An overview of the efficacy of vegetation management alternatives for conifer regeneration in boreal forests

by Alan Wiensczyk[1], Kathie Swift[1], Andrée Morneault[2], Nelson Thiffault[3], Kandyd Szuba[4] and F. Wayne Bell[5]

ABSTRACT

In this paper, we discuss the broad array of treatments that could be used to control competitive vegetation in conifer plantations in the boreal forests of Canada. We present vegetation management alternatives screened based on their treatment efficacy, which we defined as their ability to (a) control competitive vegetation and (b) not cause undue damage to conifer seedlings. The treatments reviewed range from pre-harvest (preventative) to post-plant release (reactive) treatments, and are organized into five categories: (i) silvicultural and harvest systems, (ii) physical treatments such as mechanical site preparation, cutting, girdling and mulching; (iii) thermal treatments such as prescribed fire and steaming; (iv) cultural treatments such as seedling culture, cover cropping, and grazing; and (v) chemical and biological spray treatments. We based our assessment of treatment efficacy on previous reviews, expert opinion, and published literature. We conclude on the need to further assess the effectiveness of forest vegetation management strategies in the context of multi-purpose plantations that consider ecological, social and silvicultural objectives.

Key words: plantation, vegetation management, competition, silviculture

RÉSUMÉ

Cet article aborde le large spectre des traitements sylvicoles utilisés pour maîtriser la végétation de compétition dans les plantations de conifères établies en forêt boréale au Canada. Nous présentons les diverses options sous l'aspect de leur efficacité, définie comme étant leur capacité (a) à maîtriser la végétation de compétition (b) sans causer de dommages aux conifères plantés. Les traitements considérés s'étendent des opérations pré-récolte (approches préventives) aux dégagements qui suivent la mise en terre des plants (approches réactives). Ils sont organisés en cinq catégories : (i) les systèmes sylvicoles et de récolte; (ii) les traitements physiques tels la préparation mécanique du terrain, la coupe, l'annelage et le broyage; (iii) les traitements thermiques tels le brûlage dirigé et le passage à la vapeur; (iv) les traitements culturaux tels la production des plants, l'utilisation de plantes de couverture et le broutement; et (v) la pulvérisation de produits chimiques ou biologiques. Nous avons basé notre évaluation de l'efficacité des traitements sur des revues de littérature déjà publiées, des opinions d'experts et la littérature scientifique récente. Nous concluons sur le besoin d'acquérir des connaissances concernant les stratégies de gestion de la végétation de compétition adaptées aux plantations multi-usages, dans lesquelles des objectifs écologiques et sociaux s'ajoutent à ceux de production de matière ligneuse.

Mots clés : plantation, contrôle de la végétation, compétition, sylviculture

Introduction

This paper, one of a series of papers published in the March/April, 2011 issue of *The Forestry Chronicle* regarding forest vegetation management (Bell *et al*. 2011c), summarizes information available on the array of vegetation management treatment alternatives and their effectiveness in controlling plants that compete with the growth and development of planted and natural Canadian boreal conifer species such as pine (*Pinus* spp.), spruce (*Picea* spp.), fir (*Abies* spp.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), larch (*Larix* spp.), and cedar (*Thuja* spp.). While the paper attempts to present a comprehensive assessment of all vegetation management options, it is necessarily influenced by the availability of the information. According to Thompson and Pitt (2003), most publications on vegetation management address mechanical, chemical, and manual approaches, while relatively few have considered biological controls, burning, alternate stocking, alternate harvesting, or genetics.

This synthesis is not meant to be a silvicultural guide; we assume readers are aware of the proper use, including timing, of the various vegetation management alternatives that are described. Rather it provides an updated source of information for forest managers on the efficacy of the various vegetation management treatments used in Canada. Treatment efficacy is defined in this paper as the ability of a treatment to control competitive vegetation without causing undue damage (or death) to conifer seedlings.

[1]FORREX Forum for Research and Extension in Natural Resources, 400–1488 4th Ave, Prince George, British Columbia V2L 4Y2. E-mail: alan.wiensczyk@forrex.org
[2]Southcentral Science Section, Ontario Ministry of Natural Resources, 3301 Trout Lake Rd., North Bay, Ontario P1A 4L7.
[3]Direction de la recherche forestière, Ministère des Ressources naturelles et de la Faune du Québec, 2700 Einstein, Québec, Québec G1P 3W8, and Associate Member, Centre d'étude de la forêt.
[4]EACOM Timber Corporation, 100 Old Nairn Rd., Nairn Centre, Ontario P0M 2L0.
[5]Ontario Forest Research Institute, Ontario Ministry of Natural Resources, 1235 Queen Street East, Sault Ste. Marie, Ontario P6A 2E5.

