Forest Ecology and Management, 50 (1992) 75–84
Elsevier Science Publishers B.V., Amsterdam

Sheep grazing effects on coastal Douglas fir forest growth: a ten-year perspective

Steven H. Sharrow, Wayne C. Leininger and Khalid A. Osman
Department of Rangeland Resources, Oregon State University, Corvallis, OR 97331, USA

(Accepted 19 April 1991)

ABSTRACT

Sharrow, S.H., Leininger, W.C. and Osman, K.A., 1992. Sheep grazing effects on coastal Douglas fir forest growth: a ten-year perspective. *For. Ecol. Manage.*, 50: 75–84.

Interest in using livestock as a biological control agent to suppress unwanted vegetation in conifer plantations has expanded rapidly in the last 10 years. Additional information concerning the silvicultural implications of livestock grazing, particularly the effects of browsing and competition suppression on timber tree growth, are needed if grazing is to be widely adopted as a forest management tool. Tree diameter and height growth were measured during 1981–1990 for ungrazed and grazed tree stands in a coastal Oregon Douglas fir (*Pseudotsuga menziesii*) forest. Grazed stands were intensively used by a herded flock of 700–900 sheep for 3–4 days each May and August in 1981 and 1982. Understory vegetation phytomass and its utilization by sheep was evaluated using a before-and-after technique in 1981 and 1982. Sheep removed 28% and 64% of new tree lateral branches in 1981 and 1982, respectively. The major effect of browsing, however, appeared to be removal of terminal leaders which reduced 1990 Douglas fir tree height by 61 cm and diameter at breast height (dbh) by 1.9 cm for each terminal removed. Sheep browsed terminal leaders of 38% and 77% of grazed-plantation trees in 1981 and 1982, respectively. Grazing proved very effective in reducing red alder (*Alnus rubra*) establishment and growth. Total tree basal area in 1990 was similar for grazed and ungrazed stands. However, alder trees contributed over 45% of the tree basal area present on ungrazed stands compared to only 19% on grazed stands. Vegetation control by sheep, without associated browsing of terminal leaders, increased 1990 Douglas fir height by 16% and dbh by 34%. The net effect of grazing, reflecting the negative impacts of browsing together with the positive effects of reduced competing vegetation, was to increase the 1990 Douglas fir height by 6% and dbh by 22% on grazed compared to ungrazed timber stands.

INTRODUCTION

The coastal Douglas fir (*Pseudotsuga menziesii*) forests of the United States Pacific north-west are among the most productive forests on earth (Franklin and Dyrness, 1973). Herbaceous and woody plants rapidly occupy new tim-

Correspondence to: S.H. Sharrow, Department of Rangeland Resources, Oregon State University, Corvallis, OR 97331, USA.

ber plantations following clearcut harvesting (Dyrness, 1973; Stewart, 1978). Competition from this vegetation can markedly reduce the growth of young conifer seedlings (Dimock et al., 1983; Strothmann and Roy, 1984; Cole and Newton, 1986). In the past, silviculturalists have relied heavily upon use of herbicides as an effective means of weed control in commercial timber plantations (Cleary et al., 1978). High chemical and application costs, and perhaps more importantly, public concern about the environmental safety of pesticides in general, has substantially reduced the appeal of herbicides as a forest resource management tool. Prescription livestock grazing has proved to be effective in controlling unwanted vegetation in conifer plantations (Grieman, 1988; Allen and Bartolome, 1989; Sharrow et al., 1989). Use of livestock to consume forest weeds is generally viewed favorably by the public because it can improve the resource for native deer and elk (Rhodes and Sharrow, 1990) and is considered to be more natural than use of chemicals. Many silviculturalists are reluctant to support prescribed livestock grazing however, because of fears of browsing damage to young conifer trees and lack of sufficient long-term data to fully evaluate its silvicultural merits. The purpose of this study was to evaluate the effects of controlled sheep grazing on Douglas fir growth throughout the first decade of plantation life.

