GROWTH DYNAMICS OF EASTERN REDCEDAR WOOD FRACTIONS AS A FUNCTION OF TREE AGE AND SITE

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1982

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 1995

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ACKNOWLEDGMENTS

I extend appreciation to the Department of Agronomy at Oklahoma State University for the use of facilities and equipment. I wish to thank my major adviser, Dr. D.M. Engle who has provided every opportunity possible for learning and project completion endeavor. Dr. D.M. Engle has been unwavering in his enthusiastic support over the years it has taken for completion for which I am grateful. Dr. J.F. Wittwer and Dr. S. Anderson, my committee members, have also been an encouragement and supplied many good ideas for development and culmination of my M.S. research project.

I would especially like to thank my sponsoring organization, the Norwegian Church Aid, for the financial support and encouragement provided for the completion of my studies. Special thanks to Mr. Kjell Solberg for offering me this particular opportunity. It would not have been possible to accomplish this program successfully without his support. A thanks goes to David Gay for the computer guidance and James Kulbeth who was involved in the field data collection.

Finally, I would like to extend thanks to my wife, Sister Senait Tefera, and to my children whose encouragement, love, and support made it all possible.

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CHAPTER I

SAPWOOD, HEARTWOOD, AND STEM VOLUME OF OPEN-GROWN EASTERN REDCEDAR AS A FUNCTION OF TREE AGE AND SITE

ABSTRACT

The relationships of heartwood width and sapwood width, growth rate, and stem volume with tree age were studied in 141 eastern redcedar (Juniperus virginiana L.) trees. The sample trees were selected from seven naturally open grown stands in central (loamy prairie, shallow prairie and loamy bottomland), eastern (shallow prairie), and western (sandy prairie) Oklahoma range sites with tree ages ranging from 5 to 29 years. The relationships of tree age to tree heartwood and sapwood width, and stem volume differed with range site. On average, heartwood width increased with increasing tree age from 10 mm in fifteen year old trees to 210 mm in twenty-seven year old trees. The width of sapwood and rate of transformation of sapwood into heartwood was slow up to 15 years of age and increased thereafter at an exponential rate until about age 27. Trees up to 15 years old in western Oklahoma had smaller heartwood width than trees of the same age on other sites. Stem volume increased markedly in trees greater than 15 years old. These data indicate that any control measures applied to invading eastern redcedar should be taken when the trees are less than 15 years old or less than 2 m tall. Once the trees are older than 15 years or taller than 2 m, then allowing the trees to grow for commercial harvest should be considered as a management alternative. Tree age and range site are important factors determining heartwood and sapwood width, and stem volume of eastern redcedar.

INTRODUCTION

Eastern redcedar (Juniperus virginiana L.) is the eastern most juniper represented in North America and is indiginous to every state east of the 100th meridian (Van Haverbeke and Read 1976). The encroachment of eastern redcedar in the central United States, particularly in the tallgrass prairie of Oklahoma, is very extensive and reduces forage production for domestic livestock (Engle and Kulbeth 1992). The increase in the population and distribution of this species has interfered with the traditional uses of rangelands, primarily livestock grazing. Although trees up to 1m tall can be controlled effectively with prescribed fire at a reasonable cost (Bidwell and Mosely 1989), tree kill declines rapidly as tree height increases above 2 m (Martin and Crosby 1955, Buehring et al. 1971, Owensby et al. 1973, Engle et al. 1988).

Despite its invasive character, eastern redcedar presents a potential income source for Oklahoma landowners. The wood is highly valued because of its beauty, durability, and workability. As a result a fledgling industry has been established in Oklahoma around the harvesting and processing of eastern redcedar (Anderson and Hopper 1995). The heartwood of eastern redcedar is resistant to attack by the eastern subterranean termite Reticulitermes flavipes (McDaniel 1995) and aromatic oils repel clothing moths and their larvae (Craighead 1985). Eastern redcedar also contains oils that can be extracted commercially and are used widely in the perfume industry (Wittwer et al. 1995). Because of the dichotomy of the encroachment problem and the potential commercial value, land managers are faced with a critical decision either to control or to grow eastern redcedar as a commercial species. Knowledge of the relationship between heartwood and sapwood of eastern redcedar and how age and site influence this relationship is needed to support management decisions and to optimize management of stands of eastern redcedar in the central U.S. grasslands.

Hence, the objective of this study is to determine the growth dynamics of eastern redcedar wood fractions, particularly the heartwood and sapwood width relationship and volume, as related to tree age among major sites within Oklahoma.

MATERIALS AND METHODS

Most of the study materials were collected for use in a study on crown growth (Engle and Kulbeth 1992). Stands in central, western, and eastern Oklahoma were selected that contained a variation in size classes of open-grown eastern redcedar. The western Oklahoma stand was located in Major County on a Dill fine sandy loam (coarse, loamy, mixed Typic Ustochrept) and is classified as a Sandy Prairie range site. There were two locations in central Oklahoma with two stands in each location in Payne County. Two stands at this location were on the Coyle loam soil (fine-loamy, siliceous, thermic Udic Argiustoll), classified as a Loamy Prairie range site. Two other stands at this location were on a complex of the Grainola (fine, mixed, thermic Vertic Haplustalf) and the Lucien (loamy, mixed, thermic, shallow Typic Haplustoll) soils, both classified as Shallow Prairie range site. Another stand in Payne County was on a Pulaski fine sandy loam soil (coarse-loamy, mixed, nonacid, thermic, Typic Ustifluvent), classified as Loamy Bottomland range site. The eastern Oklahoma stand was in McIntosh County, on a Taloka silt loam (fine, mixed, thermic Mollic Albaqualf), classified as a Loamy Prairie range site. Average annual precipitation is 70, 83, and 107 cm in Major County, Payne County, and McIntosh County, respectively. The actual vegetation at all locations was dominated by perennial grasses at the time of the study.

Eastern redcedar trees of different ages and sizes were sampled in June 1987 in central Oklahoma in Payne County (Loamy Prairie, Shallow Prairie, and Loamy Bottomland) and June 1988 in western Oklahoma in Major County and in eastern Oklahoma in McIntosh County (Table 1). Only those trees separated from other trees by a minimum distance of 3 m were included in the sample to minimize overlapping of spheres of influence. Trees with abnormally shaped crowns resulting from grazing injury or other influences were not sampled. Trees were cut 2 cm above the soil surface. Crown height of the cut tree was measured from the bottom of the cut trunk to the apex. Two full cross sections were removed from the trunk of each tree one at 2 cm and one at 50 cm from ground level. A radius of the 2 cm cross-section was sanded and polished to facilitate identification of annual rings. Tree age was determined on the 2 cm cross-section from ring counts as described for eastern redcedar by Kuo and McGinnes (1973) to avoid counting false rings. Bole diameter (without bark), radius of heartwood and sapwood width were measured at two locations on each 50 cm cross-section, one of those along the longest diameter with the second perpendicular to the first. Differences in the two diameter axes were rarely greater than 5%, so the average of the measurements was used in subsequent calculations (Philip 1983, Rink 1987). A formula for approximating the volume in a tree stem up to a given top diameter limit was used by combining formulas 2 and 4 from Van Deusen and Lynch (1987). The value of 'r' is not known for eastern redcedar, so a value of r=3, which is Known as Forslund's paracone (Forsllund 1982), was used because it is intermediate in shape between a standard 2°paraboloid and a cone, such that

$$V_x = \pi/40{,}000 * D^2 (T-0.02)[3/7][1-(x/D)^{7/2}]$$

Where,

V_x = cm^3 volume in the stem below a "x" cm top diameter above a 2 cm stump.

T = total height in meters from the ground to the top of the tree (the quantity (T-0.02) is the distance from the D measurement at 2 cm and the top of the tree),

D = diameter in cm of the tree stem at 50 cm above ground

x = is the top diameter limit of 10 cm

The wood fraction variables (sapwood width and heartwood width) were transformed to natural logarithms to produce homoscedasticity in the variance (Hunt 1978). The transformed variables were expressed as polynomial functions of time (i.e., age) with functions fit to the third order by least squares regression analysis. Best fit was determined from analysis of variance to minimize overfitting with a 5% level of probability for entry level of individual parameters. Same order polynomials for different locations and sites were compared using indicator variables for locations and sites (Draper and Smith 1966). Hence, functions for locations and sites with either different order polynomials or with different ($P<0.05$) indicator variables are presented separately. Absolute rate of growth of wood fractions were determined from the derivative of the respective function with respect to age. Functions were plotted in the original units of measurement by transforming the regression model.

RESULTS AND DISCUSSION

Heartwood of eastern redcedar began forming at an exponential rate at about 10 to 15 years of age (Figs. 1a and 1b). Heartwood development starts earlier in central and eastern sites, but the rate of development is slower (Fig. 2a). Heartwood starts later in west, but rate is faster (Fig. 2b). In contrast, the maximum growth rate was only 15 mm heartwood width yr^{-1} at an age of 24 years in central and eastern Oklahoma (Fig. 2a) compared to 22 mm heartwood width yr^{-1} at an age of 27 in western Oklahoma (Fig. 2b). Hence, little overall difference in the accumulation of heartwood occurred between the western sandy prairie and other range sites in 29-year-old trees. The average annual growth rate of heartwood width in western and in central and eastern Oklahoma was 6 mm yr^{-1} and 7 mm yr^{-1}, respectively.

The sandy surface soil texture and lower precipitation may contribute to an initial slow formation of heartwood in western Oklahoma. Tree height and crown area also had slow rates of growth in western Oklahoma (Engle and Kulbeth 1992). As compared to central and eastern Oklahoma range sites, root and seedling growth at the western Oklahoma location were slower possibly because of poor water holding capacity of the soil and limited available soil moisture in the surface horizon. Heartwood width growth on the western Oklahoma range site accelerated rapidly after age 15 (Fig. 2b), possibly coincident with the roots of trees gaining access to additional water at lower levels in the soil profile. The rapid increase of heartwood formation after age 15 suggest that land managers should consider growing eastern redcedar for commercial value.

