An analysis of the effect of shelterwood, seeding density and scarification on the regeneration of Sitka spruce on a forest site in Co Wicklow

Niall Farrelly[1], Michael Keane[2] and Áine Ní Dhubháin[3]

Abstract

An experiment to measure the effect of shelterwood, scarification and seeding rate on the regeneration and survival of Sitka spruce was established in a mature stand of Sitka spruce in Co Wicklow. Two levels of shelterwood and a clearcut control were randomly assigned in a randomised block design. The shelterwood treatments were established by thinning the plantation to retain 150 or 300 stems ha^{-1}. Within the shelterwood treatments sub-plots were established comprising three seeding rates and two soil scarification treatments in factorial combination. The effect of the treatments on the establishment and survival of seedlings after one growing season was determined. Results showed that survival in the 300 stems ha^{-1} shelterwood treatment plots was significantly higher than in the other treatments. The benefit of soil scarification on seedling survival was only evident in the 300 stems ha^{-1} treatment plots. Seeding rate did not result in a significant difference in the number of seedlings surviving after the first growing season.

Keywords: Sitka spruce, regeneration, shelterwood, soil scarification, seeding rate.

Introduction and literature review

In recent years, in both Britain (Yorke 1995, Kerr 1999) and Ireland (COFORD 1994, Ní Dhubháin et al. 2002), there has been increasing interest in the use of silvicultural systems other than clearfelling for harvesting and regeneration. This is a response to criticisms of clearfelling harvesting practices and their impact on many non-wood forest resources, such as scenic values, habitats, biodiversity and recreation (Jull and Stephenson 2000). Society increasingly demands that forest products originate from sustainably managed forests, where biodiversity is conserved, and environment-friendly forest practices are used.

Traditionally, the use of silvicultural systems alternative to clearfelling was to assist the process of natural regeneration for the reforestation of forest sites. Countries and regions without a tradition of natural regeneration are now turning to it as a means of achieving a range of resource management objectives (Farnden 1994, Yorke 1995, Hollsteadt and Vyse 1997, Vyse 1997, Kerr 1999), and those associated with sustainable forest management.

The shelterwood system plays a vital role in the success of natural regeneration by influencing the environment of emerging tree seedlings (Skoklefald 1989 & 1992, Holgen 1999, D'Anjou 2000). In its use part of the forest canopy is retained and this provides shelter and a suitable microclimate for the germination and development of seedlings (Holgen 1999). The role of the shelterwood system is thought to be in regulating the light, soil moisture, and soil and air temperature that are critical to the development of seedlings. Studies investigating natural regeneration indicate that the survival of seedlings is also

1 Forest Service, Johnstown Castle, Co Wexford, Ireland (niall.farrelly@dcmnr.gov.ie).
2 Coillte, Newtownmountkennedy, Co Wicklow, Ireland (michael.keane@coillte.ie).
3 Department of Crop Science, Horticulture and Forestry, University College Dublin, Belfield, Dublin 4, Ireland (aine.nidhubhain@ucd.ie).

enhanced by the provision of canopy cover (D'Anjou 2000 & 2001). It has also been shown that the number of established seedlings increases with the density of the shelterwood at low altitudes in central Sweden (Hagner 1962, Hannell 1991, Holgen 1999).

Studies of seeding density and the effects of seedbed condition have implications also for the potential of natural regeneration in reforestation. Scarification can improve the likelihood that tree seeds will germinate and become established (Hagner 1962, Valtanen 1988, Zasanda and Wurtz 1990, Skoklefald 1989 & 1992). The disturbance of the seedbed to expose mineral soil improves the establishment of seedlings (Feller 1996, D'Anjou 2001, Jull and Stephenson, 2001).

Adequate seedfall is essential for natural regeneration (D'Anjou 2001) and is a limiting factor in some years (Eremko et al. 1989, Young and Young 1992, Leadem et al. 1997, Nixon and Worrell 1999). To reduce the probability of seedfall becoming the limiting factor, direct seeding may be needed on some site types (Jull and Stephenson 2001).