The benefits of controlling competing vegetation, especially during the first five years of conifer stand establishment, are well documented. Reducing competing vegetation can improve tree survival; diameter, height, basal area growth, and individual tree and stand volume growth; crown length and width; bud size; needle number, colour, length and retention; nutrient status; and tree vigour and resistance to damage from insects (Balandier *et al*. 2006). Stewart *et al*. (1984) reviewed many published and unpublished studies on the effects of competing vegetation on forest trees of the United States and Canada. They showed that trees respond markedly to release from competing vegetation. Following treatment, volume commonly increases 40% to 100% in the short term. Long-term studies (15 years or more) suggest that tree growth responses after release at early ages persist or increase until crown closure. After crown closure, inter-tree competition begins to control growth (Stewart 1987).

The consequences of failing to release conifers are most dramatically shown in a survey of northern Lower Michigan forest plantations. At age 40, red pine (*Pinus resinosa* Ait.), eastern white pine (*Pinus strobus* L.), and jack pine (*Pinus banksiana* Lamb.) plantations without competing overstories were 117%, 86%, and 40% taller, respectively, than overtopped trees. On red pine sites free of competition, the average standing volume was 675% greater (Stone and Chase 1962). In eastern Canada, Wagner *et al*. (2006) reported wood volume yield increases of up to 477% for planted black spruce (*Picea mariana* [Mill.] BSP) following intensive vegetation management, compared to untreated plots.

Vegetation management option loops

Vegetation management activities can be divided into two separate but related treatment option loops (Fig. 1). The *competition removal* loop, which is most common in vegetation management applications, contains treatments designed to release established crop trees from competition, hence the term *release treatments*. This loop can include broadcast, spot, or injection treatments with herbicides, and manual or motor manual cutting, including cut stump activities, girdling, and grazing. In contrast, the *competition prevention* loop can include, for example, altering the silvicultural system, harvest method and timing, site preparation (mechanical, chemical or fire), seedling culture, cover crops, and the use of mulches. Because some treatments can be used for both release and prevention (e.g., herbicides, grazing) the related information is organized here by treatment type rather than by application timing.

Choice of treatment to apply in a given situation will be influenced by the autecology of the species or groups of species to be controlled, as well as the management objectives, other site values, environmental considerations, and socio-economic considerations including public perceptions. Expert systems can be developed to assist forest managers in selecting appropriate site preparation and brushing treatments for selected ecosystems in the context of these different considerations (e.g., Sachs *et al*. 2009). Key autecology information for the major competitive species in the boreal and sub-boreal forest regions of Canada is provided in Bell *et al*. (2011b, this issue).

One of the best methods to determine potential competition problems is to conduct pre-harvest vegetation assessments (Wagner *et al*. 2001). These can occur in conjunction with pre-harvest timber cruising or as part of silviculture prescription development. Observing sites close to the planned harvest area that have been recently disturbed can also be helpful (Wagner *et al*. 2001). This approach provides the opportunity to apply pre-harvest silviculture treatments such as girdling, herbicide injection, or understory spraying, which may reduce or eliminate future vegetative competition. These treatments are discussed in more detail below.

Application timing also influences the effectiveness of most vegetation management treatments. Species that reproduce via suckering or stump sprouts are most effectively controlled by treatments applied during or shortly after the period of active growth in mid summer when carbohydrate