Except in the central Oklahoma loamy bottomland (Fig. 3b) the sapwood width growth pattern was sigmoid (Fig. 3a and 3c). Similarly, in Norway spruce (Picea abies), sapwood thickness increased curvilinearly with tree age attaining constant values after the age of 30 years (Sellin 1991). The decline in growth rate of sapwood in older trees might be correlated with the narrower growth rings produced in older trees. Within a species the width of sapwood is directly related to dominance of the tree in the stand. Also the sapwood is widest in the upper trunk toward the crown, and sapwood decreases in width towards the base (Wyssling and Bosshard 1959).

The maximum growth rate of sapwood width in central and western and in eastern Oklahoma was 5 mm yr^{-1} and 7 mm yr^{-1} at 17 years of age, respectively (Figs. 4a and 4c). In contrast, the rate of growth of sapwood in trees in central Oklahoma loamy bottomland increased linearly with age with growth rate of 4 mm yr^{-1} (Fig. 4b). Trees in central Oklahoma Loamy bottomland are 14 to 29 years old, larger on average in height and wider in bole diameter as compared to other central Oklahoma and western Oklahoma range sites.

The process of sapwood formation and process of sapwood to heartwood transformation are counter to each other in the accumulation of sapwood (i.e., sapwood width). Sapwood formation is primarily under genetic control but it is also affected by various environmental factors such as precipitation, temperature, and site (Lassen & Okkonen 1969, Hillis and Ditchburne 1974). Good site conditions (e.g., sufficient and evenly distributed precipitation, low stand density, good soil depth) are conducive to formation of wider growth rings of sapwood at early stages before the heartwood appears

(Whitehead 1978). At these early growth stages, larger sapwood width is related to wider crowns and higher leaf areas typical of better sites (Whitehead 1978). But, because sapwood parenchyma is the storage tissue in the trunk, trees on good sites accumulate more food substances that contribute to the transformation of sapwood to heartwood width during high water loss (Whitehead 1978). On poorer sites, however, higher rates of water loss from the inner rings into the outer rings and lower site fertility can contribute to slower transformation of sapwood into heartwood and smaller heartwood width (Whitehead 1978).

The transformation of sapwood into heartwood is a metabolic change influenced by age, species, and environment. The formation of heartwood occurs after a certain stage of growth, depending on the species (Hills and Ditchburne 1974). This change is accompanied in varying degrees by a decrease in water content, an increase in extractives content, death of parenchyma cells, and a decrease in permeability within the cell (Hills and Ditchburne 1974). Jorgsen (1962) suggested that heartwood is formed in live sapwood by a change in metabolic rates and a decrease in enzymatic activity resulting in a change in wood density and coloration of heartwood. As the trees ages , the photosynthetic output declines slightly with increasing difficulty in the translocation of food, water, and minerals, while respiratory consumption of food increases appreciably (Kramer and Kozlowski 1979).

Marked differences in potential of marketable timber occur among range sites in Oklahoma (Fig. 5). Trees just less than 30 years old produced about 1000 cm^3 of stem volume on western Oklahoma and about 2500 cm^3 on the upland range sites of central

Oklahoma compared to about 4000 cm^3 on eastern Oklahoma shallow prairie. Unfortunately, the largest area of eastern redcedar occuring on Oklahoma rangelands is on uplands of central Oklahoma (Snook 1985). The low growth rate in stem volume for young trees in all stands of Oklahoma (Fig. 5a) mirrors the slow growth rate of heartwood and stem volume in trees up to 15 to 20 years of age (Figs. 2 and 6). Once trees are over 20 years of age, a remarkable increase in stem volume occurs (Fig. 6a-d) that has implications to commercial values of the trees. Moreover, the growth rate of stem volume in all stands of Oklahoma increased continuously up to 29 years of age (Figs. 6a and 6c). Variation of volume among sites appears to be related primarily to differences in soil type and climatic zone in these open grown stands. Competition in closed stands would alter stem volume (Ferguson 1968) as well as the influence of soil type and climate.

CONCLUSIONS

Tree age is the key factor influencing heartwood and sapwood width and stem volume of eastern redcedar. Range site, as an integrating environmental factor, also significantly influences the relationship between heartwood and sapwood width, and stem volume of eastern redcedar. Our data indicate that the ratio of heartwood width and sapwood width in eastern redcedar in Oklahoma is strongly influenced by effective precipitation, but heartwood formation in eastern redcedar is primarily an age-related process.

Control of eastern redcedar should be made before trees reach 10 to 15 years of age because tree kill declines rapidly at tree heights above 2 m (Engle et al. 1988) or when trees reach ages 8 to 14 years (Engle and Kulbeth 1992). Our findings suggest that once trees reach exponential rates of growth of heartwood and sapwood width, which occurs about the same time trees reach 2 m in height, managers should consider the value of growing eastern redcedar for commercial benefits compared to the value associated with cost in control measures especially on higher potential sites. As such, eastern redcedar represents a potential resource for economic development in the rural areas of Oklahoma and the central grasslands of the United States.

Fig. 1. Eastern redcedar heartwood width at 50 cm bole height as a function of tree age in 7 stands and 5 range sites in Oklahoma.

(a) central Oklahoma loamy prairie (LoPr central) 2 stands, central Oklahoma shallow prairie (ShPr central) 2 stands, central Oklahoma loamy bottomland (LoBo central), and eastern Oklahoma shallow prairie (ShPr eastern) and (b) western Oklahoma sandy prairie (SaPr west).

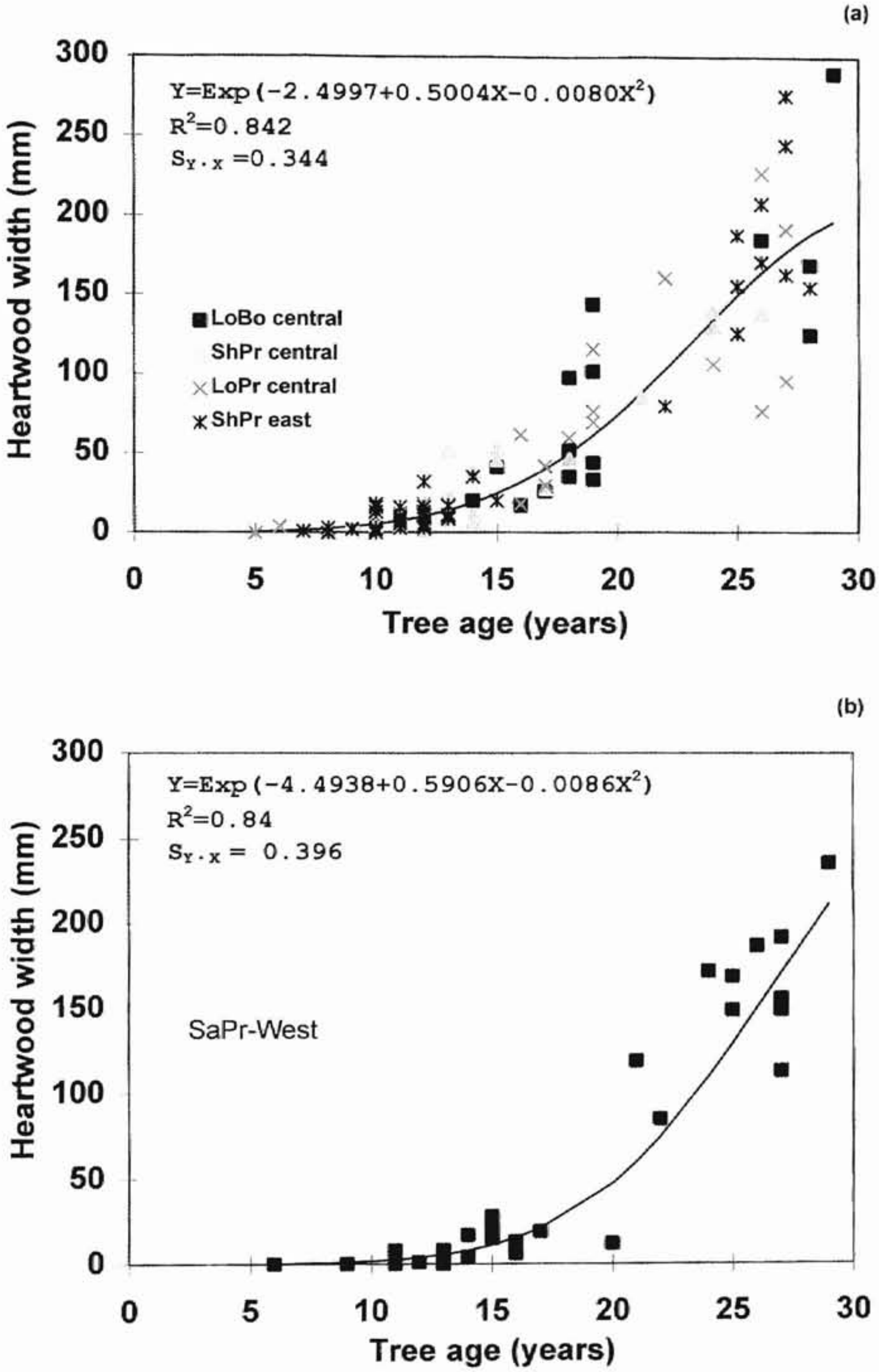
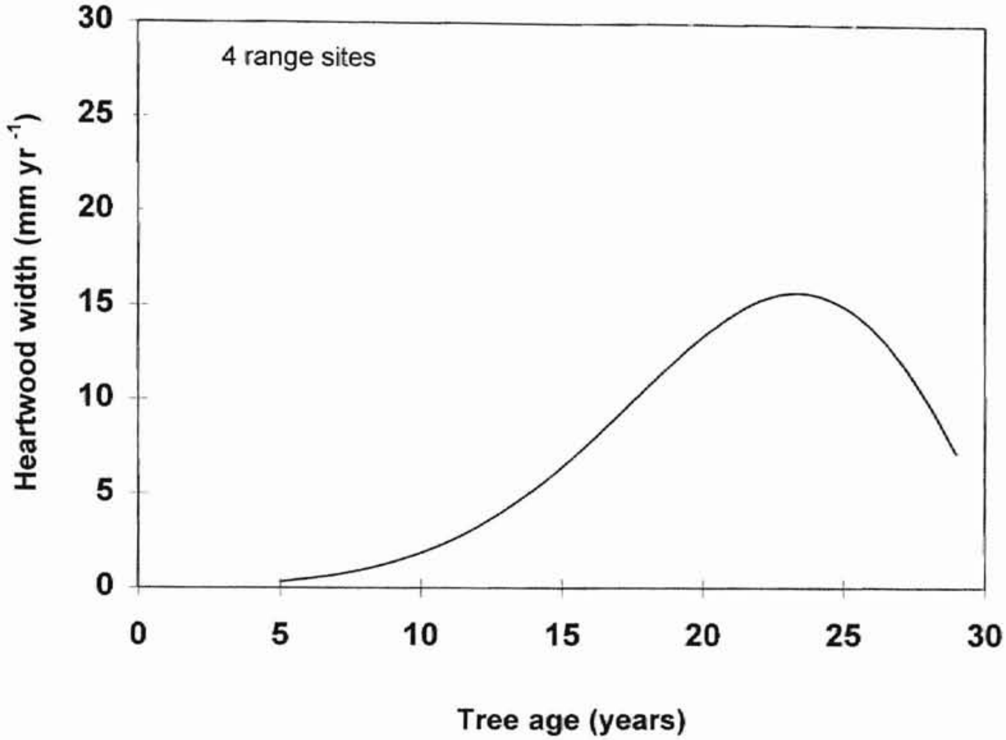