It has been shown that some factors are more critical to regeneration success than others. Burton et al. (2001) indicated that germination of four conifer species responded more strongly to seedbed treatment than to canopy treatment. Jull and Stephenson (2001) found that direct seeding increased the number of Engelmann spruce (*Picea engelmannii*) seedlings in clearcut treatments, regardless of whether the seedbed had been screefed during seedbed preparation. Feller (1996) indicated that the optimum treatment for encouraging regeneration in Engelmann spruce was to provide partial shade and expose mineral soil. Holgen (1999) recommended that in order to regenerate sites effectively the number of shelterwood trees should be more than 200 stems ha^{-1} to provide adequate protection for natural regeneration. The growth of seedlings is greater for light demanding species such as Engelmann spruce (*Picea engelmannii*) and Douglas fir (*Pseudotsuga menziesii*) in clearcuts than under a forest canopy (Feller 1997, D'Anjou 2000 & 2001, Jull and Stephenson 2001). Willen (1996) found that seedling height increment increased with light intensity up to a certain point, corresponding to 65% of that on open ground. He also found that maximum dry matter production was under open, full light conditions. Holgen (1999) found that a higher percentage of seedlings reached a height of 100 cm after eleven growing seasons in a sparse, compared to a dense, shelterwood treatment.

Materials and methods

In November 1998, a project to examine alternative silvicultural systems to clearfelling was initiated by Coillte and UCD. A trial to evaluate the potential of the shelterwood system in Sitka spruce was established as a part of the project.

Site and stand characteristics

The experiment was located in a 42-year-old stand of Sitka spruce at Djouce woods near Enniskerry, Co Wicklow, a Coillte (Irish Forestry Board) property (Figure 1). The site was at an elevation of 309 m, had an easterly aspect and a slope of 5°. The soiltype was a moderately- to well-drained brown podzolic, with a thin surface organic layer.

The crop was stable with no evidence of windthrow. Crop mean diameter at breast height (dbh) was 32.4 cm, with a top height of 22 m. Stocking was 459 stems ha^{-1}, with a standing volume (over bark, to 7 cm top diameter) of 386 m^3 ha^{-1}.

Shelterwood treatments and experimental design
Three shelterwood treatments were investigated:

1. removal of all standing and dead trees;
2. shelterwood felling to 150 stems ha^{-1} (150 sph)
3. shelterwood felling to 300 stems ha^{-1} (300 sph).

Felling took place in February 1999. In the shelterwood fellings, sufficient co-dominants were felled to arrive at the required stocking level.

Mean post-harvest stocking in the shelterwood treatments was close to the experimental requirement. Basal area was reduced by 61% and 28% and stem numbers from 466 to 158 stems ha^{-1} and from 446 to 303 stems ha^{-1} in the 150 and 300 sph treatments, respectively (Table 1). The mean dbh increased slightly following thinning. This is attributable to the removal of trees of smaller diameter than the mean (low thinning).

Table 1: *Pre- and post-felling stand structure by shelterwood treatment.*

Treatment	*Mean stocking*		*Basal area*		*Mean dbh*	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*
	stems ha^{-1}		*m^2 ha^{-1}*		*cm*	
Clearcut	467	0	38.1	0.0	32.4	0.0
150 sph	466	158	37.2	14.5	31.8	34.2
300 sph	446	303	38.6	27.6	33.1	34.1

Mean canopy cover in the 150 and 300 sph shelterwood treatments was 67.1% and 79.9%, respectively (Table 2).

Table 2: *Mean canopy cover by shelterwood treatment.*

Treatment	*Canopy* %
150 sph	67.1
300 sph	79.9

In all treatments the harvesting debris was moved into windrows, leaving just a light covering. To protect seedlings from browsing a 2 m high deer fence was erected around the entire experiment site before seeding.

Treatments were laid down in a randomised block design, with three replications. Treatment plots were 0.5 ha in area. Within each main plot six sub-plots (1 x 1 m), representing a factorial combination of three seeding rates and scarification/no scarification, were randomly assigned, giving a total of 54 plots.