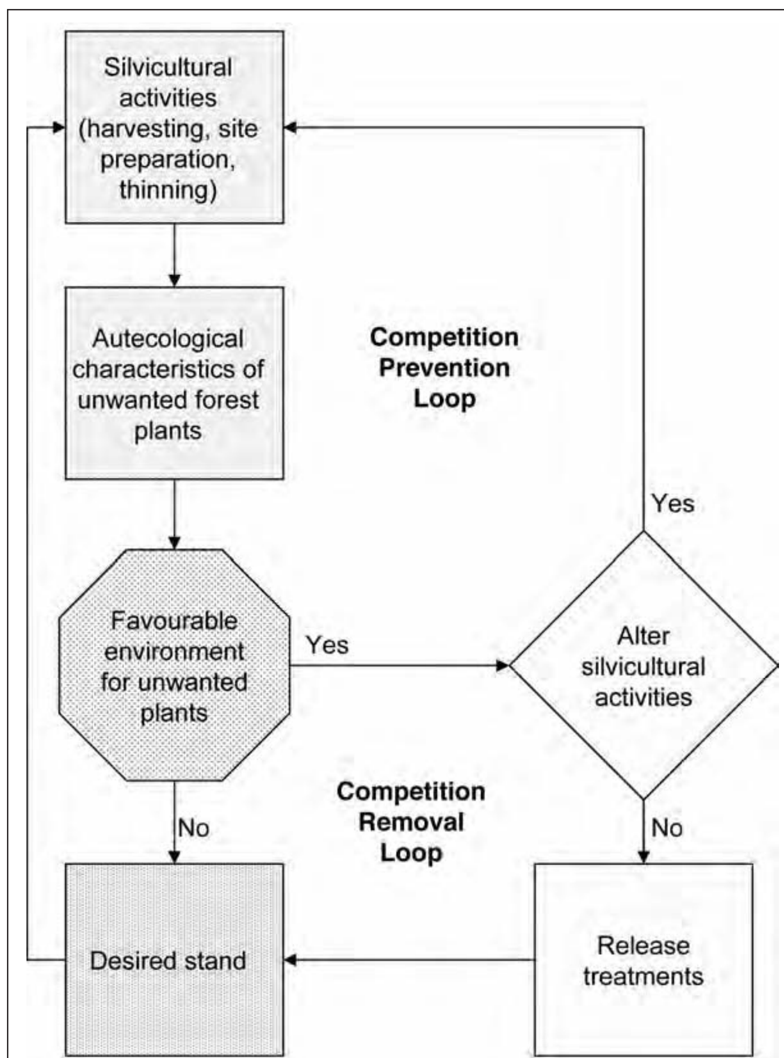


Fig. 1. Vegetation management treatment options decision making process (adapted from Wagner *et al.* 2001)

reserves in the roots are low (Hart and Comeau 1992, Jobidon and Charette 1997, Harvey *et al.* 1998, Bell *et al.* 1999, Luke *et al.* 2000, Ryans and Sutherland 2001, White 2004). Species that reproduce primarily from seed will be more effectively controlled by treatments timed to avoid the peek seed dispersal period, which is in mid-summer to early fall for most boreal species (Bell 1991). Thus, optimal treatment timing varies with species' phenology (Harvey *et al.* 1998). However, it must be noted that if site resources are freed up at rates in excess of the ability of crop trees to use them, these resources may be lost from the site (Swift and Bell 2011, this issue). Also, no matter how effective a treatment is at controlling selected competitive plant species, it may not be considered silviculturally effective unless the crop trees show a positive response in survival or growth compared with untreated sites (Sutton 1985).

Vegetation Management Practices

In this section, we address the broad array of treatments that could be considered for vegetation management in Canada. The information is organized into five categories: (i) silvicultural and harvesting systems, (ii) physical systems such as mechanical site preparation, cutting, girdling and mulching; (iii) thermal treatments such as prescribed fire and steaming; (iv) cultural treatments such as seedling culture, cover cropping, and grazing; and (v) chemical and biological spray treatments. An overview of how plant species respond to these treatments is provided in Appendix 1.

Silviculture and harvest systems

The choice of silviculture and harvest systems can influence colonization of a site by undesirable plant species and the success or failure of vegetation management treatments (Wagner *et al.* 2001). Unfortunately, for economic and operational reasons, vegetation management considerations often do not influence the timing or method of harvest (Wagner *et al.* 2001).

Silvicultural system

A silvicultural system is a planned program of treatments, including harvesting, regeneration, and tending, which spans the life of a stand and is designed to achieve specific structural objectives (Nyland 2002). The pattern and intensity of harvest influence light intensity and quality, air and soil temperature, and soil moisture on the site (Dey and MacDonald 2001). A variety of environments can be created by using different silvicultural systems to vary the density of residual trees (Fig. 2).

The most common silvicultural system used in the boreal forest is clearcutting (Whaley and Polhill 1998, Conference Board of Canada 2008). It results in full sun exposure that facilitates the establishment and growth of shade-intolerant pioneer crop species adapted to regenerating after stand-replacing disturbances (e.g., lodgepole pine [*Pinus contorta* Dougl. ex. Loud.], jack pine, and aspen [*Populus tremuloides* Michx.]). However, it also creates ideal conditions for the rapid establishment and growth of non-crop shrubs and herbaceous vegetation (Myketa *et al.* 1998) that are adapted to exploit similar open conditions. Modified clearcutting (e.g., patch and strip) can be used to create conditions unfavourable for the establishment of some competitive species. For example, strip clearcutting can be used to prevent soil temperatures in adjacent leave strips from increasing, thereby reducing the extent of aspen suckering (Racey *et al.* 1989). From a vegetation management perspective, one of the advantages of the clearcutting system is that a variety of subsequent pre-plant or pre-seeding vegetation management treatments is possible on open sites, including mechanical and chemical site preparation, prescribed burning, and grazing.

