Contents

1	Wood Variation and Wood Properties	
1.1	What Is Wood?	1
1.2	Kinds of Trees and the Wood Produced by Them	3
1.3	Important Wood Properties	6
1.4	Wood Specific Gravity (Wood Density)	8
	1.4.1 What Determines Wood Specific Gravity?	9
	1.4.2 The Importance of Specific Gravity	15
1.5	Cell Length	18
1.6	Other Wood Characteristics	20
1.7	Cell Chemistry	23
1.8	Factors Controlling Wood Properties	25
	1.8.1 The Change from Earlywood to Latewood	26
1 .9	Different Woody Tissues	28
	1.9.1 Reaction Wood	29
	1.9.2 Juvenile Wood	30
1.10	Relationships Among Wood Properties	30
1.11	The Literature Related to Wood Variation	32
2	The Effect of Provenance Variation and Exotic	
	Plantations on Wood Properties	
2. 1	The Effect of Differing Environments on Wood	
	Properties	33
2.2	Provenance Variation in Wood from Natural Stands	
	Within the Range of a Species	37
	2.2.1 Examples of Provenance Variation in Wood	
	Properties in Natural Stands	38
	2.2.2 A Summary of Provenance Variability in Wood	
	from Natural Stands	46
2.3	Wood Variation Related to Species and Provenance in	
	Plantation-Grown Trees	47
	2.3.1 Examples of the Effect of Provenance upon	
	Wood Properties of Trees in Plantations	49
2.4	Wood Properties of Trees Grown as Exotics	56
	2.4.1 General Considerations	56
	2.4.2 Changes of Wood Properties in Exotics	58
	2.4.3 Wood Properties of Exotic Conifers – General.	58
	2.4.3.1 The Tropical Pines – Pinus caribaea Example	59
	2.4.3.2 Conifers from Temperate Regions	65
	2.4.3.3 Summary – Wood Properties of Exotic Conifers	66
	2.4.4 Wood Properties of Exotic Hardwoods	67



	2.4.4.1 Exotic Hardwoods Other than <i>Eucalyptus</i>	68
	2.4.4.2 Wood of <i>Eucalyptus</i> When Grown as an Exotic	69
3	Variation Within and Among Trees	
3.1	Introduction	72
3.2	Tree to Tree Variability	73
3.3	Variation of Wood Properties Within Trees	77
	3.3.1 Wood Differences Within Annual Rings	78
	3.3.2 Wood Variability at Different Locations Within a	
	Tree	81
3.4	The Juvenile Wood Concept	82
	3.4.1 Occurrence of Juvenile Wood	83
	3.4.2 Juvenile Wood and Growth Rate	87
	3.4.3 Importance of Juvenile Wood	87
	3.4.4 The Properties of Juvenile Wood	91
	3.4.5 Can the Amount of Juvenile Wood Be Changed?	94
	3.4.6 Utilization of Juvenile Wood	95
	3.4.7 Summary of Juvenile Wood	99
3.5	Variation from the Tree Center to the Bark	100
	3.5.1 Radial Trends in Wood Properties of Conifers	101
	3.5.1.1 The Hard Pines – Specific Gravity	102
	3.5.1.2 Other Conifers – Specific Gravity	107
	3.5.1.3 Radial Changes in Conifer Wood of Properties	
	Other than Specific Gravity	107
	3.5.2 Radial Trends in Hardwoods	109
	3.5.2.1 Specific Gravity	109
	3.5.2.2 Other Wood Characteristics	113
3.6	Variation from the Base to the Top of the Tree	113
	3.6.1 Breast Height to Total Tree Correlations	119
3.7	The Effect of Total Tree Age on Wood	125
	Wood Descents Variation of Delated to Theo Form and	
4	Reaction Wood	
4.1	Introduction	132
4.2	Wood Properties Associated with Poor Tree Form	132
	4.2.1 Solid Wood Products	134
	4.2.2 Fiber Products	137
	4.2.2.1 The Effect of Limbs Upon Fiber Products	138
43	Reaction Wood	141
1.5	4.3.1 Compression Wood – Conifers	143
	4.3.1.1 Characteristics of Compression Wood	145
	4.3.1.2 Effects of Compression Wood	145
	4.3.2 Tension Wood – Hardwoods	147
	4.3.2.1 Characteristics of Tension Wood	148
	4.3.2.2 Effects of Tension Wood	148
4.4	Methods to Improve Tree Form	149
	4.4.1 Better Forest Management	149