MATERIALS AND METHODS

The study was conducted within a 29 ha coastal timber plantation in the Alsea Ranger District, Siuslaw National Forest, approximately 15 km west of Alsea, Oregon (latitude 44° 22′N, longitude 123° 35′W). Elevation is approximately 250 m. Climate is maritime with cool, rainy winters and mild dry summers. Most of the 250 cm annual precipitation falls as low-intensity rain from October through May (Corliss, 1973). Soil is slickrock, gravelly loam (Pachic Haplumbrept; Corliss, 1973). Natural ground vegetation is of the Vine Maple–Sword Fern community (*Acer circinatum–Polystichum munitum*) which is common in the area (Corliss and Dyrness, 1965). In addition to vine maple, other commonly encountered woody plants on the study site include salmonberry (*Rubus spectabilis*), California dewberry (*Rubus ursinus*), thimbleberry (*Rubus parviflorus*), and red alder (*Alnus rubra*). The original timber stand was harvested in 1977, the clearcut burned in 1978 and planted with approximately 1500 3-year-old bare root Douglas fir trees (3-0 stock) ha^{-1} in 1979. Seedlings which failed to establish in 1979 were replaced with 3-year-old (2-1 stock) trees in 1980. Orchardgrass (*Dactylis glomerata*) was aerially seeded in 1980 to slow establishment of unwanted woody vegetation, particularly salmonberry and red alder, and to provide a nutritious food source for native large herbivores. A herded flock of 700–900 sheep grazed the study plantation for 3–4 days in spring (late May) and again in summer (early August) 1981 and 1982 as part of a 600 ha circuit of clearcut units which were grazed to suppress brush and to improve forage quality for resident deer and elk. Experimental treatments consisting of four replications of grazed and ungrazed plots were established prior to grazing in 1981. Each 232 m^2 plot contained 25 study trees which were permanently marked with numbered steel tags. Ungrazed plots were protected from livestock grazing by a 81 cm high woven wire fence which excluded sheep but did not restrict wildlife access to the plots. An additional 150 trees located approximately 100 m from the study plots were marked in order to expand the sample size available to study the effects of grazing on subsequent growth of individual trees. Sheep browsing damage to trees was assessed for each grazing entry by visual estimation of the percent of current year's growth missing from lateral branches and whether the terminal leader had been browsed on each study tree both immediately prior to sheep entry and again after sheep left the plantation. Phytomass present and amount consumed by sheep were estimated using the before-and-after technique (Cassady, 1941). Ten pairs of 0.45 m^2 quadrats were sampled within each of three randomly located macroplots which served as replications in the grazed portion of the plantation. Vegetation within one quadrat of each pair was harvested immediately prior to grazing and the other just after sheep left the plantation. Current year's plant growth was separated by species, dried at 50°C for 72 h, then weighed. Height and diameter of each tree was measured at the end of the growing season in 1981–1985 and in April 1990 using a calibrated pole and caliper, respectively. Diameter during 1981–1984 was measured between the two lowermost whorls of branches. Diameter at breast height (dbh) was measured at 1.37 m above the soil surface on the uphill side of the trees in 1985 and 1990. Alder stems in each plot were counted immediately prior to tree bud burst in April 1990, and their dbh measured with a caliper. Alder height was estimated, where possible, using a Relaskop.

Grazed and ungrazed treatments were compared each year by analysis of variance using plots as replications in a completely randomized design. Height and dbh of trees with different levels of terminal browsing were compared using Student–Newman–Keul's Multiple Range test following analysis of variance (random effects model) with trees as replications in a completely random design. All treatment effects were evaluated at $P<0.05$.

RESULTS AND DISCUSSION

Native herbivores, especially deer, are common in the study area. Deer trails, beds and feces were observed both within and outside of the enclosed plots. Little browsing of Douglas fir study trees by deer was evident. Only 3% of terminal leaders and 1% of lateral branches were browsed by deer in 1981. No deer browsing was detected on Douglas fir in 1982. Although deer browsing can be an important influence on conifer establishment and growth, it did not appear to have silvicultural significance in our study plantation.

