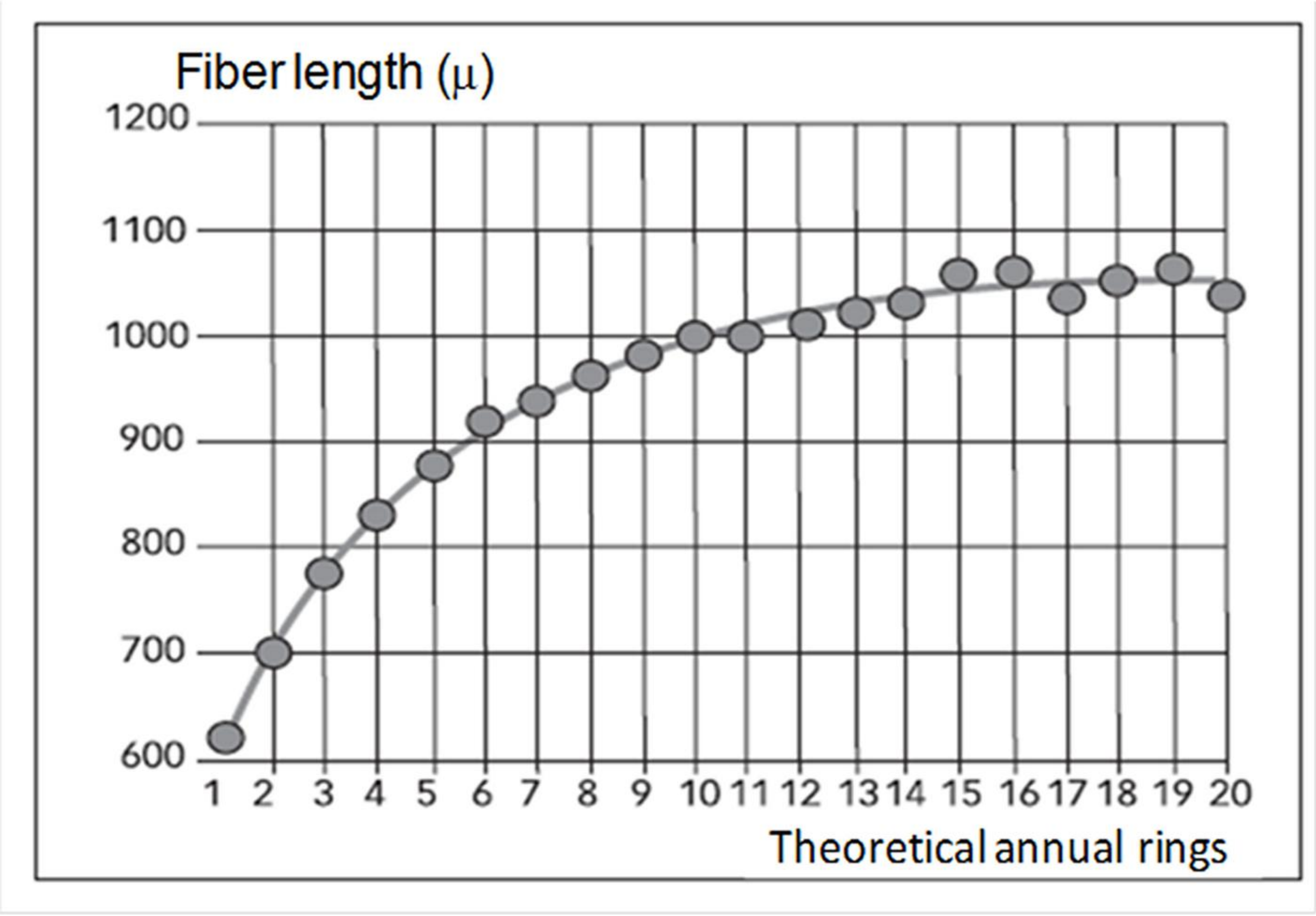


Picea abies	Age, years > 300	Four sites of natural forest in Poland
Pinus nigra	154, 176	Natural forest in the Iberian Peninsula
Pinus contorta	Up to 120	Four sites of natural forest in British Columbia, Canada
Picea abies *Pinus sylvestris* *Larix decidua*	115, 98, 80	Natural forest in Czech Republic
Picea abies	90	Natural forest in Wienerwald, Austria
Picea abies *Pinus silvestris*	80, 84	Natural forest in Norway
Picea abies	40	Plantation in North Sweden
Picea mariana	50	Plantation in Victoriaville, Quebec
Pinus taeda	35	A tree from Orange County, NC, USA
Pinus sylvestris	28, 25	Plantations in North Sweden
Pinus patula,	16	Plantations in Veracruz, Mexico
Pinus caribaea	5, 7, 15, 20, 25	Plantations in Nigeria
Acer saccarum *Acer rubrum*	140	Natural forest in Canada: - Ottawa - Montreal
Fagus sylvatica	83	Natural forest in Czech Republic
Betula pendula	40	Waldsieversdorf, Germany
Eucalyptus citriodora	32	Sao Paulo, Brazil
Eucalyptus grandis	18, 17, 16, 9	Plantations in: -3 sites in Brazil -1 site in Argentina
Eucalyptus nitens	15	New Zealand
Eucalyptus Globulus *Eucalyptus nitens*	15	Australia
Eucalyptus urophylla	14	Progeny test in Republic of Congo
Acacia mangium *A. auricuriformis* *Paraserianthes falcataria*	11, 11, , 8, 7	Plantations in: - Malaysia - Indonesia
Eucalyptus globulus *Eucalyptus grandis*	11, 14	Australia
E. grandis × urophylla clones	8	Plantations in four sites in Brazil
Polupus deltoides cv. "129-60"	17	Plantations in Buenos Aires, Argentina
Populus clones	11, 12	Plantations in China
Populus clones	9	Plantations in Washington, USA

Juvenile wood

- Juvenile wood cells could be:
  - Three to four times smaller than normal cells in softwoods
  - Twice as small in hardwoods.
- Cell structure is also different
  - In juvenile wood there is a greater proportion of thin-walled cells.
- Density and resistance are lower in juvenile wood than in mature wood.