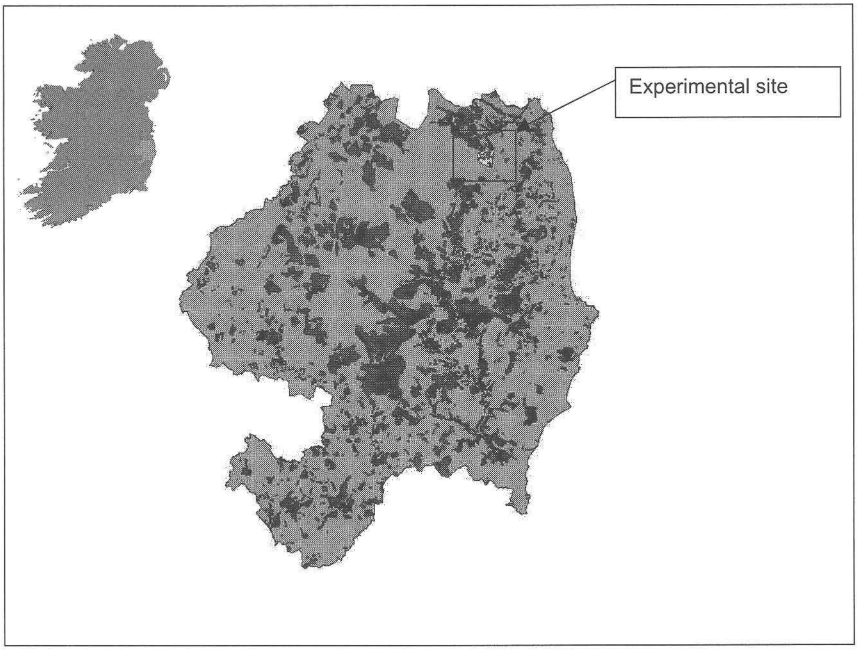

Figure 1: *Location of experiment site in Co Wicklow.*

Seeding rates (1.08, 2.17 and 4.34 g plot^{-1}, corresponding[4] to 5, 10 and 20 million seeds ha^{-1}) were based on seed fall densities reported in Nixon (1998 & 1999). The seed (viability 95%), which had been stratified, was obtained from Coillte's Ballintemple nursery. Seed was evenly spread over each sub-plot from a height of 1.3 m, taking care to avoid any spread outside the plot boundary. Scarification was carried out by manually raking off the humus layer to expose the underlying mineral soil. The no scarification control plots were left untouched.

Measurement and statistical analysis

Diameter breast height (dbh) of all trees over 7 cm dbh in each shelterwood plot was measured, from which stocking, mean dbh, basal area/ha were computed (Table 1). Post-harvest stand measurement was undertaken directly after harvest. Canopy cover in the shelterwood plots was calculated by categorising each intersection point of a 1 x 1 m grid as 0 or 1, depending on the absence or presence of canopy (see Jennings et al. 1999 for a description of the technique used). Both the dbh measurement and the canopy cover assessment were undertaken in April and May 1999.

Seedling density was determined in September 1999, after the first growing season, by placing a 20 x 20 cm grid (400 cm^2) over the centre of each sub-plot and counting the

4 Based on an average weight of 2.17 g/1000 for Sitka spruce seed (Brown & Neustein 1974).

number of seedlings within the grid. In addition, the height of the tallest seedling in the grid was measured to the nearest 0.5 cm.

The effect of the treatments on seedling density and seedling height was determined using an analysis of variance.

Results

Seedling germination and survival

The mean density of seedlings after one growing season ranged from 550,000 to 10,700,000 ha^{-1} (Table 3). The density in the 300 sph shelterwood plots was almost double the density in the 150 sph treatment plots and triple the number in the clearfell plots. The difference in density between the 300 sph treatment and the two other treatments was highly significant ($p \leq 0.01$) while the difference between the 150 sph and clearfell treatments was not significant.

The mean density of seedlings in the moderately (10,000,000 ha^{-1}) and heavily (20,000,000 ha^{-1}) seeded plots was similar, while the density in the lowest seed application although considerably lower (Table 3), was not statistically different from the other two.

On average the seedling density in the scarified plots was higher than in the unscarified plots. However, there was a significant interaction ($p \leq 0.05$) between scarification and shelterwood treatment. In the 300 sph shelterwood, scarified plots, the mean number of seedlings was almost three times greater than the mean number in the unscarified plots ($p \leq 0.01$). In contrast there was little or no difference between the scarified and unscarified treatments in the other shelterwood treatments (Table 3).