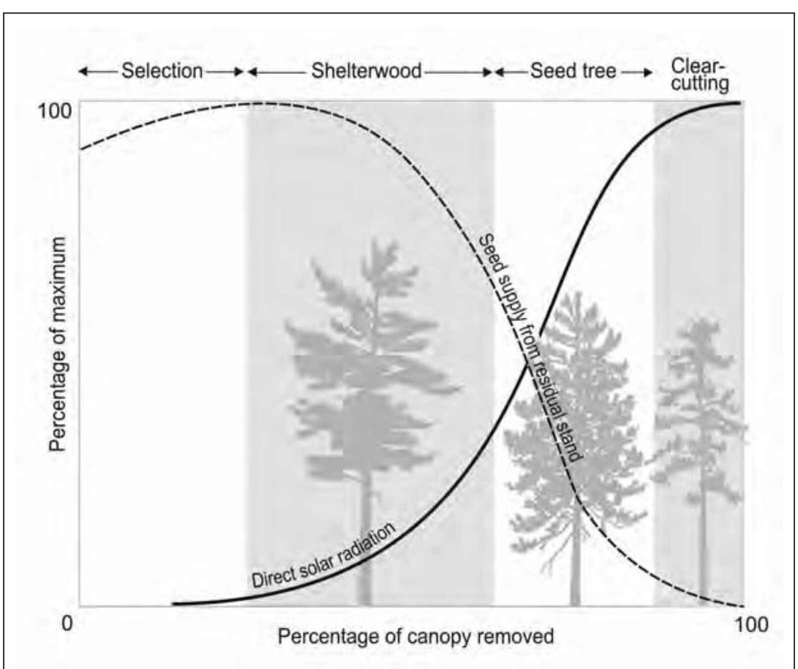


Fig. 2. General relationship between percent canopy removal, available light in the understory, and stand response. The grey silhouettes represent the Boreal/Great Lakes–St. Lawrence conifer tree species typical of the environmental conditions created by the silvicultural system (l-r, white pine, red pine and jack pine) (adapted from Smith 1962).

The shelterwood system is a versatile regeneration method (Dey and MacDonald 2001, Raymond *et al.* 2009) suitable for regenerating shade-tolerant or moderately shade-tolerant tree species, e.g., Douglas-fir, white spruce (*Picea glauca* [Moench] Voss], Engelmann spruce (*Picea engelmannii* Parry), black spruce, balsam fir (*Abies balsamea* [L.] Mill.), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), eastern and western white pine (*Pinus monticola* Dougl.), western red cedar (*Thuja plicata* Donn), red oak (*Quercus rubra* L.), and yellow birch (*Betula alleghaniensis* Britton) (Myketa and McLaughlan 1996, Wurtz and Zasada 2001, Day *et al.* 2011b). The shade provided by the overstory regulates temperature, moisture, and light conditions in the understory (Frey et al. 2003b). From a vegetation management perspective, overstory shade also reduces cover and growth of shade-intolerant competing vegetation (e.g., red raspberry [*Rubus idaeus* L.], bindweed [*Convolvulus arvensis* L.], pin cherry [*Prunus pensylvanica* L.] and, aspen) (Myketa and McLaughlan 1996, Dey and MacDonald

2001, Day *et al.* 2011a). A disadvantage of the shelterwood system is that the residual trees can make it difficult to apply vegetation management treatments such as mechanical site preparation, broadcast aerial herbicide application, and prescribed fire (Myketa and McLaughlan 1996).

The selection silvicultural system maintains an uneven-aged forest structure and is used to promote the growth of shade-tolerant species such as sugar maple (Robertson and Myketa 1998). Variations include the group selection system, which can be used for moderately shade-tolerant species such as yellow birch (Robertson and Myketa 1998). This system is rarely used in the boreal forest, except where pockets of tolerant hardwoods occur, as it is not ecologically suited to the shade-intolerant species that dominate boreal forests (Robertson and Myketa 1998).