Evolution of fiber length with age in *Eucalyptus grandis* (Argentina)



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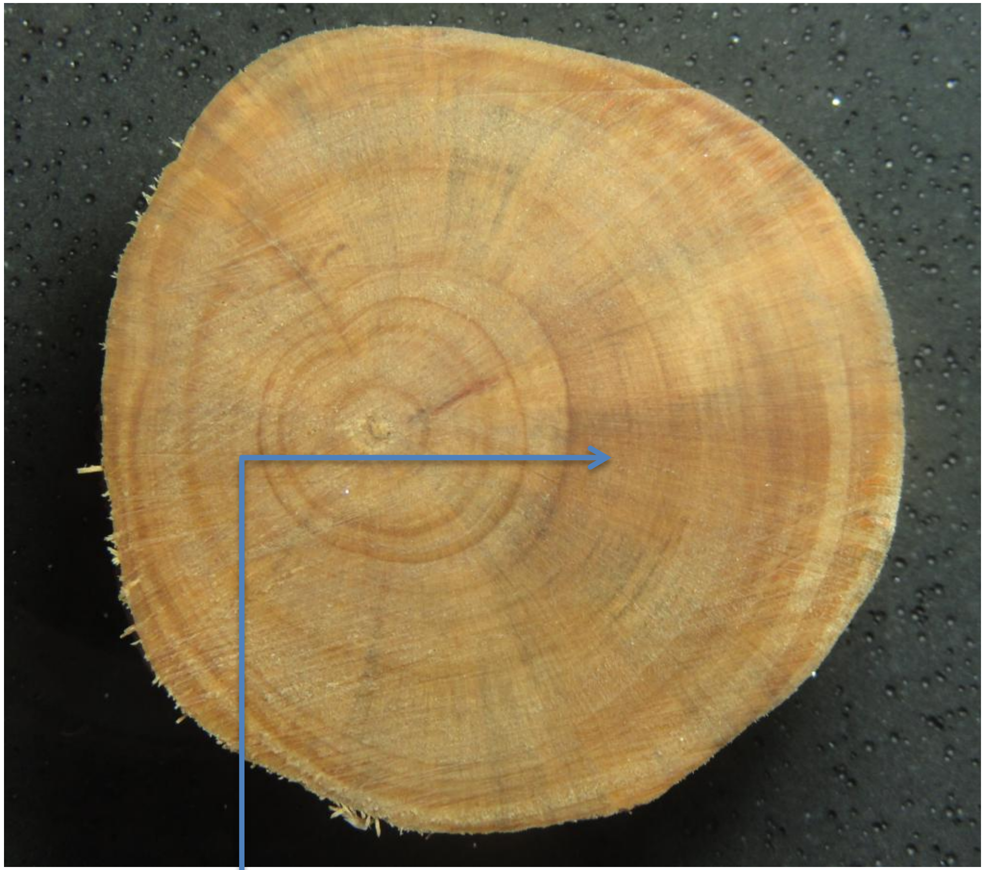
Reaction wood

- When the tree is subjected to abnormal stress (e.g. gravity, persistent winds or other causes) it is pushed from its original direction while it tries to regain its correct orientation.
- As a result of the tree's reaction to disturbance, it develops an abnormal tissue named as “reaction wood”
  - Compression wood in softwoods
  - Tension wood in hardwoods

Compression wood in a conifer stem (Misiones, Argentina)

The compression wood tracheids have:

- ✓ less mean length and width.
- ✓ low contents of glucose, mannose, xylose and arabinose
- ✓ high galactose and lignin.



Abnormally wide annual rings and dark regions

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Tension wood

- In contrast to the compression wood, it has a greater proportion of cellulose and less lignin than normal wood.
- Tension wood fibers in many species show an additional characteristic structural feature called the G-layer.
  - It is an additional layer on the lumen side which can replace the S3-layer or even the S2-layer of the secondary cell wall, and can even fill the whole lumen of the tension wood fiber.

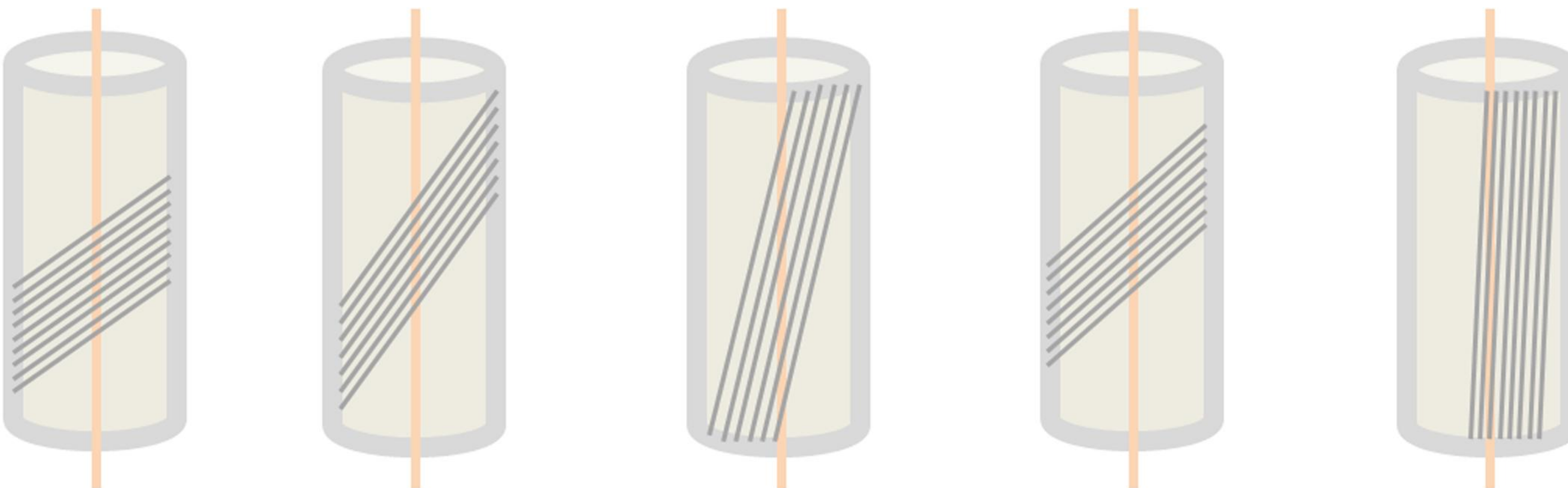
Pulps from reaction wood

- Pulps from compression wood fibers are of definitely lower quality than those from normal fibers.
- Pulps from tension wood fibers are considered to be quite acceptable.