Sheep consumed 68%, 39% and 29% of the total understory phytomass available in the grazed plots during the May 1981, May 1982 and August 1982 grazing periods, respectively (Table 1). Plot harvest data are not available for the August 1981 grazing period; however, optical estimates made immediately after sheep left the plantation were 30% utilization for total phytomass, with less than 1% browsing use of Douglas fir terminal and 3% use of lateral branches. Sheep removed 38% of Douglas fir terminal leaders and 28% of new lateral branches in May, 1981. Relatively low amounts of browsing on conifer foliage by livestock during the summer compared to spring (Leininger and Sharrow, 1989), as in 1981, is commonly attributed to the presence of new, succulent, immature growth on conifers during the spring growth period (Leininger and Sharrow, 1987; Doescher et al., 1987). Conifer bud break and the expansion of palatable new Douglas fir growth was well underway during the May 1982 grazing period. Unfortunately, the second grazing entry in August 1982 coincided with secondary bud break when palatable new conifer growth similar to that of the spring was present. Substantial browsing of both terminal leaders and lateral branches occurred in 1982. Of the 250 grazed-plantation study trees, only 28% had intact terminal leaders at the end of August. Thirty-five percent of trees had terminal leaders removed during the May grazing, while an additional 43% of the trees had both their primary spring terminal leader, and their secondary summer terminal leader consumed by sheep. Sixty-four percent of all current year's lateral Douglas fir branches were browsed by sheep during 1982.

Removal of tree terminal leaders once, twice or three times by sheep during 1981–1982 reduced 1985 average Douglas fir height by approximately 16%, 22% and 34%, respectively, compared to grazed-plantation trees with intact terminal leaders (Table 2). Reduced height of trees whose terminal leader had been browsed is understandable in the light of the determinant nature of

TABLE 1

Average plant phytomass present before grazing and percentage consumed by sheep in a coastal Oregon Douglas fir plantation during 1981 and 1982

Plant type	May 1981		May 1982		August 1982	
	Present ($kg\ ha^{-1}$)	Consumed (%)	Present ($kg\ ha^{-1}$)	Consumed (%)	Present ($kg\ ha^{-1}$)	Consumed (%)
Graminoids	1500±381[1]	71±5	2040±78	42±1	1300±183	29±2
Forbs	500±29	56±5	340±57	25±6	400±117	22±10
Ferns	31±7	54±26	5±2	32±32	2±2	<1
Shrubs	240±20	87±2	83±20	21±7	250±56	47±5
Douglas fir	34±1	40±2	10±1	42±2	120±11	15±6
Total phytomass	2300±390	68±3	2470±30	39±2	2100±161	29±2

[1]Data are mean ± SE.

TABLE 2

Sample size, mean tree height and mean diameter at breast height (dbh) for Douglas fir trees whose terminal was not browsed (0), browsed once (1), browsed twice (2), or browsed three times (3) during 1981 and 1982 (cumulative)

Item	Number of times terminal leader browsed			
	0	1	2	3
Sample size 1985	54	66	103	10
Height (m) 1985	3.99[a]	3.37[ab]	3.11[b]	2.67[b]
dbh (cm) 1985	5.07[a]	3.50[b]	2.87[c]	2.36[d]
Sample size 1990	54	64	101	10
Height (m) 1990	8.95[a]	7.97[b]	7.16[c]	7.11[c]
dbh (cm) 1990)	13.51[a]	10.45[ab]	9.03[b]	7.82[b]

Means in a row not sharing a common letter differ $P<0.05$, Student–Newman–Keul's multiple-range test.

TABLE 3

Average percentage of current year's lateral branch growth removed by sheep from trees whose terminal leader was ungrazed (0), browsed once (1), browsed twice (2), and grazed three times (3) during 1981 and 1982 (cumulative)

Terminals browsed	% Laterals browsed 1981	% Laterals browsed 1982
0	32±3.2[1]	43±2.7
1	24±2.9	49±2.7
2	38±2.1	53±1.9
3	48±5.5	92±6.7

[1]Data are mean ± SE.

Douglas fir height growth. Consumption of the current year's leader not only directly removes the height of the leader consumed, but also removes the potential which that meristem represents for subsequent growth. The 0.3–0.6 m height loss for each terminal removed corresponds approximately to one year's height growth during the 1981–1983 study period.