Harvest system

Harvesting severs woody plants at the base and disturbs the soil to a degree depending on the harvest system (e.g., full tree, tree length, cut-to-length, etc.) employed and the machinery used. This can increase the abundance of certain crop trees as well as competing vegetation (Wagner *et al.* 2001). The amount of disturbance caused by harvesting is also influenced by the season of harvest and operator training and skill. Harvest systems that minimize forest floor disturbance generally slow the reinvasion of the site by windborne seed and seed-banking species (e.g., fireweed [*Epilobium angustifolium* L.], pin cherry, raspberry) but increase the abundance of species that regenerate from root suckers (e.g., aspen, blueberry) or stump sprouts (e.g., mountain maple [*Acer spicatum* Lam.], red maple [*Acer rubrum* L.], alder [*Alnus* spp.], beaked hazel [*Corylus cornuta* Marshall], willow [*Salix* spp.], birch [*Betula* spp.]) (Buse and Bell 1992, Myketa *et al.* 1998) (Table 1). Harvest systems that minimize site disturbance can also protect advanced growth, which may be particularly beneficial for renewal of boreal mixedwood stands (Waters *et al.* 2004). However, by influencing the amount of post-harvest slash, harvest systems can also affect microclimate (Devine and Harrington 2007) and subsequent regeneration. For example, heavy slash loads may be associated with reduced regeneration of jack pine (Waters *et al.* 2004). Yet heavy slash may reduce competition from aspen, especially on wet sites (Steneker 1976) or moist clay-loam sites (Bella 1986) by lowering soil temperature thereby reducing suckering (Steneker 1976) or by delaying the onset of suckering (Frey et al. 2003a). Heavy slash can also reduce the availability and receptivity of seedbeds affecting the establishment of competing understory species that commonly seed in on disturbed sites (e.g., blue-joint grass [*Calamagrostis canadensis* (Michx) P. Beauv.]); on the other hand, it can provide shade and conserve moisture for shade-tolerant species (e.g., white spruce, balsam fir) (Myketa *et al.* 1998).

Season of harvest

Season of harvest also affects non-crop vegetation competition following harvest depending on the level of site disturbance (Myketa *et al.* 1998, Frey et al. 2003a). Winter harvesting on frozen soil or deep snowpack causes minimal soil disturbance, reducing the potential for seed banking and windborne seeding species (e.g., red raspberry, rose [*Rosa spp.*], blue-joint grass) to establish. It also protects advance regeneration. However, winter harvesting can stimulate reproduction of species that reproduce vegetatively from suckers or basal sprouts (e.g., aspen [Frey et al. 2003a], balsam poplar [*Populus balsamifera* ssp. *balsamifera* L.], black cottonwood [*Populus balsamifera* ssp. *trichocarpa* (Torr. & Gray ex Hook.) Brayshaw], alder, beaked hazel, willow).

Physical post-harvest treatments

Mechanical site preparation

Mechanical site preparation (MSP) involves the use of machinery to create desirable microsites for crop trees at prescribed spacing and abundance and to remove/rearrange physical obstructions to renewal and tending treatments (Örlander *et al.* 1990, White 2004). Applied at the appropriate intensity on appropriate sites, this treatment option provides the best opportunity to control the colonization of competitive non-crop vegetation on newly disturbed sites (Wagner *et al.* 2001). Mechanical site preparation has a longer treatment window and is not as sensitive to weather conditions as chemical site preparation or prescribed fire (Ryans and Sutherland 2001).

The effectiveness of MSP treatments in suppressing the establishment of competitive non-crop species depends on site productivity (White 2004), the type and intensity of the treatment, and the interaction of the treatment with the autecological characteristics, particularly the primary mode of reproduction of the non-crop species (Wagner *et al.* 2001, White 2004) (Table 1). On productive sites with more abundant, diverse, and vigorous vegetation, MSP alone is rarely effective in suppressing non-crop vegetation adequately to optimize the establishment and growth of crop trees (Walstad *et al.* 1987, Thiffault *et al.* 2003, Thiffault and Jobidon 2005). On lower productivity sites, harvesting alone may be sufficient disturbance to achieve site preparation objectives (White 2004). MSP on such sites (e.g., ericaceous heaths) can also effectively reset ecological succession by creating appropriate growing conditions for conifers if competition from ericaceous plants such as *Kalmia angustifolia* L. is a problem (Thiffault and Jobidon 2006, Thiffault *et al.* 2010).

Research indicates that MSP improves microsites for pine (Sutton and Weldon 1993; Bedford and Sutton 2000; Macadam *et al.* 2001; Thiffault *et al.* 2004, 2005, 2010; Thiffault 2006; Fu *et al.* 2007), spruce (Sutherland and Foreman 2000; Sutton *et al.* 2001; Prévost and Dumais 2003; Thiffault *et al.* 2004, 2005, 2010; Thiffault 2006; Thiffault and Jobidon 2006; Boateng *et al.* 2006; Fu *et al.* 2007; Wiensczyk 2008), and eastern larch (Thiffault *et al.* 2004, 2010). However, light MSP may stimulate suckering of aspen (Appendix 1, and Frey et al. 2003a).

For details on MSP techniques, including information on treatment intensity, area coverage, and disturbance category as well as equipment options, readers are referred to White (2004), Evans (2005), Von der Gonna (1992), Sutherland and Foreman (1995), and MacKinnon *et al.* (1987).