Microfibrillar angle (MFA)

- MFA in juvenile wood is more similar to MFA in compression wood than that in normal wood.
- Nevertheless, juvenile wood is different from compression wood in morphology and chemical characteristics, such as tracheid shape and length, sugar composition, and lignin structure.

Variation of S2 microfibrillar angles at different ages or in different parts of the stem, in normal and reaction wood



1st year (S2 MFA 50°) | Juvenile wood (S2 MFA 30°) | Mature wood (S2 MFA 10°) | Compression wood (S2 MFA 45°) | Tension wood (G MFA 5°)

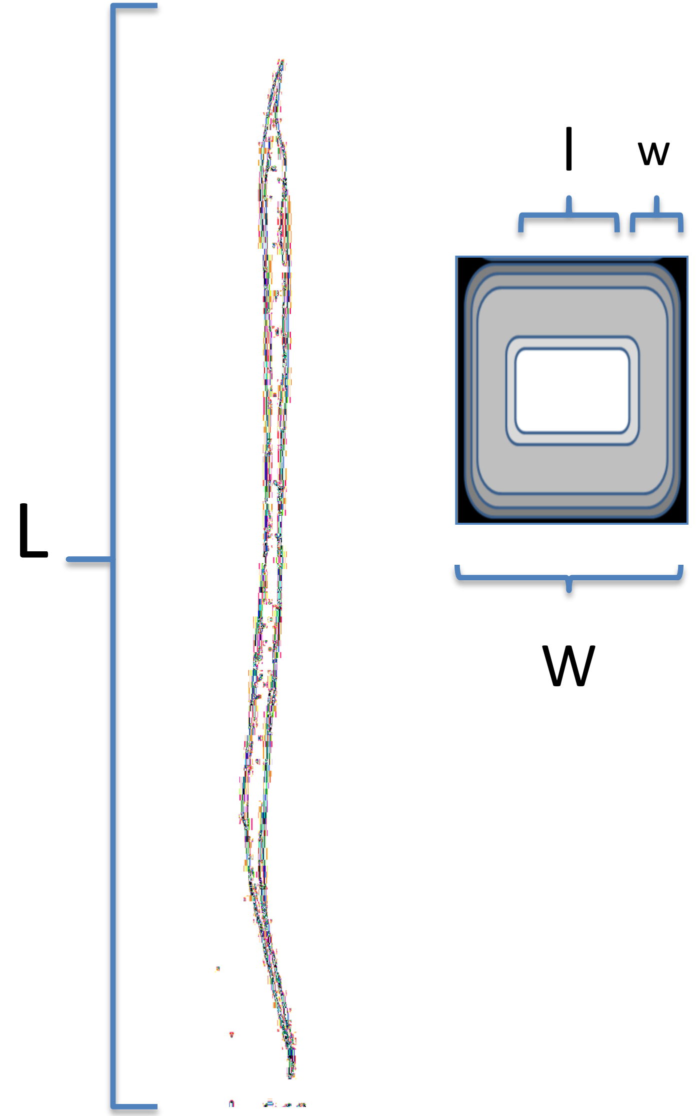
Characteristics of cells, biometric relationships and pulp properties

Relationships between fiber dimensions

- In the first half of the twentieth century the length of the fibers was taken as the most influential feature on the properties of paper.
- Subsequent work showed that all fiber dimensions, or the relationship between them, were associated with the different kinds of pulp strength.
- At the beginning of a series of evaluation work about the aptitude of tropical timber for pulp and paper, the biometric relationships were presented as an issue of special attention as indexes of quality in forest studies.

Fiber dimensions

L:	Length
W:	Width
l:	Lumen
w:	Cell wall thickness



Biometric relationships

- Felting Index, also named "slenderness ratio":
  - FeI = (L/W) * 100
- Flexibility Coefficient:
  - F = (l / W) * 100 or [(W – 2 w) / W)] * 100

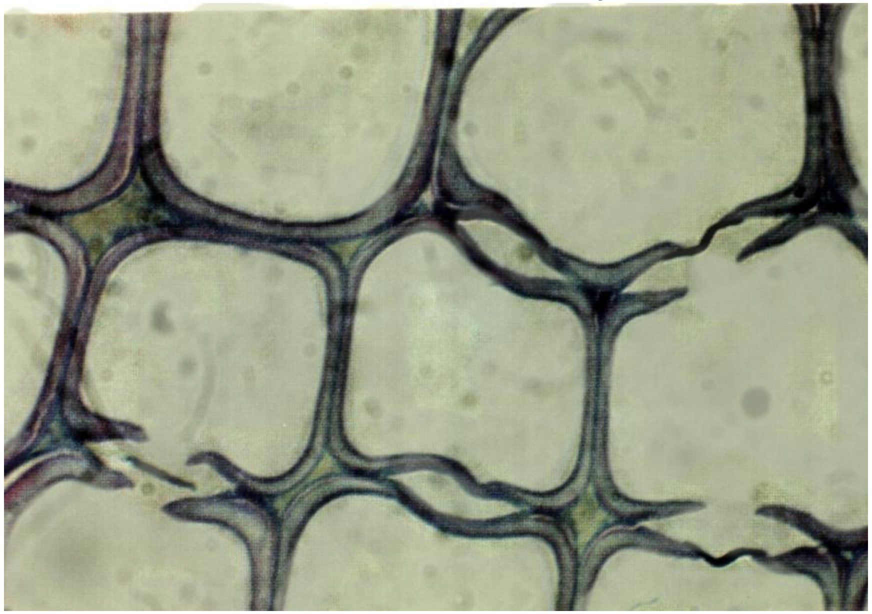
Biometric relationships

- Runkel ratio:
  - $R = 2w / l$
- Wall Fraction:
  - $WF = (2w / W) * 100$
- Solids factor:
  - $SF = (W^2 - l^2) * L$