	4.4.2	Use of the Proper Seed Source	150
	4.4.3	Breeding for Branching Characteristics and Bole	
		Straightness	151
	4.4.3.1	Summary of Form Improvement Through	
		Genetics and Silviculture	156
5	The Ef	fect of Growth Rate on Wood Properties	
5.1	Introdu	iction	157
	5.1.1	Patterns in Wood Production Resulting from	
		Growth Rate Differences	159
	5.1.1.1	Growth Rate – Wood Property Grouping of	
		Forest Trees	1 60
	5.1.2	Literature on Growth Rate and Wood Properties .	161
5.2	Growth	n Rate and Wood Specific Gravity in Conifers	162
	5.2.1	Growth Rate – Specific Gravity Relationship in	
		the Hard Pines	165
	5.2.1.1	Summary – Specific Gravity and Growth	
		Relationships in Hard Pines	168
	5.2.2	Growth Rate – Specific Gravity Relationships in	4.50
		Other Conifers	170
5.3	Growt	h Rate and Wood Specific Gravity in Hardwoods .	1/3
	5.3.1	Specific Gravity and Growth Rate in Ring-Porous	174
	522	Hardwoods	1/4
	5.3.2	Specific Gravity and Growth Rate in Diffuse-	175
5 1	Summ	rolous Haldwoods	178
5.4		horosteristics and Growth Rate	180
5.5	551	Summary of the Relation of Cell Length to	100
	5.5.1	Growth Rate	181
56	Growt	h Rate and Aesthetic Qualities of Wood	185
5.7	Practic	cal Application of Wood Changes Caused by	
211	Growt	h Rate Differences	1 86
	**/ 1	Design Affected by Environmental Dislocical	
0	and O	ther External Agencies	
61	Introd	uction	189
62	Effect	of Site Soil, and Climate on Wood Properties	189
0.2	6.2.1	Soil Properties and Wood	194
	6.2.2	Summary – Effect of Site, Soil, and Climate on	
		Wood Properties	195
6.3	Moist	ure Availability and Wood Properties	197
	6.3.1	Moisture Effects on Wood – A Summary	203
6.4	Miscel	llaneous Biological Factors that Affect Wood	
	Proper	rties	204
	6.4.1	Forest Pests and Wood	204
	6.4 .1.1	Disease and Wood Properties	204
	6.4.1.2	2 The Influence of Insects on Wood	208

	6.4.1.3	Effects of Other Pests on Wood Properties	210
	6.4.2	Compass Direction in the Tree Stem	211
	6.4.3	Temperature, Light, and Wood Production	213
	6.4.4	Position of the Tree in the Stand	214
6.5	Unusua	al Causes for Wood Variability	215
6.6	Growth	Stresses and Strains in Tree Stems	216
7	The Ef	fect of Silvicultural Practices on Wood Properties	
7.1	Introdu	iction	218
7.2	Effect	of Nutrient Differences and Fertilization on Wood	220
	7.2.1	Fertilizing Conifers	223
	7.2.2	Fertilizing Hardwoods	229
	7.2.3	Wood Uniformity Following Fertilization	231
7.3	Tree Sr	pacing and Wood Properties	231
	7.3.1	Stocking Control by Thinning as Related to	
		Wood Properties	232
	7.3.2	Plantation Spacing and Wood Properties	238
7.4	Effect	of Pruning on Wood	241
	7.4.1	Direct Effect of Pruning on Wood Properties	241
	7.4.2	Pruning to Improve Tree Form and Quality	243
	7.4.3	Other Considerations About Pruning	245
7.5	Plantin	g Techniques and Wood Properties	245
7.6	Resin 7	Tapping, Resin Induction, and Wood Properties	246
7.7	Wood	Properties of Coppice and Root Sprouts	247
	noou		
8	Contro	l of Wood Properties by Breeding	
8.1	Geneti	cs of Wood Properties	249
	8.1.1	What Are Genetic Differences and How Are They	
		Measured?	250
	8.1.1.1	Types of Genetic Variation	250
	8.1.1.2	What Kind of Tests Are Necessary to Determine	
	011112	Genetic Variation?	252
	8.1.1.3	How Is Genetic Control Measured?	253
8.2	Geneti	c Control of Wood Specific Gravity	255
	8.2.1	What Are the Components of Wood Specific	
		Gravity?	255
	8.2.2	Inheritance of Wood Specific Gravity in Conifers	255
	8.2.2.1	Genetic Variation Among Provenances	255
	8.2.2.2	Stand to Stand Variation in Specific Gravity	257
	8.2.2.3	Tree to Tree Variation in Specific Gravity	258
	8.2.3	Inheritance of Wood Specific Gravity in	
	01210	Hardwoods	261
8.3	Geneti	c Control of Wood Properties Other than Specific	
0.0	Gravity		262
	8.3.1	Latewood Percent	264
	8.3.2	Cell Length	265
	8.3.3	Tracheid Diameter and Wall Thickness	268
	····		