Radial tree growth was more sensitive to browsing than was tree height. Average dbh in 1985 was reduced by 31%, 43% and 54% by removal of 1, 2 or 3 terminal leaders, respectively, during 1981 and 1982 (Table 2). The general sensitivity of diameter growth to silvicultural management variables is well known. In our study, trees with high levels of lateral branch browsing were also those most likely to have their terminal leaders removed by sheep. Therefore, terminal leader removal and degree of lateral foliage removal are to some extent correlated (Table 3). The independent effects of each one are difficult to isolate. One might logically conclude that reduced diameter growth of browsed trees largely accrues from less leaf area available to support growth. However, while average levels of total lateral branch defoliation were similar between treatments 0 and 1 in both 1981 and 1982, dbh in 1985 differed significantly. Recent defoliation research in the Alsea area (K.A. Osman, unpublished data, 1990) suggests that diameter growth of Douglas fir trees decreases by only 1% for every 10% lateral branch removal when the terminal leader is left intact. These observations suggest that loss of the terminal leader may directly affect diameter growth. Moreover, both tree height and diameter growth appear to be more sensitive to loss of the terminal leader than they are to the amount of new lateral leaders removed. The mechanism for such an effect is unclear, but may involve changes in the balance of growth hormones within browsed trees. Browsing of the terminal meristem removes an important source of auxin (Salisbury, 1985), a compound which facilitates plant cell expansion (Rayles and Cleland, 1979). Presumably, removal of the terminal meristem while many lateral branch meristems are intact may favor growth of lateral branches at the expense of the main stem.

Similar to 1985, average Douglas fir height and dbh in 1990 exhibited a pattern of decreasing tree growth as the number of terminals removed increased. However, the numerical magnitude of treatment differences present in 1990 was greater than those present in 1985. Averaged over all levels of removal, 1985 tree height declined by 44 cm and dbh by 0.9 cm for each terminal leader browsed. By 1990, these differences had increased to 61 cm of tree height and 1.9 cm of dbh reduction for each terminal browsed. Tendency of treatment effects on tree size to become more pronounced over time reflects the geometric nature of conifer growth in which future growth is strongly influenced by present plant size.

The net silvicultural effects of livestock grazing were evaluated by comparison of grazed and ungrazed plots. Grazing effects on tree growth generally represent a balance between the direct negative effects of browsing and trampling of seedlings compared to the indirect positive effects of reduced competition between planted trees and other vegetation in the plantation. No trampling damage to young study trees was observed during the course of this research. Only 1–2% of study trees each year suffered branch breakage or other types of mechanical injury from sheep. The predominant direct impact of sheep upon trees was through browsing as previously discussed. Although individual tree height and diameter growth were reduced by browsing in grazed stands (where all trees got the benefits of grazing), average tree diameter for grazed and ungrazed stands were similar during 1981–1985 (Table 4). Grazing effects on average stand height were not detected until 1984. In 1985, the grazed stand was similar in average dbh, but 35 cm shorter than the ungrazed stand. Apparently, positive effects of grazing were more effective in compensating for browsing impacts upon dbh than for height. The plantation, with the exception of study plots, was thinned to 500 trees ha^{-1} in 1985. Thinning

TABLE 4

Average Douglas fir diameter and height for trees growing in ungrazed (U) and grazed (G) plots near Alsea, OR

Year	Diameter (cm)		Height (m)	
	U	G	U	G
1981[1]	1.1±0.04[2]	1.2±0.03	0.80±0.02	0.79±0.02
1982[1]	1.6±0.11	1.6±0.05	1.02±0.04	0.98±0.03
1983[1]	2.4±0.06	2.4±0.07	1.44±0.06	1.47±0.07
1984[1]	4.6±0.13	4.5±0.12	2.87±0.08	2.57±0.09*
1985[3]	4.2±0.15	3.9±0.11	3.76±0.10	3.41±0.09*
1990[3]	8.2±0.30	10.0±0.34*	7.54±0.04	7.97±0.11*

[1]Basal diameter.
[2]Data are mean ± SE.
[3]Diameter at breast height.
*Grazed differs from ungrazed, $P<0.05$.