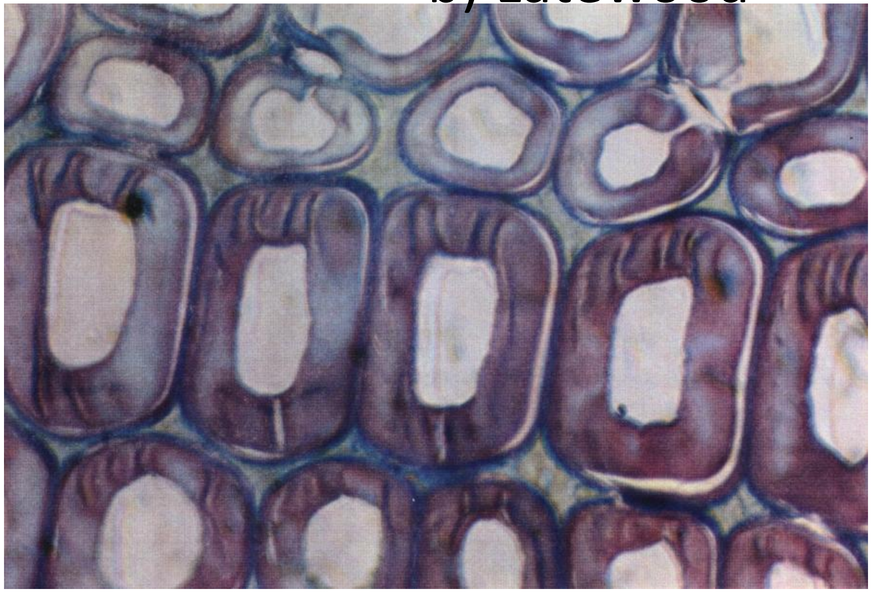
Reference values of biometrical ratios

- FeI 70-80, satisfactory pulp strengths, especially tear.
- F > 50, good pulp strengths, mainly tensile and burst.
- WF < 50%, suitable fibers for papermaking.

a) Earlywood

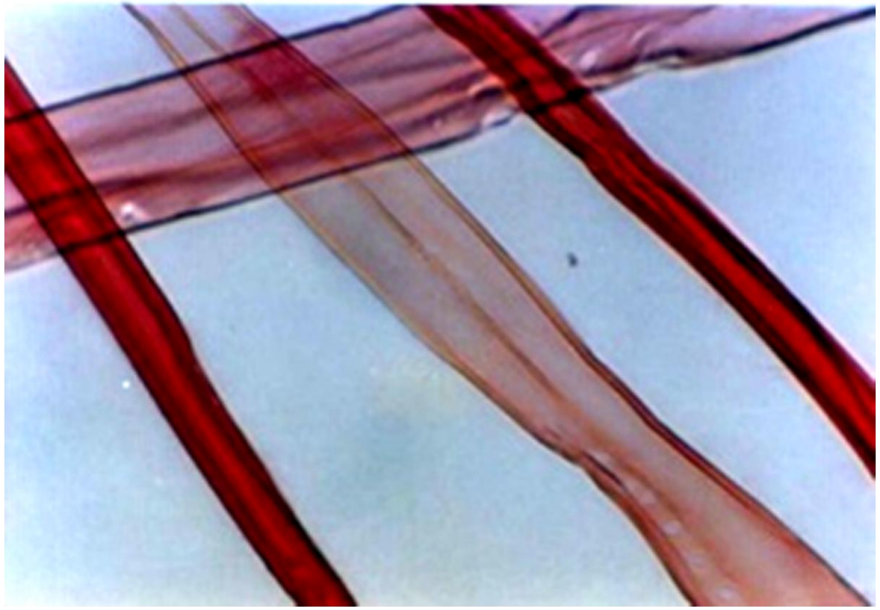


b) Latewood



Cross sections of *Pinus elliottii* wood (Misiones, Argentina

c) Earlywood and Latewood fibers in a chemical pulp.