r

0.4	8.3.4 8.3.5 8.3.6	Chemical Composition Spiral Grain Other Wood Properties	268 271 272
8.4	8.4.1	Genetic Relationships Between Specific Gravity	213
		and Growth Traits	276
	8.4.2	Relationships Between Wood Specific Gravity and	
		Its Components	279
	8.4.3	Relationships Among Other Wood Properties	28 1
8.5	Contro	olling Wood Properties by Breeding	283
	8.5.1	Breeding for Wood Specific Gravity	286
	8.5.2	Breeding for Other Wood Properties	287
	8.5.3	How Are Genetic Gains Obtained Operationally?	288
8.6	Summa	ary	289
9	Future	Importance of Knowing and Manipulating Wood	
	Variab	ility	
9. 1	Genera	al Concepts	291
9.2	The N	eed for Wood Improvement	294
9.2	The N 9.2.1	eed for Wood Improvement A Specific Need – Uniformity	294 296
9.2	The N 9.2.1 9.2.2	eed for Wood Improvement A Specific Need – Uniformity Possibilities and Trends for Changing Wood	294 296 298
9.2 9.3	The N 9.2.1 9.2.2 Wood	eed for Wood Improvement A Specific Need – Uniformity Possibilities and Trends for Changing Wood Properties Related to Product Quality –	294 296 298
9.2 9.3	The N 9.2.1 9.2.2 Wood The Fr	eed for Wood Improvement A Specific Need – Uniformity Possibilities and Trends for Changing Wood Properties Related to Product Quality – uture	294 296 298 303
9.2 9.3 9.4	The N 9.2.1 9.2.2 Wood The Fu Nonco	eed for Wood Improvement A A Specific Need – Uniformity Description Possibilities and Trends for Changing Wood Description Properties Related to Product Quality – Description Iture Description Inventional Wood Products Description	294 296 298 303 305
9.2 9.3 9.4 9.5	The N 9.2.1 9.2.2 Wood The Fu Nonco Summ	eed for Wood ImprovementA Specific Need – UniformityPossibilities and Trends for Changing WoodProperties Related to Product Quality –aturenventional Wood Productsary	294 296 298 303 305 307
 9.2 9.3 9.4 9.5 	The N 9.2.1 9.2.2 Wood The Fu Nonco Summ	eed for Wood Improvement A Specific Need – Uniformity Possibilities and Trends for Changing Wood Properties Related to Product Quality – uture nventional Wood Products ary	294 296 298 303 305 307
 9.2 9.3 9.4 9.5 Refe 	The N 9.2.1 9.2.2 Wood The Fi Nonco Summ	eed for Wood Improvement A Specific Need – Uniformity Possibilities and Trends for Changing Wood Properties Related to Product Quality – ature inventional Wood Products ary	294 296 298 303 305 307 311
 9.2 9.3 9.4 9.5 Refe 	The N 9.2.1 9.2.2 Wood The Fu Nonco Summ rences.	eed for Wood Improvement A Specific Need – Uniformity Possibilities and Trends for Changing Wood Properties Related to Product Quality – uture onventional Wood Products ary	294 296 298 303 305 307 311
 9.2 9.3 9.4 9.5 Refe Subj 	The N 9.2.1 9.2.2 Wood The Fu Nonco Summ rences.	eed for Wood Improvement A Specific Need – Uniformity Possibilities and Trends for Changing Wood Properties Related to Product Quality – nture Proventional Wood Products ary Product Quality –	294 296 298 303 305 307 311 351
9.2 9.3 9.4 9.5 Refe Subj	The N 9.2.1 9.2.2 Wood The Fu Nonco Summ rences.	eed for Wood Improvement A Specific Need – Uniformity Possibilities and Trends for Changing Wood Properties Related to Product Quality – nuture Products ary Products ex Product	294 296 298 303 305 307 311 351