Manual, motor-manual, and mechanical brushing treatments

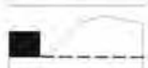
Brushing treatments include manual (e.g., shears, Sandviks, machetes, brush hooks and axes), motor-manual (e.g., brush saws, chainsaws) (Boateng and Ackerman 1990), and mechanical (e.g., brushing tools mounted on a prime mover

Table 1. Relative influence of microsite categories created by silviculture on non-crop vegetation based on their primary reproduction strategy (adapted from Sutherland and Foreman 1995, OMNR 1997, Ryans and Sutherland 2001, White 2004).

Microsite description
Effect of disturbance on reproduction

↑ = promotes (↑↑ = strongly promotes)
0 = no effect
↓ = discourages (↓↓ = strongly discourages)

organic (hatched)
mineral (grey)

Silvicultural treatment	Microsite category		Vegetative reproduction: Shoot origin sprouts	Vegetative reproduction: Root origin sprouts – Roots in organic layer	Vegetative reproduction: Root origin sprouts – Roots in mineral soil	Sexual reproduction: Windborne seed	Sexual reproduction: Seed bank
			e.g., maple, alder, birch, dogwood, hazel, willow, Labrador tea	e.g., grasses, blueberry	e.g., poplar, rose, raspberry	e.g., grasses, birch, fireweed, poplar, willow	e.g., dogwood, cherry, rose, raspberry, blueberry
None	Undisturbed		0	0	0	0	0
Harvest	Overstory removed; ground undisturbed		↑↑	↑	↑	0 to ↑[1]	↑
Mechanical site preparation	**Upland mineral soil**[2]						
	Organic partially displaced L and part of F (e.g. shallow screef)		↑	↑	↑	↑	↑↑
	LFH removed and mineral soil either: Depressed (deep screef)		↓↓	↓↓	↓↓ to↓[3]	↑↑	↓↓
	LFH removed and mineral soil either: Level (screef)		↓↓ to↓[4]	↓	↑↑	↑↑	↓
	LFH removed and mineral soil either: Raised (mineral soil mound)		↓↓	↓↓	↓↓ to↓[5]	↑	↓↓
	LFH inverted with mineral soil cap (mineral mound on organic layer)		↑ to ↑↑	↓ to ↑	↓	↑	↓
	LFH and mineral soil mixed (tilling)[6]		↓ to ↑	↓ to ↑	↑	↑↑	↑↑
	Lowland Organic soil[7] Part of Of removed (e.g., by shearblading)		↓[8]	↓ to↑[9]	N/A	↑	↑
	Drainage of layer (e.g., by ditching)		↑	↑	N/A	0	↑
Prescribed fire	Light[10]		↑↑[a]	↑↑[a]	↑↑[a]	↑[b]	↑↑[c]
	Moderate[11]		↓	↑	↑↑	↑↑	↑
	Severe[12]		↓↓	↓↓	↓	↑↑	↓↓
Cutting	Active	< 25 cm	↑	↑	↑	–	–
		> 25 cm	↑	↑	↑	–	–
	Dormant	< 25 cm	↑↑	↑↑	↑↑	–	–
		> 25 cm	↑↑	↑	↑	–	–

[1]Will promote if organic layer is shallow and/or moist
[2]Upland organic horizons: L–litter, F–fermentation, H–Humic
[3]Control of sprouting depends on removal of root systems
[4]Control of sprouting is improved for species that root in organic layer
[5]Control of sprouting increases with increased depth of scalping
[6]Control depends on degree of mixing: fine mixing (e.g., rototilling) discourages; coarse mixing (e.g., single discing) encourages
[7]Of, Om, Oh represent fibric, mesic and humic organic horizons, respectively
[8]Will promote Labrador tea and Vaccinium species
[9]Control depends on degree of removal of root systems and stimulation of residuals
[10]Moss/litter is singed; more than 60% of the shrub canopy is consumed; some leaves and small twigs remain on plants and are either unharmed or slightly singed

[a]Endurers – plants that sprout from stem bases, rhizomes or roots
[b]Invaders – plants that produce windborne seed
[c]Evaders – plants that are seedbankers or have serotinous cones
Resistors – plants able to withstand fire because of traits such as thick bark (e.g., white pine, ponderosa pine),
Avoiders – not able to withstand fire – appear later in succession (e.g., white spruce, balsam fir, twinflower) (Rowe 1983)

[11]Most of the moss/litter layer is charred but not turned into ash; 40 to 80% of the shrub canopy is consumed; only medium-sized twigs (0.5 to 1.5 cm diameter) remain and are charred

such as a skidder or tractor) options. Both manual and motor-manual cutting are commonly used for crop tree release while mechanical brushing equipment can be used for both release and site preparation depending on the equipment used (Harvey *et al.* 1998). Ryans and Cormier (1994) provide more information on mechanical brushing equipment options.