Table 3: *Effect of shelterwood, scarification and seeding rate on seedling density.*

Seeding rate	*Shelterwood treatment*						
	Clearcut		*150 sph*		*300 sph*		
	Scarification						
	US[1]	*S*[2]	*US*	*S*	*US*	*S*	*Seeding rate mean*
seeds ha^{-1}	*seedlings ha^{-1}*						
5,000,000	550,000	550,000	2,325,000	1,875,000	1,500,000	4,125,000	1,825,000
10,000,000	2,325,000	1,050,000	3,300,000	4,075,000	3,575,000	5,800,000	3,350,000
20,000,000	1,250,000	3,125,000	2,050,000	2,250,000	2,675,000	10,700,000	3,675,000
Scarification x shelterwood mean	550,000	550,000	2,325,000	1,875,000	1,500,000	4,125,000	
Shelterwood mean		1,575,000		2,725,000		6,875,000	

[1]Unscarified

[2] Scarified

Early growth

The mean height of the tallest seedling in the clearfell plots was 3.7 cm after one growing season (Table 4) while in the 150 sph and 300 sph shelterwood plots it was 2.9 cm and 2.2 cm respectively. The difference was not statistically significant. Furthermore, scarification and seed density did not significantly influence seedling height at the end of one growing season.

Table 4: *Effect of shelterwood, scarification and seeding rate on seedling height.*

	Shelterwood treatment						
	Clearcut		*150 sph*		*300 sph*		
Seeding rate	*Scarification*						
	US[1]	*S*[2]	*US*	*S*	*US*	*S*	*Seeding rate mean*
Seeds ha^{-1}	*cm*						
5,000,000	3.5	3.3	3.5	3.2	1.7	2.0	2.9
10,000,000	3.5	4.7	3.2	2.3	2.2	2.5	3.1
20,000,000	3.8	3.8	2.3	2.7	2.8	1.8	2.9
Scarification x shelterwood mean	3.6	3.9	3.0	2.7	2.2	2.1	
Shelterwood mean	3.7		2.9		2.2		

[1]Unscarified
[2] Scarified

Discussion

The removal of trees in the shelterwood treatments resulted in relatively small reductions in canopy cover but corresponding large reductions in basal area. Canopy cover of 79.9% in the 300 sph plots equated to a basal area of 27.6 m^2 ha^{-1}. This represents a reduction of 28.5 % of the original pre-harvest basal area. The effect of reducing stem numbers from 300 sph to 150 sph in the shelterwood treatments resulted in a reduction in basal area from 27.6 m^2 ha^{-1} to 14.5 m^2 ha^{-1}, a reduction of 50%. However, the corresponding decrease in canopy cover was just over 12%. As only co- and sub-dominants were removed (low thinning) it is unclear whether the reduction in canopy cover would have been greater had larger diameter trees been removed in thinning. It would be expected that the removal of larger trees with larger canopies would result in a greater decrease in canopy cover. Overall the removal of co-dominant trees had very little effect on the level of canopy cover. These results are similar to those reported for Douglas fir (*Pseudotsuga menziesii)* by Burton et al. (2000). They found that removal of up to 30% and 50% of the basal area resulted in light levels that were only 20% and 38%, respectively, of levels in clearfell treatments. This indicates that when fewer trees are retained they can still provide relatively high degrees of shade.

The trends in seedling density agree with those of Hagner (1962) and Hannell (1991) where the density of seedlings increased with the density of shelterwood. Seedling density was significantly greater in the 300 sph than in the 150 sph shelterwood and clearfell plots. It is clear that the retention of canopy cover in the shelterwood treatments had a positive impact on the number of seedlings surviving. Similar results were reported by D'Anjou (2000 & 2001).

Seedling density in the 150 sph shelterwood plots was intermediate between that in the clearfell and 300 sph shelterwood plots. This suggests that retaining some degree of cover results in greater seedling densities.

In all treatments the density of seedlings after one growing season exceeded by two orders of magnitude what is currently the normal planting density for spruce. While the analysis showed that there was no significant difference in the number of seedlings surviving in relation to the weight of seed sown, the data suggest that higher seeding densities, equivalent to 10,000,000 and 20,000,000 seed ha^{-1}, resulted in higher seedling densities compared with the lowest seeding rate. Considerable seedling mortality can occur during the first two years (MacNeill and Thompson 1982, Clarke 1991 and Nixon and Worrell 1999). It is also important to remember that seeds used in this study had a high viability; under natural conditions this viability might be considerably lower.