TABLE 5

Average density, basal area at breast height (cm^2), and total basal area at breast height (m^2) of Alder and Douglas fir growing in ungrazed (U) and grazed (G) plots near Alsea, OR in 1990

Item	Alder		Douglas fir	
	U	G	U	G
Stems ha (N)	548±58[1]	314±80*	1500	1500
Basal area stem^{-1} (cm^2)	182±27	99±14	53±1	79±6*
Basal area ha^{-1} (m^2)	6.5±1.1	2.8±0.7*	7.9±0.1	11.8±0.9*

[1]Data are mean ± SE.
*Grazed and ungrazed differ, $P<0.05$.

of study plots to this density by removing trees with the smallest dbh in 1985 would have yielded grazed and ungrazed stands with similar ($P>0.05$) average dbh and height (dbh = 5.04 cm and 5.08 cm; height = 3.96 m and 4.43 m for grazed vs. ungrazed, respectively).

Sheep (Hedrick and Keniston, 1966; Sharrow et al., 1989) or cattle grazing (Krueger and Vavra, 1984; Allen and Bartolome, 1989) can effectively reduce competition between unwanted woody vegetation and young conifers. Reduction of competing vegetation is often reflected in greater conifer diameter and height growth. In Oregon, cattle grazing has been reported to increase Douglas fir diameter growth by 26–31% and height growth by 7–18% (Krueger and Vavra, 1984; Doescher et al., 1989), while sheep grazing (Hedrick and Keniston, 1966; Jaindl and Sharrow, 1988; Sharrow et al., 1989) has increased height growth by 5–27% and diameter growth by 7–39% compared to ungrazed controls. Sheep in our plantation were very effective in removing both grass and shrub phytomass (Table 1).

Dense grass stands may benefit from grazing which removes the leaf canopy so that light can reach the plant crown to stimulate initiation of new tillers (Chapman et al., 1983; Motazedian and Sharrow, 1986). Total grass phytomass production on ungrazed plots declined to 260 kg ha^{-1} in 1982 compared to 680 kg ha^{-1} in 1981, while grazed plots produced 540 and 800 kg ha^{-1} of grass in 1981 and 1982, respectively. As with pastures (Sharrow et al., 1981), seedings of potentially high-producing grass species in forest plantations may require grazing by either livestock or native herbivores if they are to persist for longer than 1 or 2 years.

The combination of grass seeding and grazing proved to be very effective in suppressing alder establishment and growth. Alder began to establish from seed in the ungrazed plots in 1981. No alder seedlings were seen in the grazed plots until sheep grazing was discontinued in 1983. Alder on ungrazed plots had overtopped Douglas fir by 1990, being approximately 12–13 m tall compared to only 7.5 m for Douglas fir. Grazed timber stands contained 43% fewer alder stems and less than half as much alder basal area as ungrazed stands in 1990 (Table 5). Average Douglas fir height in 1990 was 6% and dbh 22% greater on grazed compared to ungrazed stands (Table 4), presumably as a result of reduced competition with alder in grazed stands. Total tree basal area (alder + Douglas fir dbh) in 1990 was similar ($P > 0.05$) for both grazed and ungrazed stands (Table 5). However, Douglas fir contributed only 55% of total tree basal area in ungrazed stands compared to 81% in grazed stands. Examination of 24 trees within grazed stands whose terminal leaders were not browsed in either 1981 or 1982 suggests that vegetation control by sheep without associated terminal leader browsing would have increased 1985 height by 6%, 1985 dbh by 34%, 1990 height by 16% and 1990 dbh by 46% compared to ungrazed controls. The potential benefits of vegetation suppression were, to some extent, offset by loss of growth due to browsing. However, the net effect of sheep grazing was to increase subsequent tree growth.