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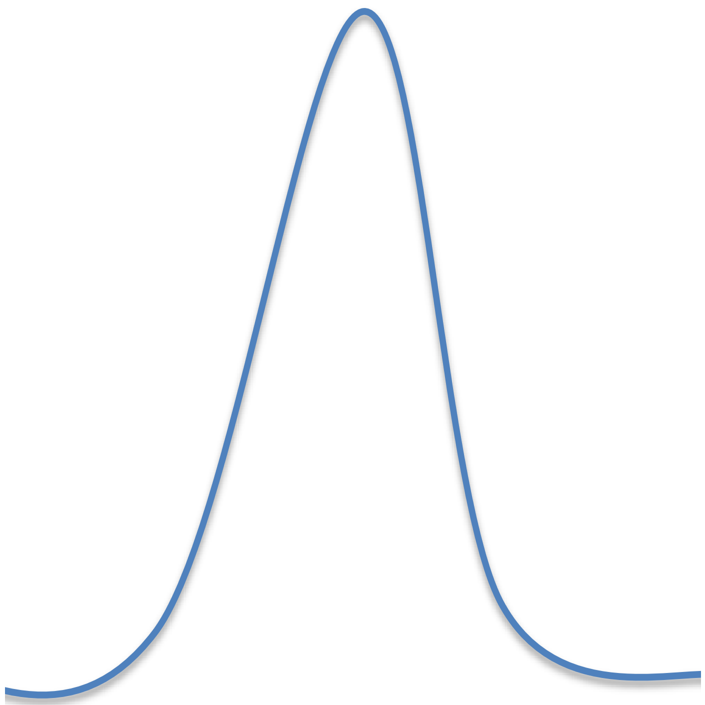
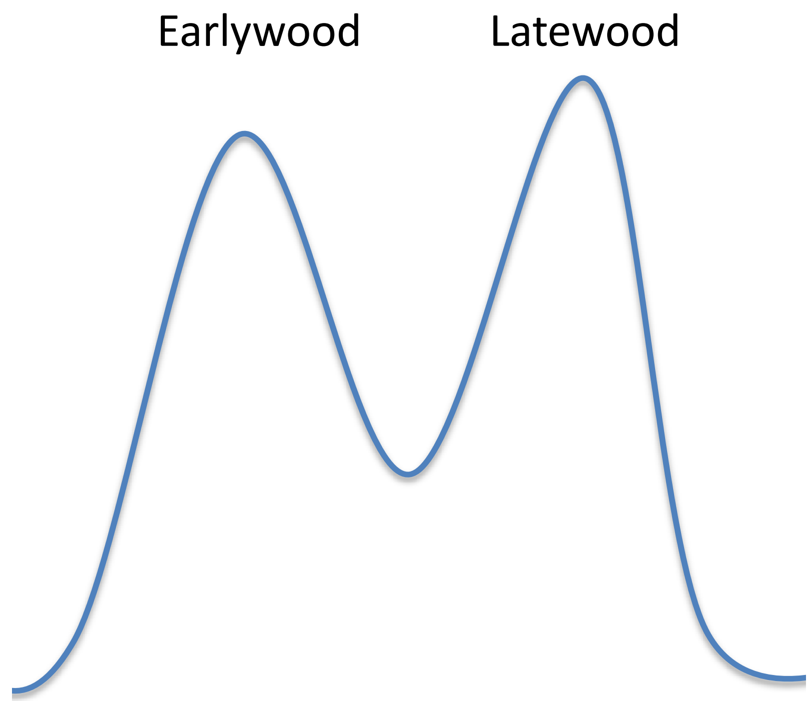
Wall fractions in usual woodpulp fibers



Unimodal distributions of
Wall fraction in hardwoods



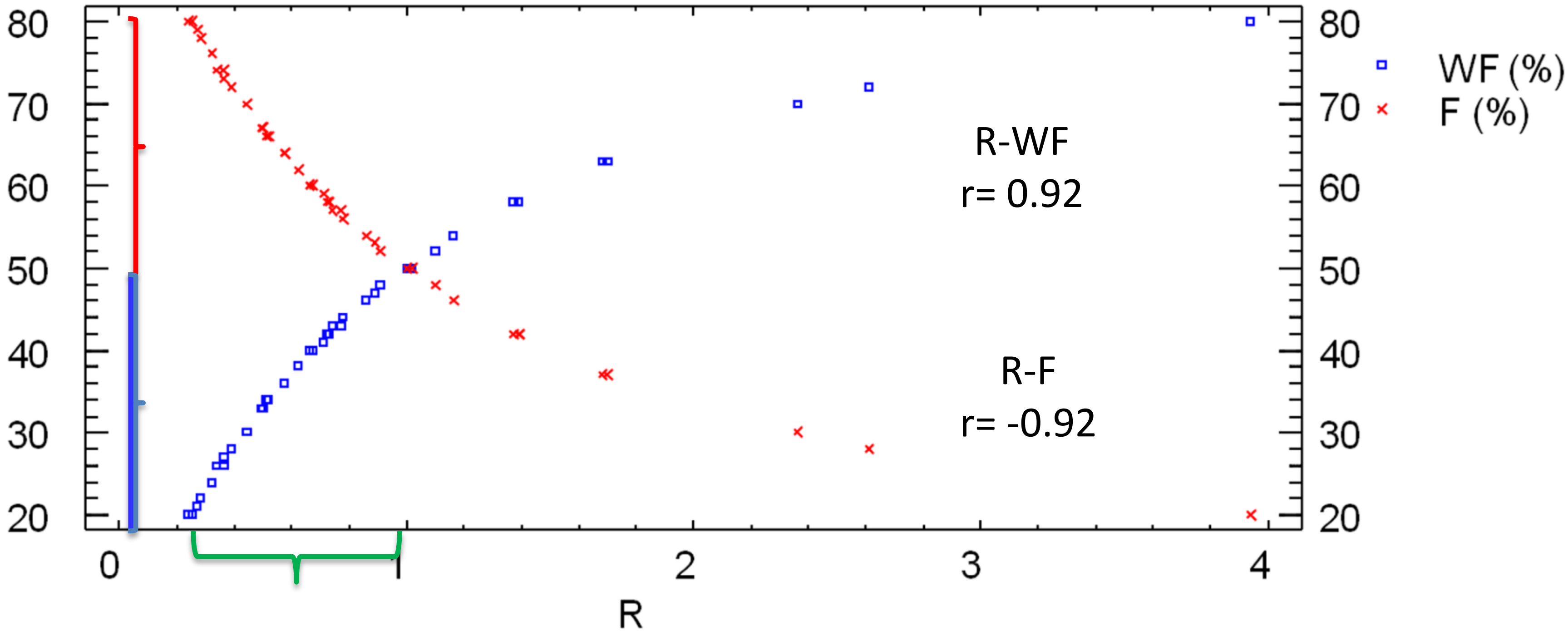
Bimodal distribution of
Wall fraction in softwoods