(a)
Y=Exp(-2.4997+0.5004X-0.0080X²)
R²=0.842
S_Y.X =0.344
LoBo central
ShPr central
LoPr central
ShPr east
Heartwood width (mm)
Tree age (years)
0
50
100
150
200
250
300
0
5
10
15
20
25
30
(b)
Y=Exp(-4.4938+0.5906X-0.0086X²)
R²=0.84
S_Y.X = 0.396
SaPr-West
Heartwood width (mm)
Tree age (years)
0
50
100
150
200
250
300
0
5
10
15
20
25
30

Fig. 2. Growth rate of heartwood width at 50 cm bole height in eastern redcedar as a function of tree age in 7 stands and 5 range sites in Oklahoma.

(a) central Oklahoma loamy prairie, central Oklahoma shallow prairie , central Oklahoma loamy bottomland; and eastern Oklahoma shallow prairie; (b) western Oklahoma sandy prairie.

(a)


4 range sites
Heartwood width (mm yr $^{-1}$)
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Tree age (years)

(b)

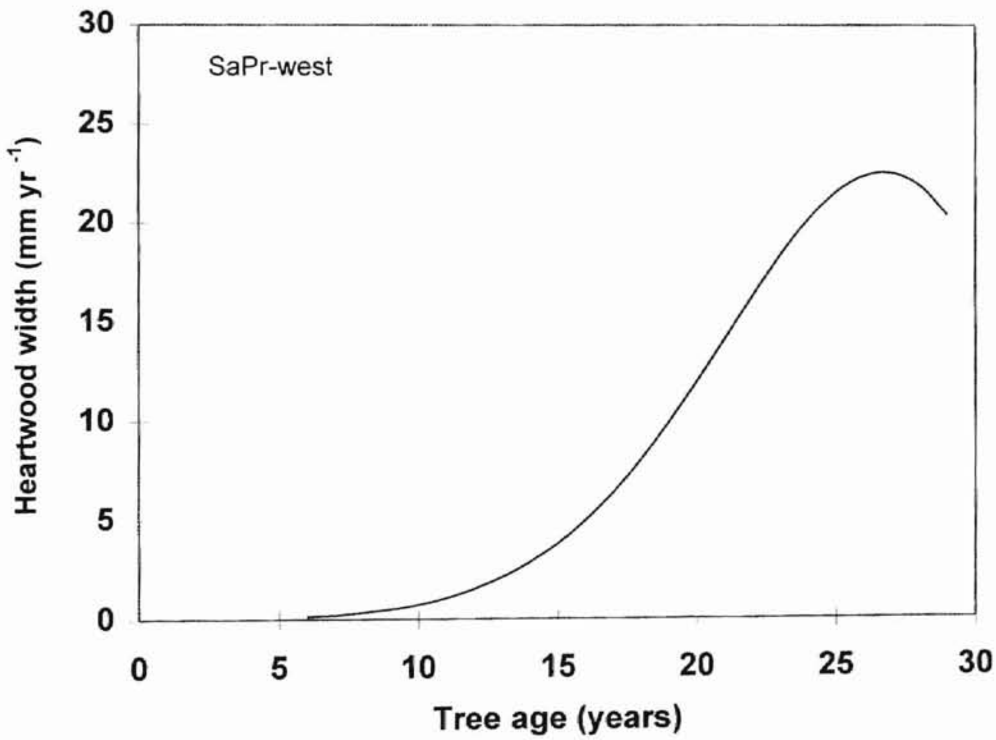

SaPr-west
Heartwood width (mm yr $^{-1}$)
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Tree age (years)

Fig. 3. Eastern redcedar sapwood width at 50 cm bole height as a function of tree age in 5 stands and 5 range sites in Oklahoma.

(a) central Oklahoma loamy prairie (LoPr central) 2 stands, central Oklahoma shallow prairie (ShPr central) 2 stands, western Oklahoma sandy prairie (SaPr west); (b) central Oklahoma loamy bottomland (LoBo central); and (c) eastern Oklahoma shallow prairie (ShPr east).

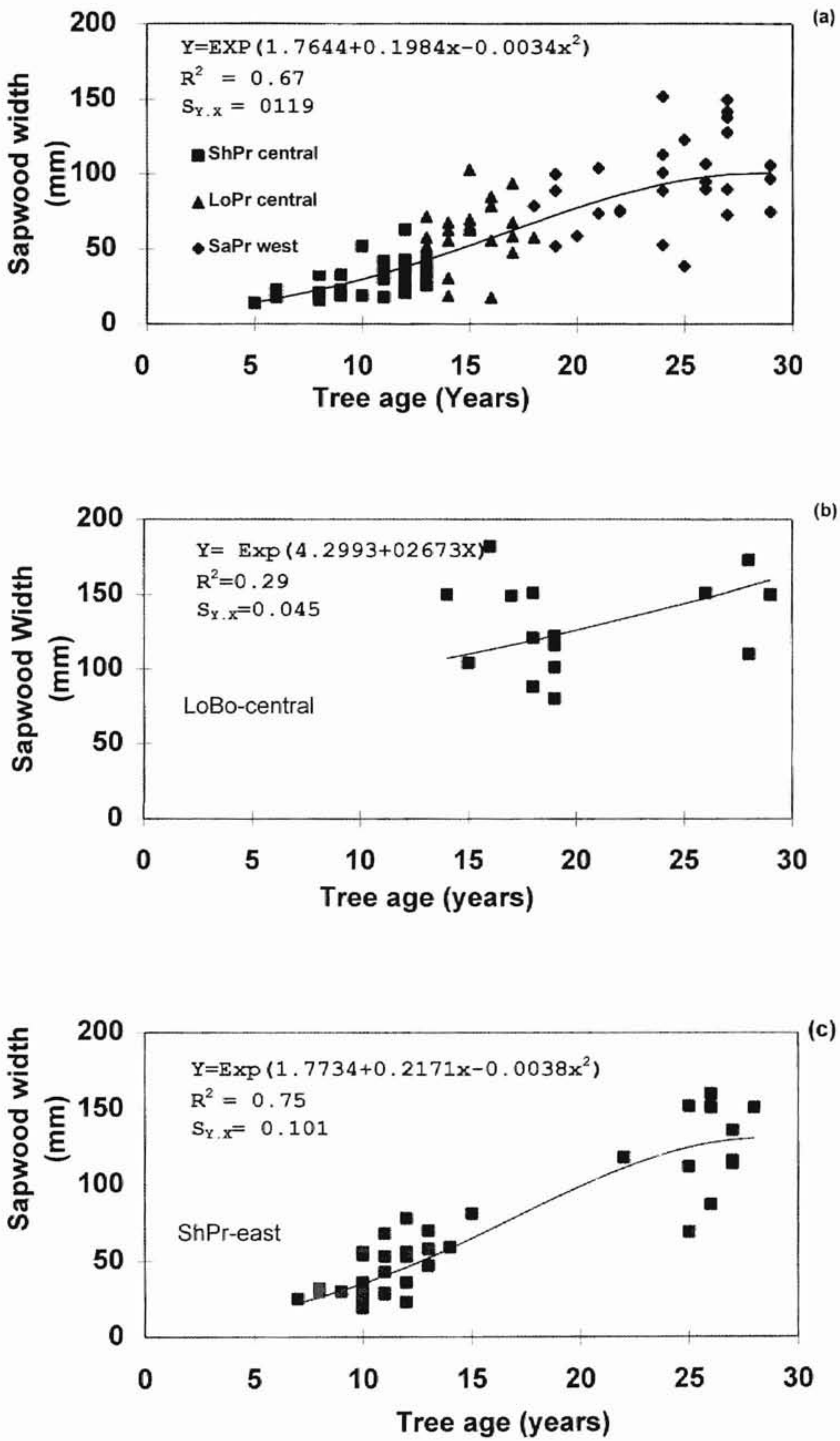
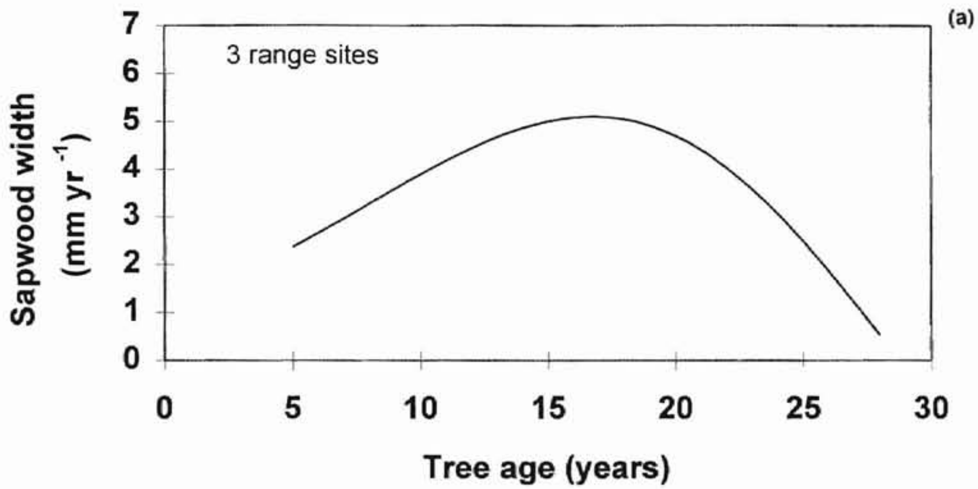
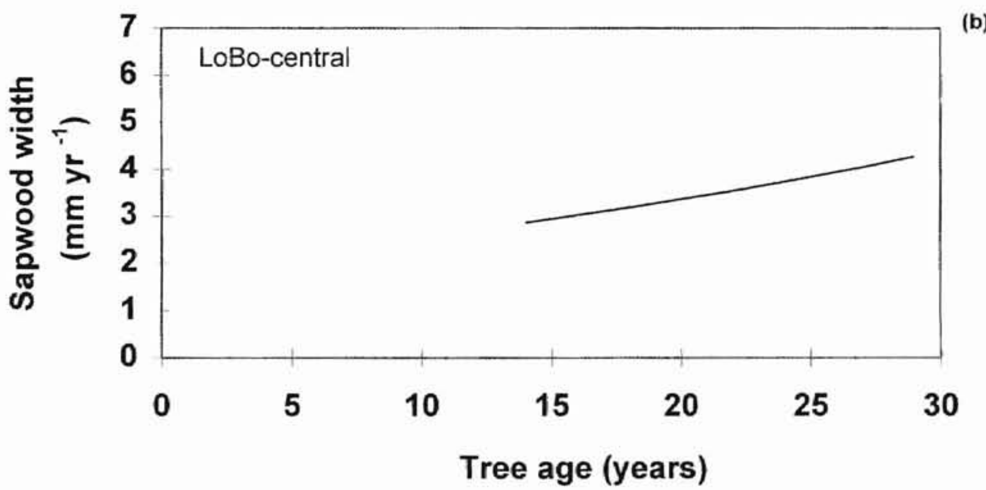