CONCLUSIONS

Our data suggest that sheep grazing may be useful to reduce competition between Douglas fir regeneration and native hardwoods such as red alder. Increased Douglas fir growth attributable to grazing was not apparent until 3 years after grazing had ceased, when the stand was 5–6 years old. This delayed response to grazing probably reflects both initial browsing impacts of sheep on Douglas fir trees and increased competition between Douglas fir and red alder as both grew. The levels of browsing sustained by trees in this study are the result of timing and degree of grazing by sheep which tended to maximize sheep use of trees (Leininger and Sharrow, 1989). Other research in the Alsea area has achieved high levels of understory plant control (Sharrow et al., 1989) with less than 5% of Douglas fir terminal leaders browsed (Leininger and Sharrow, 1989). Increases in tree growth over the 10 years reported in this paper are, therefore, probably substantially less than those obtainable by skillfully applied sheep grazing.

ACKNOWLEDGEMENTS

Technical Paper No. 9517, Oregon Agricultural Experiment Station, Corvallis. Work was funded by the Alsea Ranger District, Siuslaw National Forest, US Forest Service and the Oregon Agricultural Experiment Station. Authors gratefully acknowledge the advice and support of Alsea Ranger District personnel, Gene Klingler, Ned Davis and Steven Smith for their assistance throughout the conduct of the study, and particularly to Ken McCall who assisted in collecting tree growth data.

REFERENCES

Allen, B. and Bartolome, J.W., 1989. Cattle grazing effects on understory cover and tree growth in mixed conifer clearcuts. Northwest Sci., 63: 214–220.

Cassady, J.T., 1941. A method of determining range forage utilization by sheep. J. For., 39: 667–671.

Chapman, D.F., Clark, D.A., Land, C.A. and Dymock, N., 1983. Leaf and tiller growth of *Lolium perenne* and *Agrostis* spp. and leaf appearance rates of *Trifolium repens* in set stocked and rotationally grazed hill pasture. N.Z. J. Agric. Res., 26: 156–168.

Cleary, B.D., Greaves, R.D. and Herman, R.K., 1978. Regenerating Oregon's Forests. Oregon State Univ. Agr. Ext. Serv., Corvallis, 286 pp.

Cole, E.C. and Newton, M., 1986. Fifth-year responses of Douglas-fir to crowding and nonconiferous competition. Can. J. For. Res., 17: 181–186.

Corliss, J.F., 1973. Soil survey, Alsea area, Oregon. US Govt. Printing Office, Washington, DC, 36 pp.

Corliss, J.F. and Dyrness, C.T., 1965. A detailed soil–vegetation survey of the Alsea area in the Oregon Coast Range. In: C.T. Youngberg (Editor), Forest Soil Relationships in North America. Oregon State Univ. Press, Corvallis, pp. 457–483.

Dimock, E.J. II, Beebe, T.F. and Collard, E.B., 1983. Planting-site preparation with herbicides to aid conifer reforestation. Weed Sci., 31: 215–221.

Doescher, P.S., Tesch, S.D. and Alejandro-Castro, M., 1987. Livestock grazing: a silvicultural tool for plantation establishment. J. For., 85: 29–37.

Doescher, P.S., Tesch, S.D. and Drewien, W.E., 1989. Water relations and growth of conifer seedlings during three years of cattle grazing on a southwest Oregon plantation. Northwest Sci., 63: 232–240.

Dyrness, C.T., 1973. Early stages of plant succession following logging and burning in the western Cascades of Oregon. Ecology, 54: 57–69.

Franklin, J.F. and Dyrness, C.T., 1973. Natural vegetation of Oregon and Washington. USDA Forest Serv. Gen. Tech. Rep. PNW-8, 417 pp.

Grieman, H.L., 1988. Sheep grazing in conifer plantations. Rangelands, 10: 99–101.

Hedrick, D.W. and Keniston, R.F., 1966. Grazing and Douglas-fir growth in the Oregon white-oak type. J. For., 64: 735–738.