Reference values of biometrical ratios

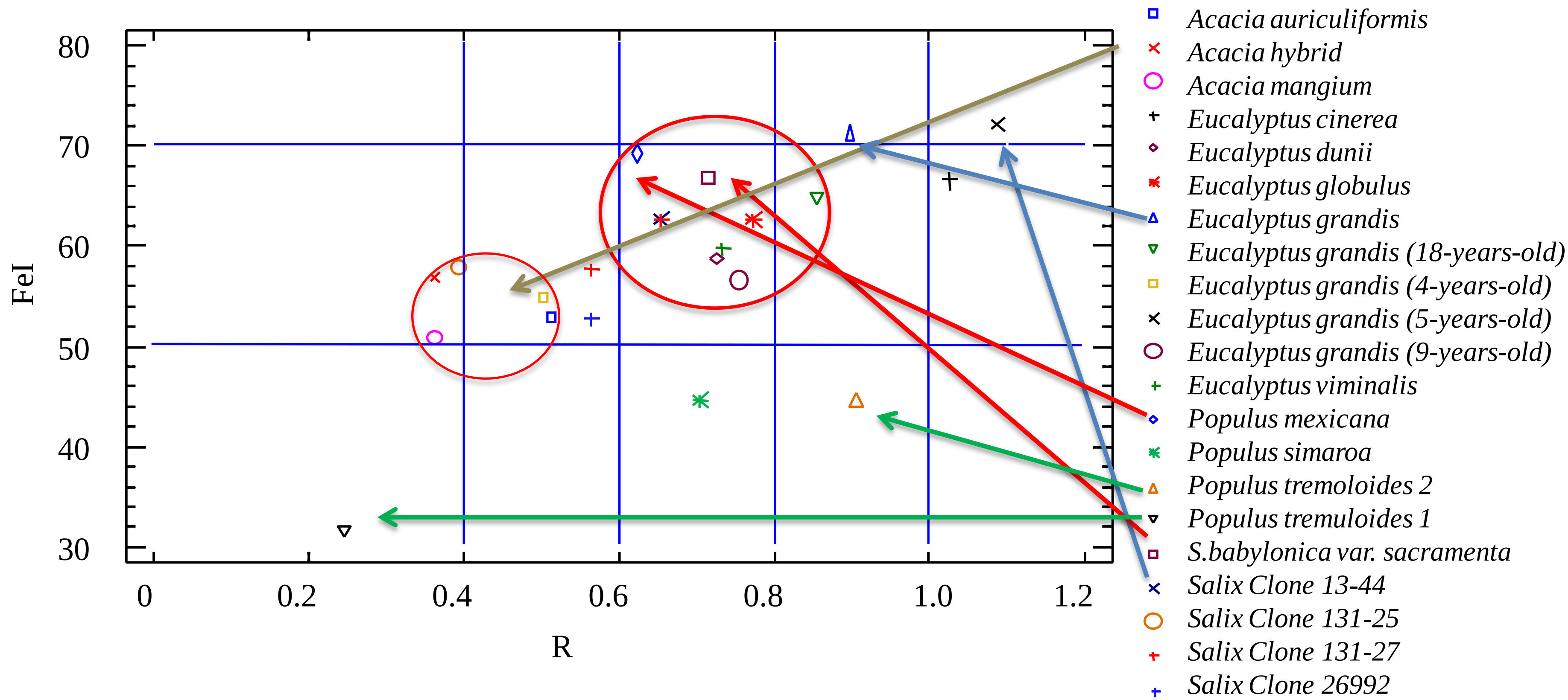
- R < than 0.25, excellent fibers for papermaking
- 0.25 < R < 0.50, very good fibers
- 0.50 < R < 1.00, good fibers
- 1.00 < R < 2.00, mediocre fibers
- R > 2.00, thick walls, the fiber does not collapse, they retain their tubular shape and therefore they have poor adhesion.

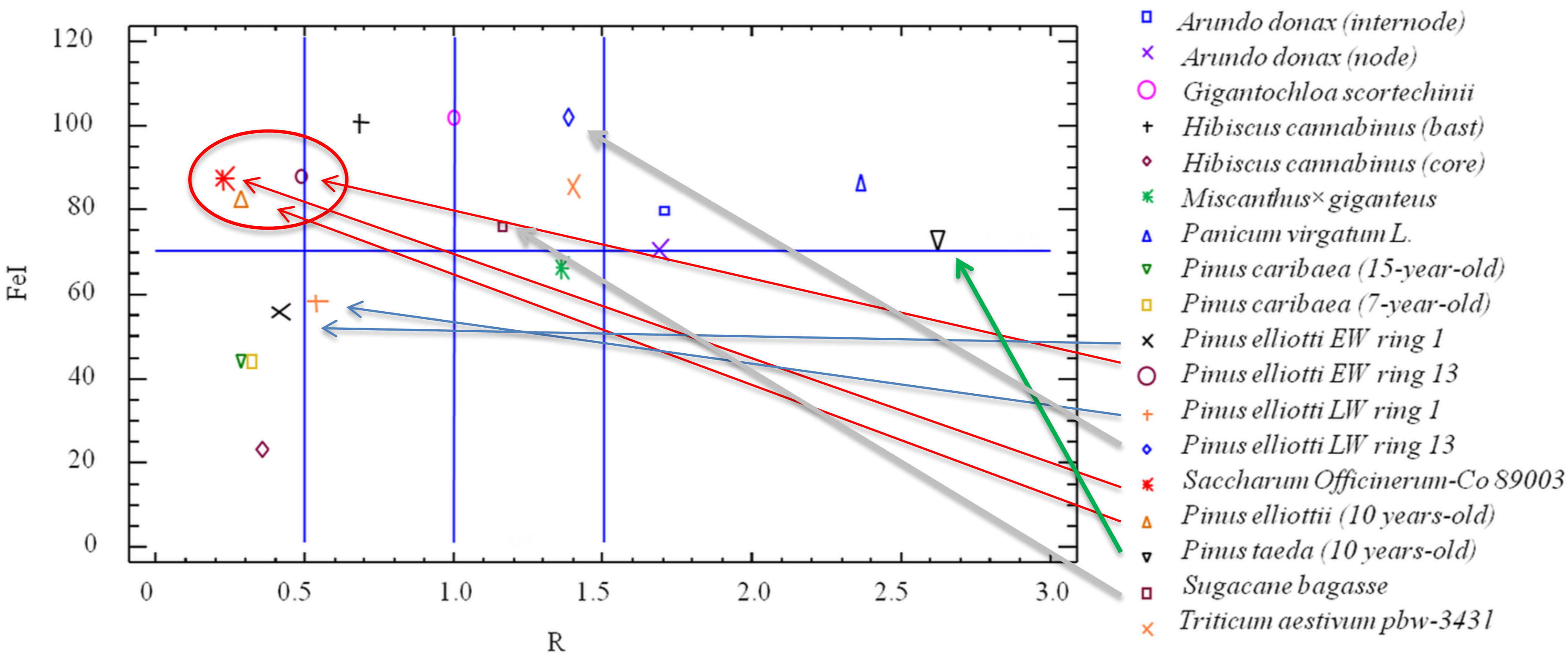
Acacia hybrid	*Pinus elliotti* EW ring 1
Acacia mangium	*Pinus elliotti* LW ring 1
Acacia auriculiformis	*Pinus elliotti* EW ring 13
Eucalyptus grandis (4-years-old)	*Pinus elliotti* LW ring 13
Eucalyptus grandis (5-years-old)	*Pinus elliottii* (10 years-old)
Eucalyptus grandis (9-years-old)	*Pinus taeda* (10 years-old)
Eucalyptus grandis (18-years-old)	*Pinus caribaea* (7-year-old)
Eucalyptus grandis	*Pinus caribaea* (15-year-old)
Eucalyptus globulus	*Arundo donax (node)*
Eucalyptus viminalis	*Arundo donax (internode)*
Eucalyptus dunii	*Gigantochloa scortechinii*
Eucalyptus cinerea	*Hibiscus cannabinus (bast)*
Populus tremuloides (1)	*Hibiscus cannabinus (core)*
Populus tremuloides (2)	*Miscanthus giganteus*
Populus mexicana	*Panicum virgatum L.*
Populus simaroa	*Saccharum Officinerum-Co 89003*
Salix Clone 13-44	Sugarcane bagasse
Salix Clone 250-33	*Triticum aestivum pbw-343 l*
Salix Clone 131-27	*Eulaliopsis binata*
Salix Clone 131-25	*Bambusa tuda*
Salix Clone 26992	
S.babylonica var. *sacramenta*	