(a)
Y=EXP(1.7644+0.1984x-0.0034x²)
R² = 0.67
SY.X = 0119
ShPr central
LoPr central
SaPr west
Sapwood width (mm)
200
150
100
50
0
0
5
10
15
20
25
30
Tree age (Years)
(b)
Y= Exp(4.2993+02673X)
R²=0.29
SY.X=0.045
LoBo-central
Sapwood Width (mm)
Tree age (years)
(c)
Y=Exp(1.7734+0.2171x-0.0038x²)
R² = 0.75
SY.X= 0.101
ShPr-east
Sapwood width (mm)
Tree age (years)

Fig. 4. Growth rate of eastern redcedar sapwood width at 50 cm bole height as a function of tree age in 5 stands and 5 range sites in Oklahoma.

(a) central Oklahoma loamy prairie, central Oklahoma shallow prairie, and western Oklahoma sandy prairie; (b) central loamy bottomland, and (c) eastern Oklahoma shallow prairie.


(a)
3 range sites
Sapwood width (mm yr^{-1})
Tree age (years)
0
1
2
3
4
5
6
7
0
5
10
15
20
25
30


(b)
LoBo-central
Sapwood width (mm yr^{-1})
Tree age (years)
0
1
2
3
4
5
6
7
0
5
10
15
20
25
30

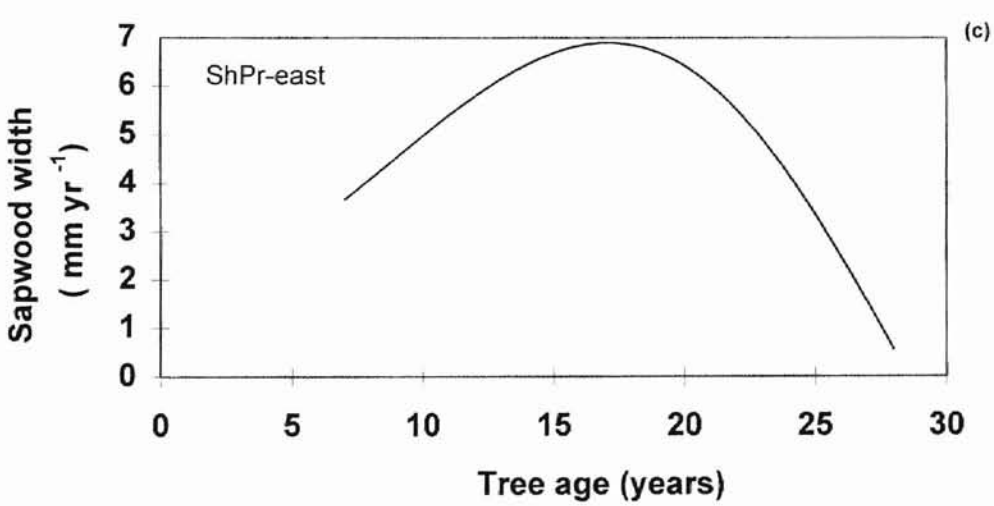

(c)
ShPr-east
Sapwood width (mm yr^{-1})
Tree age (years)
0
1
2
3
4
5
6
7
0
5
10
15
20
25
30

Fig. 5. Eastern redcedar marketable stem volume as a function of tree age in 4 stands and 4 range sites.

(a) western Oklahoma sandy prairie; (b) central Oklahoma loamy prairie (LoPr central); and central Oklahoma shallow prairie (ShPr central) 4 stands; and, (c) eastern Oklahoma shallow prairie; and (d) central Oklahoma loamy bottomland.

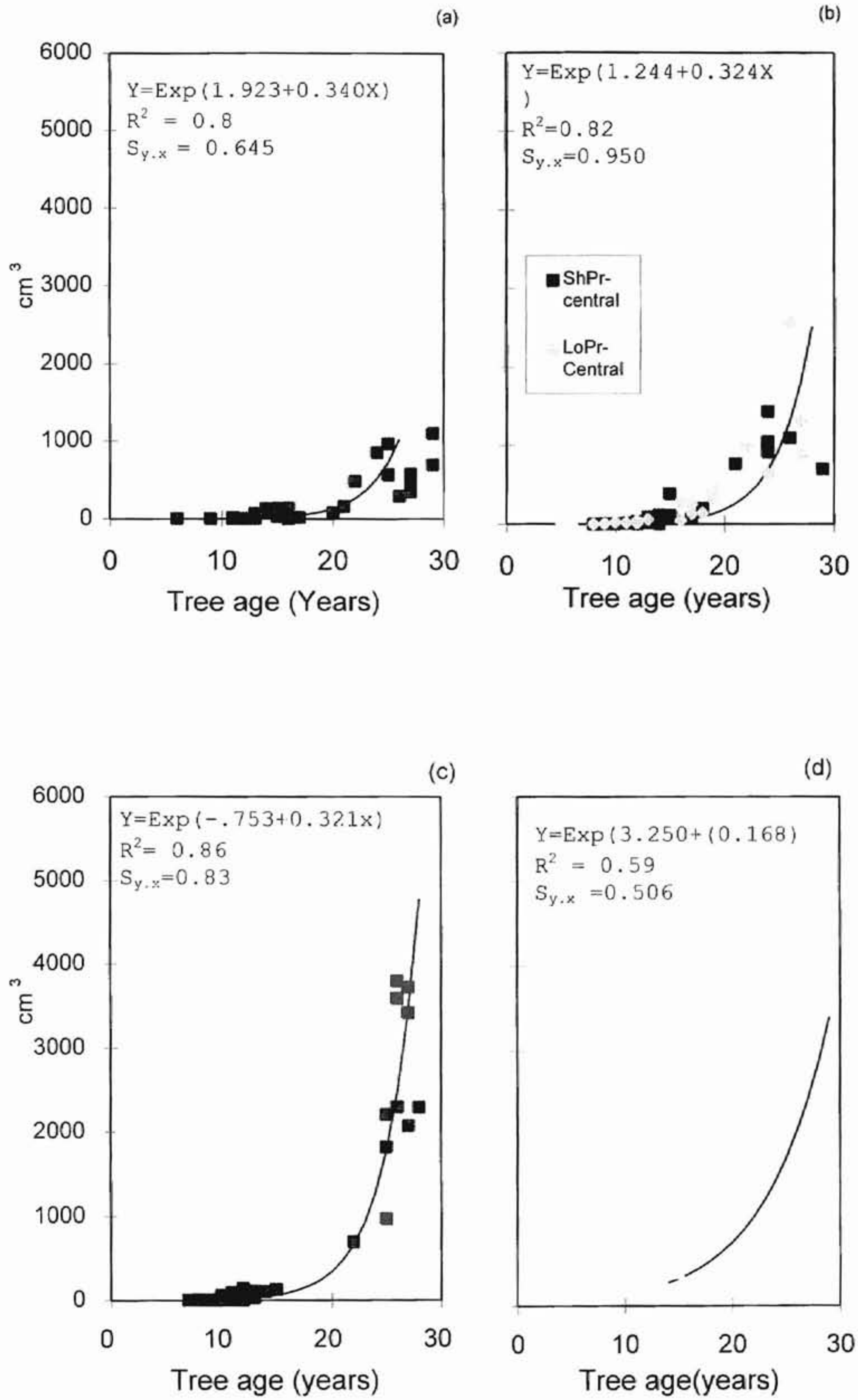

(a)
Y=Exp(1.923+0.340X)
R^2 = 0.8
Sy.x = 0.645
6000
5000
4000
3000
2000
1000
0
cm 3
0
10
20
30
Tree age (Years)
(b)
Y=Exp(1.244+0.324X
)
R^2=0.82
Sy.x=0.950
ShPr-
central
LoPr-
Central
0
10
20
30
Tree age (years)
(c)
Y=Exp(-.753+0.321x)
R^2= 0.86
Sy.x=0.83
6000
5000
4000
3000
2000
1000
0
cm 3
0
10
20
30
Tree age (years)
(d)
Y=Exp(3.250+(0.168)
R^2 = 0.59
Sy.x =0.506
0
10
20
30
Tree age(years)

Fig. 6. Growth rate of stem volume as a function of tree age in 4 stands and 4 range sites in Oklahoma.