Jaindl, R.G. and Sharrow, S.H., 1988. Oak/Douglas-fir/sheep: a three-crop silvopastoral system. Agroforestry Sys., 6: 147–152.
Krueger, W.C. and Vavra, M., 1984. Twentieth-year results from a plantation grazing study. In: Research in Rangeland Management. Oregon Agr. Exp. Sta. Spec. Rep. 715, Corvallis, pp. 20–24.
Leininger, W.C. and Sharrow, S.H., 1987. Seasonal diets of herded sheep grazing Douglas-fir plantations. J. Range Manage., 40: 551–554.
Leininger, W.C. and Sharrow, S.H., 1989. Seasonal browsing of Douglas-fir seedlings by sheep. West. J. Appl. For., 4: 73–76.
Motazedian, I. and Sharrow, S.H., 1986. Defoliation effects on forage dry matter production of a perennial ryegrass-subclover pasture. Agron. J., 78: 581–584.
Rayles, D.L. and Cleland, R., 1979. Control of plant cell enlargement by hydrogen ions. Curr. Topics Biol., 11: 187–214.
Rhodes, B.D. and Sharrow, S.H., 1990. Effect of grazing by sheep on the quantity and quality of forage available to big game in Oregon's Coast Range. J. Range Manage., 43: 235–237.
Salisbury, F.B., 1985. Plant Physiology. Wadsworth, Belmont, CA, 540 pp.
Sharrow, S.H., Krueger, W.C. and Thetford, F.A., Jr., 1981. Effects of stocking rate on sheep and hill pasture performance. J. Anim. Sci., 52: 210–217.
Sharrow, S.H., Leininger, W.C. and Rhodes, B., 1989. Sheep grazing as a silvicultural tool to suppress brush. J. Range Manage., 42: 2–4.
Stewart, R.E., 1978. Origin and development of vegetation after spraying and burning in a coastal Oregon clearcut. USDA Forest Serv. Res. Note PNW-317, 10 pp.
Strothmann, R.O. and Roy, D.F., 1984. Regeneration of Douglas-fir in the Klamath Mountains region, California and Oregon. USDA Forest Serv. Gen. Tech. Rep. PSW-81, 35 pp.

Forest Ecology and Management, 50 (1992) 85–101
Elsevier Science Publishers B.V., Amsterdam

An economic comparison of black spruce and jack pine tree improvement

Daniel McKenney[a], Glenn Fox[b] and Willem van Vuuren[b]
[a]*Forest Resource Economics, Forestry Canada–Ontario Region, Sault Ste. Marie, Ont. P6A 5M7, Canada*
[b]*Department of Agricultural Economics and Business, University of Guelph, Guelph, Ont. N1G 2W1, Canada*

(Accepted 18 April 1991)

ABSTRACT

McKenney, D., Fox, G. and van Vuuren, W., 1992. An economic comparison of black spruce and jack pine tree improvement. *For. Ecol. Manage.*, 50: 85–101.

Black spruce and jack pine seed orchard programs in Ontario are compared using cost–benefit analysis. The analysis illustrates economic relationships that should be considered when developing tree improvement programs, particularly if budgets are limited. Important factors include stumpage values, potential size of the improved planting program, magnitude of the genetic gain, quality of the land-base, the discount rate and the fecundity of seed orchards through time. Optimal economic rotation ages were calculated for unimproved and improved plantations. The difference in net present value of an infinite number of unimproved and improved plantations was compared to research costs to determine if tree improvement was economically worthwhile. This approach enables each generation of tree improvement activities to be considered on its own potential merits. Jack pine tree improvement consistently outperformed black spruce tree improvement in its economic potential.

INTRODUCTION

Tree improvement has become an increasingly important component of forest management in Canada and other countries in recent years. The goal of tree improvement is to improve the productivity of plantations by using genetically superior planting stock that increases volume and/or improves wood quality. This increased productivity, however, can only be obtained at a cost. Much of the justification of tree improvement programs in Canada has been drawn from the success of programs in other parts of the world. However, data are now available to estimate the economic impact of some Canadian tree improvement programs.

Currently there are two approaches to tree improvement in Ontario: (1) the seed orchard approach; (2) a clonal forestry/rooted cuttings approach (Rauter, 1984). A previous paper by McKenney et al. (1989) compared these

Correspondence to: D. McKenney, Forest Resource Economics, Forestry Canada–Ontario Region, Sault Ste. Marie, Ont. P6A 5M7, Canada.