Relationship between Runkel ratio, Flexibility coefficient and Wall fraction



Considering Runkel ratio values between 0.2 and 1, the relationship is linear (r= 0.98 for WF and r= -0.98 for F) ⟹ Consistent with the recommended values of R (<1), WF (<50%) and F (> 50%).


FeI
R
80
70
60
50
40
30
0
0.2
0.4
0.6
0.8
1.0
1.2
Acacia auriculiformis
Acacia hybrid
Acacia mangium
Eucalyptus cinerea
Eucalyptus dunii
Eucalyptus globulus
Eucalyptus grandis
Eucalyptus grandis (18-years-old)
Eucalyptus grandis (4-years-old)
Eucalyptus grandis (5-years-old)
Eucalyptus grandis (9-years-old)
Eucalyptus viminalis
Populus mexicana
Populus simaroa
Populus tremoloides 2
Populus tremuloides 1
S.babylonica var. sacramenta
Salix Clone 13-44
Salix Clone 131-25
Salix Clone 131-27
Salix Clone 26992


FeI
R
120
100
80
60
40
20
0
0
0.5
1.0
1.5
2.0
2.5
3.0
Arundo donax (internode)
Arundo donax (node)
Gigantochloa scortechinii
Hibiscus cannabinus (bast)
Hibiscus cannabinus (core)
Miscanthus×giganteus
Panicum virgatum L.
Pinus caribaea (15-year-old)
Pinus caribaea (7-year-old)
Pinus elliotti EW ring 1
Pinus elliotti EW ring 13
Pinus elliotti LW ring 1
Pinus elliotti LW ring 13
Saccharum Officinerum-Co 89003
Pinus elliottii (10 years-old)
Pinus taeda (10 years-old)
Sugacane bagasse
Triticum aestivum pbw-3431

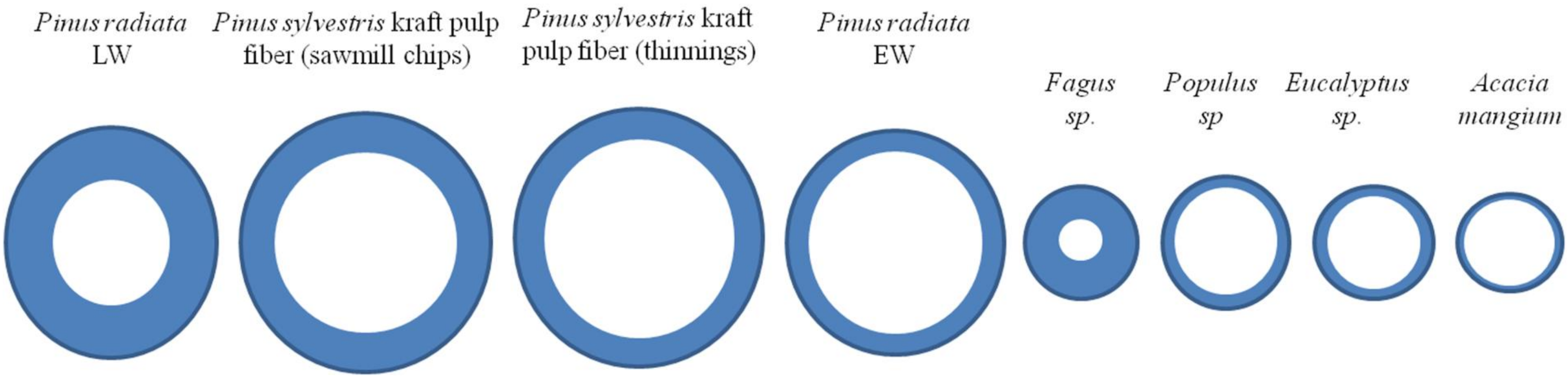
Characteristics of pulp fibres and pulp properties

- In fact, fibre properties in pulps are not directly related to fibre dimensions in the tree.
- There are a lot of factors which affect the weight and dimensions of fibres, as:
  - pulping process (mechanical, chemimechanical, semichemical and chemical pulping)
  - pulping yield
  - consistency and the intensity of refining
  - others

Fiber coarseness

- Coarseness is defined as the weight per unit length of a fiber expressed as mg per 100 m
- Accurate determination of fiber coarseness has always been difficult until the appearance of automatic measuring equipment