(a) western Oklahoma sandy prairie; (b) central Oklahoma loamy prairie and central Oklahoma shallow prairie(4 stands); (c) eastern Oklahoma shallow prairie; and (d) central Oklahoma loamy bottomland.

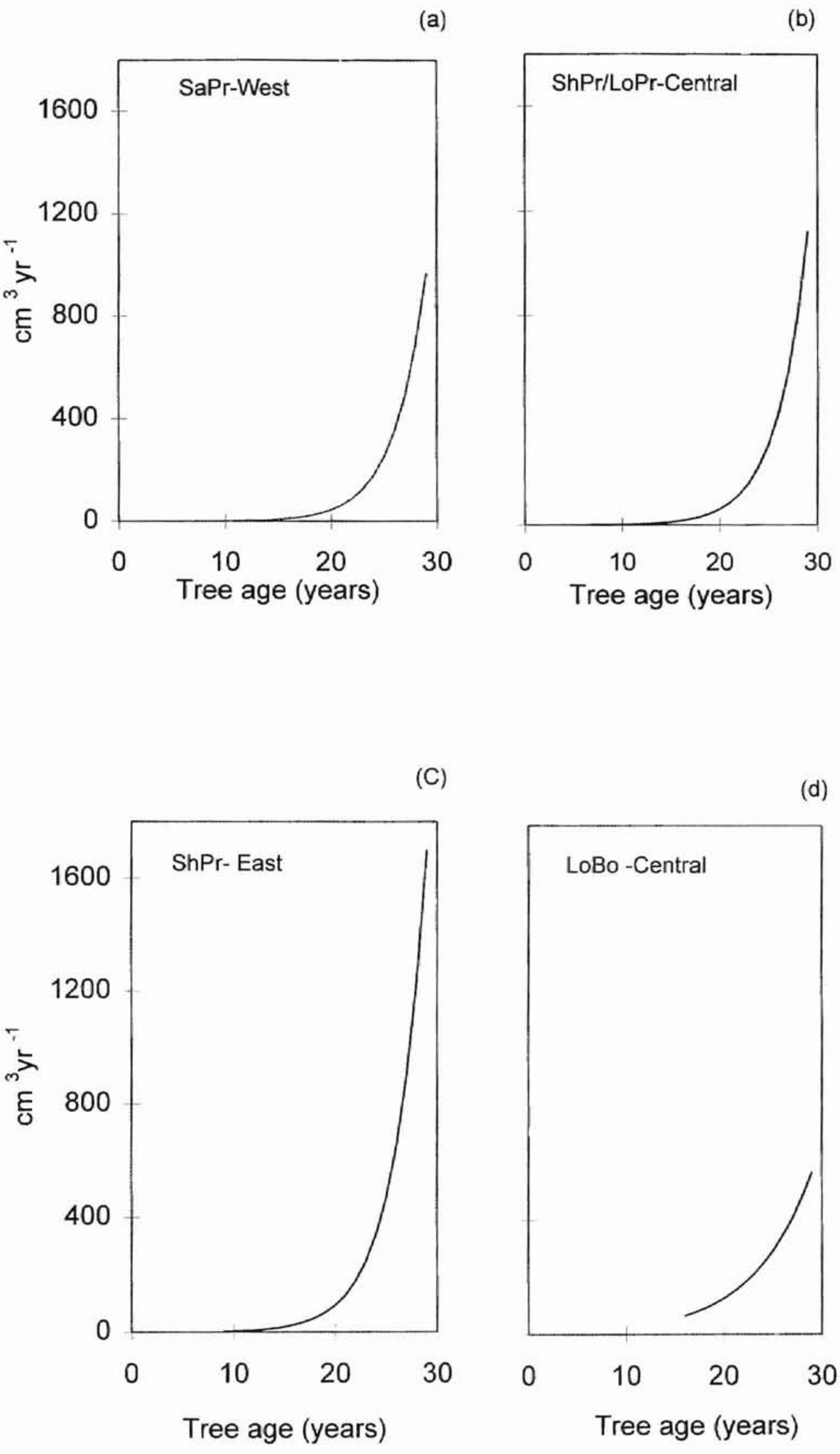

(a)
SaPr-West
(b)
ShPr/LoPr-Central
(C)
ShPr- East
(d)
LoBo -Central
cm 3 yr -1
1600
1200
800
400
0
0
10
20
30
Tree age (years)

Table 1. Range site, geographic location, average annual precipitation, tree age, heartwood (HW) width and sapwood (SW) width of eastern redcedar trees collected in Oklahoma .

Range site	Georgraphic location	Annual ppt (cm)	No.of trees	No.of stands	Age (range)	HW width (mm)	SW width (mm)
Sandy prairie west	Western	70	33	1	6-29	0-236	8-150
Loamy prairie cent	Central	83	23	2	5-27	0-227	14-128
Shallow prairie cent	Central	83	27	2	8-29	0-140	6-152
Loamy bottomland	Central	83	15	1	14-29	17-290	80-182
Shallow prairie east	Eastern	107	40	1	7-28	0-290	19-160

REFERENCES

Anderson, S. and G. Hopper. 1995. Opportunities for farmers and ranchers: What makes a quality cedar log? pp. 6-15, In: S. Anderson, ed., Proceedings of the 4th Annual Oklahoma Redcedar Association Annual Convention. Geary, Oklahoma. October 28, 1994.

Bidwell, T.G., and M.E. Mosely. 1989. Eastern redcedar ecology and management. OSU Extension Facts No. 2868. Oklahoma Extension Service. Oklahoma State University. 4p.

Buehring, N., P.W. Santelmann, and H.M. Elwell. 1971. Responses of eastern redcedar to control procedures. J. Range Manage. 24:378-382

Chalk, L. 1951. Water and growth of Douglasfir. Q. J. For. 45:237-242.

Chattaway, M. M. 1952. The sapwood-heartwood transition. Australian Forestry 16:25-34.

Craighead, M.R. 1985. Economic potential of eastern redcedar, p. 35-39, In: D.M. Engle and R.F. Wittwer (eds), Eastern redcedar in Oklahoma. Conf. Proc., Coop. Ext. Serv., Oklahoma State Univ., Stillwater.

Draper, N.R., and H. Smith. 1966. Applied regression analysis. John Wiley & Sons, Inc. N.Y.

Engle, D.M., J.F. Stritzke, and P.L. Claypool. 1988. Effects of Paraquat plus prescribed burning on eastern redcedar (Juniperus virginiana). Weed Tech. 2:172-174.

Engle, D.M., T.G.Bidwell., J.F. Stritzke, and B. Lochmiller. 1990. Eastern redcedar update -1990. Current Report 2863, Coop. Ext. Serv., Div. Agr. Oklahoma State Univ., Stillwater.

Engle, D.M., and J.D. Kulbeth. 1992. The growth dynamics of crowns of eastern redcedar at 3 locations in Oklahoma. J. Range Mange. 45:301-305.

Forslund, RR. 1982. A geometrical tree volume model based on the location of the center of gravity of the bole. Can. J. For. Res. 12:215-221.

Harris, J. M. 1954. Heartwood formation in Pinus radiata. For. Res. Ins., New Zealand For Sci. Tech. Paper No. 1.

Hills, WE, and N. Ditchburne. 1974. The prediction of heartwood diameter in radiata pine trees. Can. J. For. Res. 4: 524-529.

Hillis, W.E., 1987. Heartwood and tree exudates. Springer, New York. 268 p.

Hunt, R. 1978. Plant growth analysis. Studies in Biology, No. 96. Edward Arnold (Publ.) Ltd. London.

Iharan, N. 1972. A dendrometrical study on heartwood formation of forest trees. Bull. Kyushu Univ. For. 461(March): 123-129.

Ito, M. 1953. Studies on the heartwood and its quantity in trunk. (1) On the relation of heartwood percentage to age of tree for Asunaro and Sawara. Faculty of Liberal Arts Education, Gifu University, Gifu-Ken, Japan. Sci. Rep. 1:63-68.

Jorgensen, Erick. 1962. Observation on the formation of protection wood. For. Chron. 38:292-4.

Keane, M.G., and Weetman, G.F. 1987. Leaf area -sapwood cross sectional area relationships in repressed stands of lodgepole pine. Can. J. For. Res. 17:205-209.

Kramer, P.J., and T.T. Kozlowski. 1979. Physiology of Woody Plants. Academic Press, Inc. New York.

Kuo, M., E.A. McGinnes, Jr. 1973. Variation of anatomical structure of false rings in eastern redcedar. Wood Sci. 5:205-210.

Lassen, L.E., and E. A. Okkeonen. 1969. Sapwood thickness of douglas-fir and five other western softwoods. Res. Pap. FPL For. Prod. Lab. U.S. No.124.

Lawson, E.R. 1985. An American wood. USDA Forest Service, FS-260. Washington, DC. 7p.

Long, J.N., and F.W. Smith. 1988. Leaf area-sapwood area relations of lodgepole pine as influenced by stand density and site index. Can. J. For. Res. 18:247-250.

Martin, S.C., and J.S. Crosby. 1955. Burning on a glade range in Missouri. USDA Forest Exp. Sta. Tech. Pap. 147.