Scarification increased seedling density, confirming the findings of Hagner (1962), Valtanen (1988), Zasanda and Wurtz (1990) and Skoklefald (1989 & 1992). Germination is more rapid on mineral soil than on litter, especially so when seeds are pressed into the soil rather than scattered on the surface (Scarratt 1968, Feller 1996, D'Anjou 2001, Jull and Stephenson 2001). However, the results from this study show that the benefits of scarification were only evident in the dense shelterwood with almost three times the seedling density in the scarified compared with the unscarified plots. In contrast, in both the clearfell and 150 sph shelterwood plots scarification had little impact.

Conclusions

The results suggest that maintaining a dense canopy cover for at least the first year after germination increases the likelihood of seedling survival, perhaps at the expense of height growth. The results further suggest that scarification will not improve seedling density on clearfelled sites or under relatively sparse shelterwood, but will do so under a denser canopy. The optimum treatment for the successful establishment of regeneration in Sitka spruce therefore seems to be to provide partial shade and expose the mineral soil. Feller (1996) and Holgen (1999) have reported similar results. Retaining significant proportions of the final crop can provide this shelter.

As indicated forest operations can play a significant part in the preparation of stands for regeneration by carrying out silvicultural and site preparation operations. Indications are that seeding rate is a less important factor once the quantity sown is above a certain threshold, suggesting that satisfactory stocking levels in good seed years using similar methods may be achieved. The results reported here, were, however, achieved with seeding rates greater than expected rates in an average seed year. It is also anticipated that the number of seedlings will considerably reduce over time. Furthermore, observations suggest that the spatial distribution of regeneration will be considerably more uneven under natural conditions, from that achieved in this study.

In order to provide more information on the long-term survival and development of seedlings further research is necessary. The use of silvicultural systems also needs to take account of their wind stability under Irish conditions and the likely level of damage to the remaining trees in the shelterwood. These considerations and investigations are necessary in order to provide fuller recommendations on alternatives to clearfelling in Sitka spruce crops.

Acknowledgements

The funding for this study was provided by COFORD and Coillte. The authors would like to thank Mr Donal O'Hare and Mr John Casey for help with establishing the experiment and with seedling measurements.

References

Brown, J.M.B. and Neustein, S.A. 1974. *Natural regeneration of conifers in the British Isles*. Proc. Roy. Hort. Soc. 3rd Conf. 29 – 38.

Burton, P.J. 1997. Conifer germination on different seedbeds influenced by partially cut canopies (abstract). *Bull. Ecol. Soc. Am.* 78 (Suppl.): 230.

Burton, P.J., Sutherland, D.C, Daintith, N.M., Waterhouse, M.J and Newsome, T.A. 2000. *Factors influencing the density of natural regeneration in uniform shelterwoods dominated by Douglas fir in the sub-boreal spruce zone*. British Columbia Working Paper 47. British Columbia Ministry of Forests, Victoria.

Clarke, G.C. 1992. The natural regeneration of spruce. *Scottish Forestry* 46 (2): 107 – 129.

COFORD 1994. Pathway to Progress: Silviculture and Forest Management. In *Pathway to Progress: A Programme for Research and development in Ireland*. COFORD, Dublin, pp 51–52.

D'Anjou, B. 2000. *Alternative Silvicultural Systems on Steep-Sloped Old-growth Forests on the Queen Charlotte Islands - Project Overview and Regeneration Development*. British Columbia Ministry of Forests, Research Section, Vancouver Forest Region.

D'Anjou, B. 2001. *Effects of Alternative Silvicultural Systems on Windthrow and Conifer Regeneration in a Coastal, Douglas-Fir-Dominated Forest: Summary of year 3 results from the Roberts Creek Study Forest*. Technical Report TR-0B07.C, British Columbia Ministry of Forests, Research Section, Vancouver Forest Region.

Eremko, R.D., Edwards, D.G.W. and Wallinger, D. 1989. *A guide to collecting cones of British Columbia conifers*. FRDA report 055. Forestry Canada and British Columbia Ministry of Forests, Victoria.

Farnden, C. 1994. *Forest regeneration in the ESSF zone of north-central British Columbia*. Info. Rep. No. BC-X-351. Natural Resources Canada and Canadian Forest Service, Victoria.

Feller, M. 1997. The Sciamous Creek Silvicultural Systems Project: Regeneration of Engelmann Spruce and Subalpine Fir from seed in ESSFwc2 Forests. In *Sciamous creek Silvicultural Systems Project: workshop proceedings*. Eds. Hollsteadt, C. and Vyse, A., British Columbia Ministry of Forests, Working Paper 24, pp. 154-169.