Fiber coarseness



Species	L (mm)	W (μm)	w (μm)	l (μm)	Coarseness (mg/100m)
Pinus radiata LW	3.00	31	7.0	17.0	26
Pinus sylvestris kraft pulps (sawmill chips)	2.42	35	6.1	22.8	25
Pinus sylvestris kraft pulps (thinnings)	1.87	35	5.1	24.8	18
Pinus radiata EW	3.10	31	4.0	23.0	16
Fagus sp.	1.30	15	5.0	5.0	12
Populus sp.	0.90	16	2.6	10.8	7.0
Eucalyptus sp.	0.74	15	2.7	9.5	6.0
Acacia mangium	0.65	14	2.0	10.1	4.6

Fiber coarseness

- Fiber coarseness serves as a predictor of mechanical properties only when considering the same kind of pulp or pulps from similar species.
- It is ideal for monitoring or control of a process in the factory, since any significant alteration in the process could alter the weight of the fibre.
- However, it cannot be used to compare raw materials, or to establish the suitability of species to papermaking.

CONCLUSIONS

- The proliferation of plantations has marked the last decade and it is expected to be continued and intensified in the near future.
- The remarkable increase of forest genetic breeding assays, generally aimed at increasing productivity and shortening the age of rotation, makes trees entering the mill possess an <u>increasingly important proportion of juvenile wood</u>.

CONCLUSIONS

- With some exceptions, especially in very aged trees (with strong duraminization), characteristics of juvenile wood are:
  - lower density
  - shorter and wider fibers
  - highest microfibrilar angle than mature wood.

CONCLUSIONS

- This produces alterations on yield and on intrinsic strength, elongation, and shrinkage of fibers.
- Juvenile wood fibers have characteristics that:
  - reduce the quality of chemical pulps
  - could be suitable for mechanical pulps.
- Juvenile wood is recommended in cases where raw materials have <u>thick fibers</u>.

CONCLUSIONS

- In this survey of more than a decade, it has been found that the suitability of new species for papermaking is being continuously testing, particularly in the Middle East and Asia.
- From the appearance of the automatic equipments for fibrous parameter determination, they have undergone a revival.
  - These devices have certainly facilitated the determination of the monitoring characteristics of pulping and refining processes, such as coarseness, curl, kink etc.

CONCLUSIONS

- Runkel ratio combined with Felting index remain the more relevant and more used fibrous relationships in the assessment of the fibers.
- Most other relations are redundant.

CONCLUSIONS

- Gathered data show that pines have:
  - Runkel ratios between 0.2 and 0.5
  - Very variable Felting index:
    - lower than 50 for Caribbean pine,
    - 50 to 60 for Brazilian pine (Sao Paulo)
    - 80 to 100 for Argentina (Northeast) pines
      - these data are isolated, and cannot be taken as reference.

CONCLUSIONS

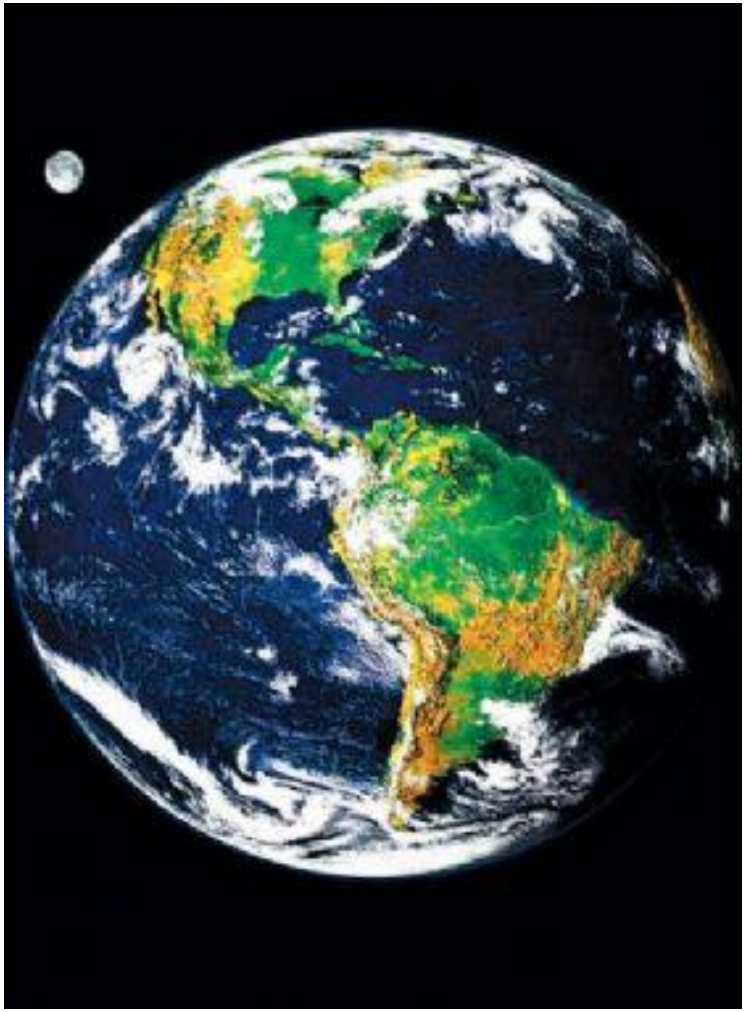
- Most hardwood species currently in commercial use (eucalyptus and hybrid of willows and poplars) have:
  - Runkel ratios between 0.5 and 1
  - Felting index between 50% and 70%
    - which deviates from the premises established in the '60s.

CONCLUSIONS

- Most nonwood recently tested possesses:
  - Runkel ratios between 1 and 2
  - Felting index between 60 and 100.
    - Fibers from sugar cane bagasse (widely used for paper production in Central and South America) reported in this work, fall within these ranges.

Extracted and adapted from:

Area, M.C. "Updating the knowledge about the relationship between fibers characteristics and pulp properties", Chapter 8 in: Pulp Production and Processing: From papermaking to high-tech products. Valentin Popa (Ed.). Smithers Rapra Publishing House, Singapore. 2012. (In press)



¡GRACIAS!
Obrigada!
Thanks!