McDaniel, C. A. 1995. Recent studies on the extractives from the heartwood of eastern redcedar, Juniperus virginiana L.pp. 25-28. In:S.Anderson, ed., Proceedings of the 4th Annual Oklahoma Redcedar Association Annual Convention. Geary, Oklahoma. October 28, 1994.

Nelson, N. D. 1976. Gross influences on heartwood formation in black walnut and black cherry trees. USDA For. Serv. Res. Pap FPL 268.

Owensby, C.E., K.R. Blan, B.J. Easton, and O.G. Russ. 1973. Evaluation of eastern redcedar infestations in the northern Flint Hills. J. Range Manage. 26:256-260

Philip, M.S., 1983. Measuring trees and forests. A textbook written for students in Africa.

Pothier, D., H.M. Margolis, and R.H. Waring 1988. Patterns of change of saturated sapwood permeability and sapwood conductance with stand development. Can. J. Res. 11:432-439.

Rink, G. 1987. Heartwood color and quantity variation in a young black walnut progeny test. Wood and Fiber Sci. 19:93-100.

Ryan, M.G. 1989. Sapwood volume for three alpine conifers:predictive equations andecological implications. Can. J. For. Res. 19:1397-1401.

Sellin, A. 1991. Variation in sapwood thickness of Picea abies in Estonia depending on the tree age. Scand. J. For. Res. 6:463-469.

Sellin, A. 1994. Sapwood-heartwood proportion related to tree diameter, age, and growth rate in Picea abies. Can. J. For. Res. 24:1022-1028.

Snook, E.C. 1985. Distribution of eastern redcedar in Oklahoma, p. 45-52, In: D.M. Engle and R.F. Wittwer (eds), Eastern redcedar in Oklahoma. Conf. Proc., Coop. Ext. Serv., Oklahoma State Univ., Stillwater.

Van Deusen, P.C. and T. B. Lynch. 1987. Efficient unbiased tree-volume estimation. For. Sci. 33 :583-590.

Van Haverbeke, D.F., and R.A. Read. 1976. Genetics of eastern redcedar. USDA Forest Serv. Res. Pap. WO-32.

Waring, R.H., and Schlesinger, W.H. 1985. Forest ecosystems. Academic Press, Inc., Toronto. p. 30-80.

Whitehead, D. 1978. The estimation of foliage area from sapwood basal area in Scots pine. Forestry 51:137-149.

Wittwer, R.F., and S. Anderson, and R. Lykins, and E.R. Eisenbraun, and K. Payne 1995. Preliminary estimates of biomass and oil content of eastern redcedar in Oklahoma. In: S.Anderson, ed., Proceedings of the 4 th Annual Oklahom Redcedar Association Annual Convention. Geary, Oklahoma. October 28, 1994

Wyssling, A.F., and H.H. Boddhard. 1959. Cytology of the ray cells in sapwood and heartwood, Holzforschung, 13:129-136.

Yang, K.C., G. Hazenberg, G.E. Bradfield, and J.R. Maze 1985. Verical variation of sapwood thickness in Pinus banksiana. Lamb and Larix lariciana (Du Roi) k, Koch. Can. J. For. Res. 15:822-828.

Yang, K.C., and G. Hazenberg. 1991. Sapwood and heartwood width relationship to tree age in Pinus baksiana. Can. J. For. Res. 21:521-525.

CHAPTER II

THE GROWTH DYNAMICS OF EASTERN REDCEDAR

LITERATURE REVIEW

Introduction

Eastern redcedar (Juniperus virginiana L) is the most widely distributed conifer of tree size in the eastern United States and is found in every state east of the 100th meridian (Van Haverbeke and Read 1976). The species extends northward into southern Ontario and the southern tip of Quebec (Williamson 1965). In Oklahoma, eastern redcedar occupied 0.6 million ha in 1950 (Bidwell et al. 1990). Grumble (1989) estimated that by 1989, eastern redcedar had invaded more than 4 million ha in Oklahoma and over 55,000 ha in east-central Texas (Schmidt and Kuhns 1990).

Eastern redcedar is a small to medium sized tree that may grow to 5 to 8 m tall and 30 to 60 cm bole diameter (Engle et al. 1992). The crown is dense and narrowly pyramidal, or columnar and the tapering bole terminates below in a deep root system (William and Harrar 1969).

Climate

The wide natural distribution of eastern redcedar clearly indicates its ability to grow under varying and extreme climatic conditions. Average annual precipitation varies from 380 mm in the northwestern section to 1520 mm in the southern parts of its range

(Albertson 1940). Average annual temperature varies from about 4°C in the north to 20°C in the southern part of the range (Albertson 1940). Because eastern redcedar has been able to withstand extremes of drought, heat, and cold it ranked high in survival among conifers in the Great Plains Shelter Belt plantings (Albertson and Weaver 1945). In the northwestern part of its range, redcedar was only slightly injured by the severe winter conditions of 1947-48 (Stoeckeler and Rudolf 1949).

Site Characteristics

The species grows on a wide variety of soils ranging from dry rock out crops to swampy land (Albertson 1940). The most common soils fall within the soil orders Mollisols and Ultisols. The species is also associated with areas commonly called glades characterized by thin rocky soils and intermittent rock out crops (Arend 1948).

Eastern redcedar grows on soils that vary in acidity. Soils found in natural stands range in pH value from 4.7 to 7.8 (Arend 1950). Although the species will grow on sites that are slightly alkaline, it is not particularly tolerant to higher pH levels (Arend 1950). Soils under eastern redcedar stands tend to become neutral or slightly alkaline because the high calcium content of the tree's foliage can change the pH of the surface soil in a relatively short time. This condition also increases earthworm activity and increases organic matter content through litter incorporation, lowers soil volume weight, and increases pore volume, air capacity and infiltration rate (Ferguson 1968, Fowells 1965).

Soil depth, texture and drainage influence the growth of eastern redcedar. Arend and Collins (1948) found site index (height of dominant trees at age 50) to increase from 8 m to 10 m when soils are less than 5 cm deep to 45 m to 50 m when soils were deeper than 10 cm in the Ozarks. Eastern redcedar plantations in Oklahoma grew poorly on light, sandy, shallow soils, 2 to 3 cm deep (Afanasiev 1949). Better growth was attained on sandy soils, 3 to 6 cm deep with a hard pan underneath. Growth was poor on heavy textured soils with 58 percent clay (Afanasiev 1949).

Topographic position of a catena can influence the height and diameter of eastern redcedar. Topographic position was related to depth of the soil, with lower slopes tending to produce taller trees because of greater soil depth (Ferguson 1968). Steep slopes reduce height and diameter of eastern redcedar. Because of erosion impact, it is more likely that steeper slopes have shallow soil depth which contributes to poorer growth of eastern redcedar than on flatter land. However, eastern redcedar grows on ridge tops, slopes, and flat land, and is frequently found on dry exposed sites and abandoned fields (Arend 1947, Bard 1952).

North and east aspects produce greater height and diameter than south and west aspects. Aspect influences the character of stands but not total growth and yield of stands (Arend and Collins 1949). In the Missouri Ozarks, there were generally fewer eastern redcedar trees because of hardwood competition on the north and east aspects, but those that did occur were slightly taller than trees on the south and west aspects (Arend and Collins 1949). Slope exposure did not significantly alter eastern redcedar populations, and invasion was accompanied by other woody species (Schmidt and Stubbendieck 1993). In the western part of the range the species is found on north facing slopes and along stream banks getting more moisture and protection from high temperature and drought than in the drier southwest slopes (Fowells 1965). In Nebraska, north-facing slopes had slower snow melt, which resulted in improved moisture availability (Schmidt and Stubbendieck 1993). These same slopes were not exposed to direct sunlight resulting in lowered temperature. The impact of aspect on eastern redcedar seedling survival was significant. The highest survival was recorded on north facing slopes, with the lowest survival found on south-facing slopes (Schmidt and Stubbendieck 1993).

Reproduction

Eastern redcedar does not reproduce naturally by sprouting or suckering (Arend 1950). However, the species can be propagated from cutting and layering as well as by grafting (Wittwer 1985). The commercial nursery trade has developed methods of vegetative propagation and consequently has produced selected horticultural varieties (Wittwer 1985). Many of the ornamental forms are propagated vegetatively (Arend 1950).

Eastern redcedar is dioecious with male and female flowers found on separate trees (Johnson and Alexander 1974). Sexual maturity is probably not reached before age 10, after which fruit production can occur annually (Hall 1952). Male flowers begin to develop conspicuously in early fall, attain mature size during the winter months, and because of their yellowish-brown color can be easily separated from female trees (Hall 1952). The female conelets do not usually become visible to the naked eye until early spring; pollination occurs from mid-February to mid-May depending on the geographic location (Hall 1952). Fruit maturity is reached in mid-September in the central part of the natural range (Van Haverbeke and Read 1977). Good seed crops occur every 2 or 3 years and the best seed bearing age is between 25 to 75 years (Fowells 1965).

Seed Dispersal, Germination, and Seedling Establishment

Seed are widely dispersed in the fall by birds and other wildlife (Van Haverbeke and Read 1977). Deer, small mammals and many species of birds, including quail, grouse, pheasant, and turkey, feed on the fruit and aid with dispersal of the seed (Arend 1950, Hahn 1945, Parker 1951).

Most of the natural germination of eastern redcedar seed occurs in the early spring of the second year after dispersal, but a few may germinate the 1st and 3rd year (Van Haverbeke and Read 1977). Delayed germination is caused by embryo dormancy and possibly by an impermeable seed coat (Parker and Johnson 1951). Passage through an animal digestive tract speeds seed germination (Parker and Johnson 1951). Cotrufo (1963) reported that citric acid treatment increased eastern redcedar germination and the action of acidic juices within the digestive tract could have a similar effect. Germination is best if fresh seeds are used. If desired, dry, stored seeds may be sown in mid-July, which accomplishes moist-warm stratification, and the over-winter period accomplishes moist-cool stratification for early spring germination (Lawson 1985).