Manual and motor-manual cutting treatments can increase crop tree survival and growth (McDonald *et al.* 1994, Boateng *et al* 2009, Cyr and Thiffault 2009). However, the effectiveness of brushing treatments in releasing crop trees depends on the autecology of the species being cut, the type of cut, and the timing. Some species are more easily controlled than others (Appendix 1). In general, brushing treatments provide long-term control of coniferous competing species (e.g., balsam fir), but only short-term control of most deciduous woody vegetation (Appendix 1). Most hardwoods (e.g., aspen, birch, cottonwood) sprout rapidly after cutting, producing an increased number of shoots per stump, and the total number of stems and percent cover may increase after treatment (Hart and Comeau 1992).

Site factors may affect a species' ability to sprout following cutting, with more effective control reported on dry than moist sites (e.g., Sitka alder [*Alnus sinuata* (Reg.) Rydb.]; Hart and Comeau 1992). Removal of woody brush competition may also result in the rapid development of a replacement competitive species (e.g., fireweed; Perry 1987).

Although brushing treatments are generally most effective when conducted during or just after the active growing season, crop trees are less visible when brush species are in full leaf, increasing the potential for damage (Harvey *et al.* 1998). To reduce this potential for damage to the crop trees by the treatment, some have tried using hockey sticks to bend the competing herbaceous vegetation (e.g., fireweed) (Hart and Comeau 1992). Crop trees can also be damaged by falling slash produced by the brushing treatment, heavy accumulations of which may increase the fire hazard (Hart and Comeau 1992).

Type and height of the cut can affect the vigour of sprouts. Bell *et al.* (1999) reported that cutting aspen at heights 50 cm to 75 cm above ground level during June–July significantly reduces the number of root suckers. Jobidon (1997) found that species that sprout from the root collar (e.g., mountain maple, paper birch (*Betula papyrifera* Marsh.) and pin cherry) should be cut at 15 cm or less to reduce sprouting. Shattered and ragged cuts produce fewer and less vigorous sprouts than clean cuts (Bell *et al.* 1997).

Girdling

Girdling has been used to control hardwood species (e.g., aspen, cottonwood, birch, maple), both pre- and post-harvest. Treatment is usually confined to trees greater than 5 cm in diameter (Hart and Comeau 1992). Thorpe (1996) reported that girdling results in reduced vigour of aspen suckers compared with those produced after cutting. He notes that to be effective, the stem must only be girdled and not broken and that the most suitable time to girdle is in the spring to mid-summer when the bark is easily peeled. Late summer and fall treatments are also effective but not as efficient (Thorpe 1996). Effective control of cottonwood (Hart and Comeau 1992) and aspen (Bancroft 1989) by girdling has been reported; however, birch is reported as difficult to girdle because its stem is often not circular and treatments do not reduce sprouting (Hart and Comeau 1992). Girdling red maple has shown some limited success. The Nova Scotia Department of Lands and Forests (1989) reports that topkill levels two years after treatment are nearly equal to those of herbicide injection treatments. However, sprouting is not effectively controlled by girdling treatments.

Mulching

Mulches can be either unconsolidated (e.g., wood chips, bark, straw) or consolidated (e.g., sheets of natural or synthetic fibres/plastics) and can be used to ameliorate harsh environmental conditions (dry or cold soils) and protect seedlings from daily temperature extremes (Land Owner Resource Centre 1997). Mulches have been shown to be effective in controlling grass and other herbaceous vegetation (Robitaille 2003), as well as sprouting shrub and hardwood communities (McDonald and Fiddler 1996), but results are variable. Mulches were effective in controlling *Kalmia* in greenhouse trials (Mallik 1991). In a small experimental field trial in a jack pine plantation in the southern boreal forest of Quebec, Prescott *et al.* (1995) found that a single application of straw mulch 60 cm deep significantly reduced competition from *Kalmia* for 14 years. The ability of plastic mulch mats to improve survival and growth of conifer seedlings by reducing competition for water by grass and herbaceous vegetation was tested in the field by Harper *et al.* (2005), who found no significant difference compared with untreated seedlings after 10 years.

Thermal treatment

Prescribed fire

Prescribed fire can be used as both a pre-harvest (Myketa and McLaughlan 1996) and a post-harvest vegetation management tool (Luke *et al.* 2000). Although pre-harvest use is limited to selected ecosystems and stand conditions, fire can be used post harvest for vegetation management as well as to promote the establishment of specific plant communities for other values such as wildlife habitat (Luke *et al.* 2000). Prescribed fire is not a useful vegetation management tool on sites where advance conifer regeneration is a key component of the regeneration strategy.