Hagner, S. 1962. Regeneration under shelterwood stands. An *analysis of the method of regeneration, its potentialities and limitations in forest management in middle north Sweden*. Rep. of the For. Res. Inst. of Sweden 52:4.

Hamilton, G.J. 1975. *Forest Mensuration Handbook*. Forestry Commission Booklet No. 39. HMSO, London.

Hannell, B. 1991. *Shelterwood regeneration of spruce forests on productive peatlands*. Swed. Univ. of Agri Sciences, Dept. of Silviculture, Umea. Report 32. (Swedish with English summary).

Holgen, P. 1999. *Seedling performance, shelter tree increment and recreational values in boreal shelterwood stands*. Swed. Univ. of Agri Sciences, Dept. of Silviculture, Umea. Ph D. thesis.

Hollsteadt, C. and Vyse, A. (Eds.) 1997. *Sciamous creek Silvicultural Systems Project: workshop proceedings*. British Columbia Ministry of Forests, Working Paper 24.

Jennings, S.B. Brown, N. D. and Sheil, D. 1999. Assessing forest canopies and understorey illumination: canopy closure, canopy cover and other measures. *Forestry* 72(1): 59 – 73.

Jull, M.J. and Stephenson, S.K (editors) 2001. *The Lucille mountain study: 8 year results of a silvicultural systems trial in the Engelmann Spruce-Subalpine Fir zones*. B.C. Work pap. 59/2001. Res. Br., B.C. Min. For., Victoria.

Kerr, G. 1999. The use of silvicultural systems to enhance biological diversity of plantation forests in Britain. *Forestry* 72(3): 191 – 205

Leadem, C.L., Gillies, S.L., Yearsley, H.K., Sit, V., Spittlehouse, D.I., and Burton, P.J. 1997. *Field studies of seed biology*. Land Management Handbook 40. British Columbia Ministry of Forests, Research Branch, Victoria.

McNeill, J.D. and Thompson, D.A. 1982. Natural regeneration of Sitka spruce in the forest of Ae. *Scottish Forestry* 36: 269 – 282.

Ni Dhubháin, A. O'Leary, D., Keane, M., Farrelly, N. and O'Hare, D. 2002. *Alternative Silvicultural Systems to Clearfell in Ireland*. COFORD, Dublin. Unpublished report.

Nixon, C.J. 1998. Personal communication.

Nixon, C.J. and Worrell, R. 1999. *The potential for the natural regeneration of conifers in Britain*. Forestry Commission Bulletin 120. HMSO, London.

Scarratt, J.B. 1966. *Investigations into the germination and early growth and survival of Sitka spruce seedlings under natural and artificial conditions*. Unpublished thesis. Department of Forestry, Univ. College North Wales, Bangor.

Skoklefald, S. 1989. *Planting and regeneration of Norway spruce under shelterwood and on clearcut area*. Norwegian For. Res. Inst. Research Paper 6.

Skoklefald, S. 1992. *Naturlig foryngelse av gran og furu*. Rapport fra Skogforsk. 12: 203–208.

Valtanen, J. 1988. *Stand reforestation at elevated sites in northern Finland*. Folia For. 718.

Vyse, A 1997. The Sciamous Creek Silvicultural Systems Project: how the project came to be and what it aims to accomplish. In *Sciamous creek Silvicultural Systems Project: workshop proceedings*. Eds. Hollsteadt, C. and Vyse, A., British Columbia Ministry of Forests, Working Paper 24, pp. 4-14.

Willen, E. 1996. *Ljusinslapp och skogsforyngring i granskarmar.* Swed. Univ. of Agri Sciences, Dept. of Silviculture, Umea, M.Sc. thesis.

Yorke, M. 1995. Continuous Cover Silvicultural Systems in Britain. *Scottish Forestry* 49(3): 162 – 165.

Young, J.A. and Young, C.G. 1992. *Seeds of woody plants in North America*. Dioscorides Press, Portland, Oregon. Revised edition.

Zasanda, J.C. and Wurtz, T.L. 1990. *Natural regeneration of white spruce on an upland site in interior Alaska*. British Columbia FRDA-Report, 84-85. Canadian Forest Service, Victoria.