Eastern redcedar can be established by hand or machine sowing (Lawson 1985). In nursery practice, eastern redcedar seeds are broadcast or sown in rows spaced 15 to 30 cm apart in well prepared soil or seedbeds and covered with about 6 mm of firmed soil or sand (Lawson 1985). Both hand and furrow seeding are successful when stratified seeds are used at the rate of 1.35 kg/ha. Seedling catch is best where litter has been removed and hardwood competition has been completely removed (Lawson 1985).

Survival of eastern redcedar plantations has been variable, with low survival being attributed to poor seedling quality, low site quality, and competition (Ferguson 1969, Lawson 1985). If these factors are considered carefully, eastern redcedar plantations can be successfully established.

In Mixed Prairie, eastern redcedar seedling survival is influenced by year of establishment and precipitation (Schmidt and Stubbendieck 1993). From a study conducted in Nebraska, year of establishment did not influence survival of seedlings at 6 months, but affected seedlings at 18 and 30 months after establishment (Schmidt and Stubbendieck 1993). Precipitation was also a factor for survival relative to year of establishment and greatest eastern redcedar seedling survival was recorded 6 months after establishment. Survival depended on weather conditions that were beneficial for establishment occurring in the particular year of establishment. However, total precipitation during the years following establishment resulted in higher long-term survival (Schmidt and Stubbendieck 1993).

Grazing effects (the type and number of animals) on the vegetation were a significant factor in the survival of eastern redcedar (Schmidt and Stubbendieck 1993). Plots were established in 1987 and 1988 under 3 different grazing levels: (1). actively grazed (2). actively grazed until 1987 and then fenced from grazing and (3). not grazed for $\geq$ 50 years. Seedlings survival was evaluated at 6, 18, and 30 months after establishment period. The three grazing periods also resulted in different survival over time. Areas fenced from grazing after 1 year had the highest survival (Schmidt and Stubbendieck 1993). The areas that had not been grazed for greater than or equal to 50 years had the lowest mean seedling survival. Survival of eastern redcedar seedlings declined over time for all three grazing treatments. The decline in survival over time was highest for the no grazing treatments. Eastern redcedar seedlings survival advantages gained in the fenced-from-grazing and grazed areas were maintained over time and were the most pronounced at the end of the 30 month period (Schmidt and Stubbendieck 1993).

Eastern redcedar seedlings are intolerant to shade. Seedling survival is better under open than closed canopies (Parker and Johnson 1952, Fowells 1965). However, it has been found to adapt to understory environments as net positive photosynthesis still occurs with maximum rates during the time immediately preceding leaf development of the hardwood overstory (Lassoie et al. 1983).

Seedlings of eastern redcedar withstand drought. During the first year seedlings do not produce much top growth, but they produce a long fibrous root system (Parker and Johnson 1952), which may aid in drought tolerance. Seedlings will often survive even on arid sites, but their top growth is slow (Albertson 1940).

Natural Enemies and Diseases

Eastern redcedar trees are intolerant of fire. The thin bark of eastern redcedar offers little protection against fire (Ferguson et al. 1968). The foliage does not burn readily and litter accumulation is limited under stands on thin soils, so the lack of fuel protects many stands in areas where fire occurrence rate is high (Ferguson 1968). On deep soils, competing species produce enough litter to support fire. Sufficient flash fuels to carry fire are usually available on grasslands and old fields which are aggressively invaded by eastern redcedar (Ferguson 1968). Crockett (1985) felt soil disturbance was the overriding factor allowing eastern redcedar establishment.

Periodic spring burning will control small trees less than 1.5 m tall and will arrest eastern redcedar invasion into grasslands (Buehring et al. 1971, Owensby et al. 1973, Bidwell et al. 1990). However, fire often is not effective on dense stands of large trees. Crown scorch, necessary for tree kill, is difficult to obtain on large trees, especially either when fine fuel loading is light or discontinuous or when weather conditions preclude an intense fire (Engle et al. 1988). An integrated approach combining burning with mechanical control appears to be the best control measure against redcedar (Stritzke and Rollins 1987).

Insects usually do not seriously damage eastern redcedar (Ferguson 1968). Boring insects sometimes feed on living and dead trees, and bag worms [Thyridopteryx ephemeraeformis. (Haw)], occasionally completely defoliate a tree. Redcedar aphids [Cinerea sabinae, (Gill)] may cluster on twigs and smaller branches, occasionally killing the infested portions and sometimes the whole stem (Done et al. 1936).

Eastern redcedar is susceptible to some fungal diseases. The most commonly known and widely spread fungi is cedar apple rust (Gymnosporangium juniperi-uriginianae schw.) (Boyce 1948). It attacks trees in all stages of development. Because it is an alternate host to this disease, the presence of eastern redcedar is a problem to apple growers (Hepting and George 1971). Another fungi that attacks the heartwood and kills the tree is root rot (Fomes annosus (Fr.)) karst.). It extends into the sapwood about the root collar of suppressed trees, and can kill weakened trees (Boyce 1948). Cubical rot fungi (Fomes subroseus (weir) Overh. and Daedalea juniperma murr.) and juniper pocket rot fungus (F. juniperinus (V. Schr.) Sacc and syd.) enter through dead branches and stubs and attack the heartwood of eastern redcedar (Boyce 1948, USDA Agricultural Service 1960).

Growth Dynamics, Yield, and Wood Characteristics

The age of a tree can be determined by ring count because of the formation of spring and summer wood (Little 1981). Rings are formed because eastern redcedar grows more rapidly in the spring and early summer than it does later in the year under temperate climate (Little 1981). False rings are additional rings of wood formed within a normal growth increment; they are distinct from discontinuous rings in that false rings are contained completely within normal growth increments and do not merge with either the latewood or earlywood of normal growth increments as discontinuous rings do (Panshin and Dezeeuw 1964). Typically, a false ring appears to the unaided eye as a thin, dark tangential band. In coniferous species, this thin, dark band is usually composed of latewood-like (thick walled), longitudinal tracheids. A long dry spell followed by a long wet spell evidently produce a false ring of the conventional type throughout all height levels (Panshin and Dezeeuw 1964).

The heartwood, which is the non-active portion of the trunk, gradually becomes darkened due to deposition of mineral wastes, and other coloring matters known as extractives which is associated with the formation of tyloses in the vessels. The sapwood, which is a light colored outer layer of the wood, serves for the upward movement of water and, mineral salts (Little 1981).

Eastern redcedar tree height and crown area as a function of age were different at eastern, central, and western Oklahoma study locations (Engle and Kulbeth 1992). Trees in the 28- to 29-year-old age class ranged in height from 6.2 m on the western Oklahoma locations to 8.3 m on the eastern Oklahoma locations. Crown area growth rate was also greatest on older trees on the eastern Oklahoma locations, but crown area on older trees on central Oklahoma locations was less than that of trees on eastern or western Oklahoma locations. These data suggest that the smaller crown area of trees at the central Oklahoma locations, which is intermediate in site potential to the western and eastern locations, might be reflecting a genetic influence such as introduction of a different race having more of a columnar growth habit (Engle and Kulbeth 1992). A distinct variety having a columnar crown form has been described for eastern redcedar (Van Haverbeke and Read 1976).

Growth rates of eastern redcedar depend largely on site quality, competition from other species, and stand density (Lawson 1985). The latter two factors probably reflect competition for available soil moisture on moist sites. In the Kansas Flint Hills, growth rate of mature trees of 20 to 30 years old was 0.15 to 0.20 cm yr^{-1} in diameter (Lawson 1985). A similar study conducted in western and eastern Oklahoma locations revealed that open-grown trees 28 to 29 years old grew in height at a rate of 0.5 to 0.6 m yr^{-1} (Engle and Kulbeth 1992). Trees on a central Oklahoma study location, which grew faster than trees on either the eastern or western study sites for the first 20 years, slowed their growth to about 0.2 m yr^{-1} at 28 years of age. The average increase in height over all age classes was 0.33, 0.24, and 0.22 m yr^{-1} at the eastern, central, and western Oklahoma study locations, respectively (Engle and Kulbeth 1992). Variation in height is due to soil type and precipitation, decreasing in amount from east to west in Oklahoma study locations.

As stocking density of eastern redcedar increases, volume and basal area increases and diameter growth decreases (Lawson 1985). Over a 10-year period in northern Arkansas, completely released stands averaged higher growth in diameter, basal area, and volume than stands where only crown competition was removed (Lawson 1985). High volume was produced with an increase in stocking density (Ferguson 1968).

Succession and Competition

Eastern redcedar in New York, New England, and the southeastern United States has been classified as intolerant to competition (Williamson 1965). On thin dry soils, the species is able to withstand competition of hardwoods, because hardwood growth is sparser and less vigorous, but on better sites, hardwoods usually replace the eastern redcedar (Arend 1948, Fletcher et al. 1955, Ferguson 1968). Studies on the Ozarks of Missouri and Arkansas and the Nashville basin in central Tennessee showed that the species is more permanent on poor sites having thin rocky soils of glades and is likely to persist for a long time if left to grow (Bragg and Hulbert 1976).

Encroachment of eastern redcedar on rangeland may cause loss of forage production, changes in grassland plant species composition, livestock handling problems, and loss of wildlife species dependent on grassland habitat (Schmidt and Stubbendieck 1993). Eastern redcedar is the most rapidly expanding wood species on rangeland in the Great Plains and is increasing in terms of tree size, acreage occupied, and number of locations (Wilson and Schmidt 1990). However, the influence of eastern redcedar on rangeland is limited to the mixed and tallgrass prairies and the prairie-deciduous forest ecotone in Oklahoma and Kansas and to a lesser extent in Nebraska and Texas (Engle 1985).

Rangelands invaded by eastern redcedar have been observed adjacent to rangelands where invasion was absent (Owensby et al. 1973, Engle 1985). Control of wildfires, genetic adaptability, expanded seed sources, and soil disturbances are primary factors responsible for expansion (Schmidt and Stubbendieck 1993). Burkhardt and Tisdale (1976) found that juniper stands in Idaho were originally confined to poor soils and rocky ridges by wildfires.

Unlike junipers of the western United States, the zone of interference with herbaceous plant production is primarily inside the drip line of the eastern redcedar crown (Engle et al. 1987). As trees increase in number and size, forage production will likely decline proportionately (Engle 1985). Juniper litter has been shown to have an inhibitory effect on grass seed germination (Lavin et al. 1968), seedling emergence (Johnson 1962), and grass coleoptile growth but not germination of grasses (Buehring et al. 1971). Again, these effects would primarily be limited to directly under the tree canopy (Engle 1985). Competition for moisture, nutrients, and light could also be limiting herbaceous plant production.

Grazing can affect the level of plant competition for eastern redcedar seedlings, plant species composition, the degree of soil compaction, and the amount of bare soil (Owensby et al. 1973, Engle 1985, Clary and Holmgren 1987, Stritzke and Bidwell 1990).

Grazing can also cause physical damage to eastern redcedar seedlings through trampling and/or breakage (Fitter and Jennings 1975). Grazing resulted in improved eastern redcedar establishment, possibly because the presence of cattle adversely impacted competing plants, which reduced competition to the new seedlings (Schmidt and Stubbendieck 1993).

The stocking rate of cattle can influence the invasion of eastern redcedar. The rate of eastern redcedar invasion declined as growing season stocking rate of cattle increased in the absence of fire or mechanical removal (Blan 1970). Proper grazing management does not prevent invasion by eastern redcedar (Stritzke 1985). Owensby et al. (1973) concluded that heavier cattle stocking rates reduced eastern redcedar invasion rates, and that eastern redcedar appeared to invade all upland range sites equally.

Summary and Conclusion

The wide natural distribution of eastern redcedar indicates its ability to grow under variable and extreme climatic conditions. Even though the species is found on many types of soil, best growth is made on deep alluvial soils. However, hardwoods compete well with eastern redcedar on such sites. Dissemination of seeds is facilitated by birds, which eat the berry-like fruits in large numbers. Delayed germination is the rule, and the seedlings do not appear until the second season after the seeds are sown. Eastern redcedar is slow growing and intolerant of shade, but adapts to the understory of hardwoods. Growth rate of eastern redcedar depends largely on site quality, competition from other species and stand density.

The rapid encroachment of eastern redcedar into pastures and rangelands is an area of growing concern for land owners and range managers. The critical point concerning the spread of this species on rangelands is to understand the factors that affect the long-term survival and establishment. Knowledge on the growth behavior is essential either to discourage or encourage the growth of this species. Eradication of eastern redcedar is not only unrealistic but also undesirable because eastern redcedar is also a valuable tree species that provides additional income to in the future.

REFERENCES

Afanasiev, M. 1949. A study of redcedar plantations in north central Oklahoma. Oklahoma Agr. Expt. Sta. Tech. Bule. T-34, 16 p.

Albertson, F. W. 1940. Studies of native redcedar in west central Kansas. Trans. Kansas Acad. Sci. 43:85-96.

Albertson, F. W. and J. E. Weaver. 1945. Injury and death or recovery of trees in prairie climate. Ecol. Monog. 15:395-433.

Arend, J. L. 1947. An early eastern redcedar plantation in Arkansas. J. Forest. 45:358-360.

Arend, J. L. 1948. Influences on redcedar distribution in the Ozarks. U.S. Forest Serv. Southern Forest Exp. Sta. Note 58.

Arend, J. L. 1950. Influence of fire and soil on distribution of eastern redcedar in the Ozarks. J. Forest. 48:129-130.

Arend, J. L., and R. F. Collins. 1949. A site classification for eastern redcedar in the Ozarks. J. Soil Sci. Soc. Amer. Proc. 13:510-511.

Bidwell, T. G., D. M. Engle, J. F. Stritzke, and B. Lochmiller. 1990. Eastern redcedar update - 1990. Current Report 2863, Coop. Ext. Serv., Div. Agr. Oklahoma State Univ., Stillwater.

Blan, K. R. 1970. Evaluation of eastern redcedar infestation in the northern Kansas Flint Hills. M.S. Thesis, Kansas State Univ., Manhattan.

Buehring, N., P. W. Santelmann, and H. M. Elwell. 1971. Responses of eastern redcedar to control procedures. J. Range. Manage. 24:378-382.

Boyce, J. S. 1948. Forest pathology. New York: McGraw-Hill Book, Co., Inc.

Bragg, T. B. and L. C. Hulbert. 1976. Woody plant invasion of unburned Kansas bluestem prairie. J. Range Manage. 29:19-24.

Burkhardt, J. W. and E. W. Tisdale. 1976. Causes of juniper invasion in southwestern Idaho. Ecology. 57:472-484.

Cotrufo, C. 1963. Stimulation by citric acid of germination of eastern redcedar (Juniperus virginiana L.). Nature. 199:92-93.

Crockett, J. J. 1985. Ecology of eastern redcedar in Oklahoma, p. 1-8. In: R. F. Wittwer and D. M. Engle (eds.), Eastern redcedar in Oklahoma Conf. Proc., Coop. Ext. Serv., Oklahoma State Univ., Stillwater.

Draper, N. R. and H. Smith. 1966. Applied regression analysis. New York: John Wiley & Sons, Inc.

Doane, R. W., E. C. Van Dyke, W. J. Chamberlin, and H. E. Burke. 1936. Forest insects. New York: McGraw-Hill Book Co., Inc.

Engle, D. M. 1985. Effects of eastern redcedar on range forage and livestock production, p. 53-60. In: R. F. Wittwer and D. M. Engle (eds.), Eastern redcedar in Oklahoma Conf. Proc., Coop. Ext. Serv., Oklahoma State Univ., Stillwater.

Engle, D. M., J. F. Stritzke, and P. L. Claypool. 1987. Herbage standing crop around eastern redcedar trees. J. Range Manage. 40:237-239.

Engle, D. M. and J. D. Kulbeth. 1992. The growth dynamics of crowns of eastern redcedar at 3 locations in Oklahoma. J. Range Manage. 45:301-305.

Ferguson, E. R., E. R. Lawson, W. R. Maple, and C. Mesavage. 1968. Managing eastern redcedar. USDA Forest Serv. Res. Pap. SO-37.

Fitter, A. H. and R. D. Jennings. 1975. The effects of sheep grazing on the growth and survival of seedling junipers (Juniperus communis). J. Appl. Ecology. 12:637-642.

Fowells, H. A. 1965. Silvics of forest trees of the United States. USDA Forest Serv. Agr. Handbook 271.

Grumbles, J. B. 1989. Control of eastern redcedar and ashe juniper with soil spot applications of picloram. Down to Earth. 45:13-16.

Hall, M. T. 1952. Variations and hybridization in Juniperus. Mo. Bot. Gard. Annu. 39:1-64.

Hepting, G. H. 1971. Diseases of forest and shade trees of the United States. USDA, Agriculture Handbook 386. Washington, DC.

Johnson, T. N., Jr. and R. A. Alexander. 1974. Juniperus L. Juniper., p. 460-469. In: Seeds of woody plants of the United States. USDA For. Serv. Agr. Handbook 470.

Kuo, M. and E. A. Jr.McGinnes. 1973. Variations of anatomical structure of false rings in eastern redcedar. Wood Sci. 5:205-210.

Lassoie, J.P. , P.M. Dougherty, P.B. Reich, T.M. Hinckley, C.M. Metcalf. 1983. Ecophysiological investigations of understory eastern redcedar in central Missouri. Ecology: 64:1355-1366.

Lavin, F., D. A. Jameson and E. B. Gomm. 1968. Juniper extract and deficient aeration effects on germination of six range species. J. Range Manage. 21:262-263.

Lawson, E. R. 1985. An American wood. USDA For. Serv. FS-260, Washington, DC 7p.

Little, E. L., Jr. 1981. Forest trees of Oklahoma. How to know them. Oklahoma Forestry Division, State Department of Agriculture.

Owensby, C. E., K. R. Blan, B. J. Easton and O. G. Russ. 1973. Evaluation of eastern redcedar infestations in the northern Flint Hills. J. Range Manage. 26:256-260.

Parker, J. 1951. Natural reproduction from redcedar. J. Forest. 49:285-286.

Parker, J. 1952. Establishment of eastern redcedar by direct seeding. J. Forest. 50:914-917.

Philip, M. S. 1983. Measuring trees and forests. A textbook written for students in Africa.

Schmidt, T. L. and M. R. Kuhns. 1990. Nebraska's forest resources: acreages and ownership. Univ. Nebraska-Lincoln, Coop. Ext. Serv. Nebguide G90-968. Lincoln.

Schmidt, T. L. and J. Stubbendieck. 1993. Factors influencing eastern redcedar seedlings on rangeland. J. Range Manage. 46:448-451.

Stoeckeler, J. H. and P. O. Rudolf. 1949. Winter injury and recovery of conifers in the upper midwest. U.S. Forest Serv. Lake States Forest Expt. Sta. Paper 18.

Stritzke, J. F. 1985. Chemical and mechanical control of eastern redcedar, p. 61-69. In: D. M. Engle and R. F. Wittwer (eds.), Eastern redcedar in Oklahoma Conf. Proc., Coop. Ext. Serv., Oklahoma State Univ., Stillwater.

Van Haverbeke, D. F. and R. A. Read. 1976. Genetics of eastern redcedar. USDA Forest Serv. Res. Pap. WO-32.

William, M. H. and E. S. Harrar. 1969. Textbook of dendrology, p. 204-206.

Williamson, M. J. 1965. Eastern redcedar (Juniperus virginiana L.). p. 212-216. In: Silvics of forest trees of the United States. USDA Agri. Handbook 271.

Wilson, J. S. and T. L. Schmidt. 1990. Controlling eastern redcedar on rangelands and pastures. Rangelands. 12:156-158.

Wittwer, R. F. 1985. Biology of eastern redcedar. p. 9-16. In: D. M. Engle and R. F. Wittwer (eds.), Eastern redcedar in Oklahoma Conf. Proc., Coop. Ext. Serv. Oklahoma State Univ., Stillwater.

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