Wildfire is one of the primary disturbance agents in the boreal forest, and, as a result, many boreal plant species have evolved fire-adapted traits to ensure their survival (Luke *et al.* 2000). Knowledge of those traits can assist forest managers in managing for these species. Rowe (1983) classified species into five groups: invaders, evaders, avoiders, resisters, and endurers (Table 1). A species' sensitivity to fire depends on its rooting depth; generally, vulnerable species have shallow root systems concentrated in the surface organic layers while resistant species have deep root systems with rhizomes more than 5 cm below the mineral soil surface or deep tap roots that can produce adventitious buds (Luke *et al.* 2000). The most important factor affecting the response of vegetation to prescribed fire is the interaction between fire severity (intensity) and the target species' vital attributes as well as its physiological and morphological characteristics at the time of the burn (Haeussler 1991, Feller 1996, Luke *et al.* 2000, McRae *et al.* 2001). As fire severity increases, more heat penetrates the mineral soil and increases the effect on below-ground reproductive organs and stored seed, thus providing more effective non-crop vegetation control (Luke *et al.* 2000) (Table 1). For example, low intensity fire can increase the abundance of white birch, mountain maple, red osier dogwood (*Cornus stolonifera* Michx.), beaked hazel, bush honeysuckle (*Diervilla lonicera* [L.] MacM.), and blueberry (*Vaccinium spp.*), but moderate to severe intensity fire will reduce their abundance (Appendix 1). Burning when soil is moist may increase effectiveness as moist heat and steam are more damaging to plant parts than dry heat. However, duff is also a very effective insulating material, especially when wet (Luke *et al.* 2000). While a prescribed fire may eliminate one target species (such as balsam fir), it may also create favourable conditions for other, sometimes more competitive species (McRae *et al.* 2001), such as speckled alder (*Alnus rugosa* [Du Roi] Spreng.) and pin cherry (Appendix 1).

Steaming

The use of steam to control recolonization of competing vegetation has been tested and found successful on several different site types in Sweden (Norberg *et al.* 1997, Zackrisson *et al.* 1997, Norberg 2000). However, further technological developments are necessary before the treatment can be applied at an operational level (Norberg 2000).

Cultural treatments

Seedling culture

Regeneration strategies, including large planting stock, can be used as preventative measures in vegetation management programs but should be matched to site conditions (McMinn 1982, Hayes, 2001). For example, larger seedlings have been shown to outperform smaller seedlings on competitive sites (Iverson 1984, Jobidon *et al.* 1998, Lamhamedi *et al.* 1998, Kiiskila 1999, Pacific Regeneration Technologies Inc. 2000, Jobidon *et al.* 2003, Boateng *et al.* 2006, Thiffault and Roy 2011). In general, the growth rates of large seedlings tend to exceed those of the competing non-crop vegetation and thus large seedlings are likely to assume a dominant or co-dominant position sooner (Mohammed *et al.* 2001).

Planting as soon as possible after site preparation is another strategy that will help reduce the impact of competing vegetation on crop tree establishment and growth (Ball and Kolabinski 1986, Thiffault and Roy 2011). Planted seedlings can then benefit from favourable establishment and growth conditions, before cutovers become invaded by competing vegetation (Thiffault *et al.* 2003).

Cover crops

Seeding sites with alternative, less competitive agronomic species (e.g., rye grass [*Lolium perenne* L.], clover [*Trifolium spp.*], alfalfa [*Medicago sativa* L.], fescue [*Festuca spp.*]) is another cultural method of non-crop vegetation control (Negrave and Kabzems 1996, Thompson and Ketcheson 1996, Thompson and Steen 1996, Balandier *et al.* 2009). Although cover crops compete with seedlings, they are potentially not as damaging as other non-crop vegetation and can reduce the need for herbicide treatments (LandOwner Resource Centre 1994). Moreover, cover plants may protect seedlings against frost, scorching temperatures, or drought (Balandier *et al.* 2009). However, results from limited studies have been variable (Thompson and Ketcheson 1996, Thompson *et al.* 1996). Negative effects of cover crops include snowpress (Negrave and Kabzems 1996) and the potential to harbour mice and other rodents that feed on conifer seedlings (LandOwner Resource Centre 1994).

Grazing

Grazing by domestic livestock such as sheep, goats, and cattle can be used for pre-plant site preparation and post-plant release treatments on some sites (Foster 1998). Since sheep are the most commonly used grazer in Canada and little information about the use of goats, cattle, and geese is available, this section focuses on sheep.

Vegetation management treatment success using sheep depends on a number of factors including the quantity, quality, and diversity of the target vegetation (Foster 1998). In addition, having a highly skilled and experienced shepherd managing the flock is critical as damage to conifer regeneration can occur if sheep are poorly controlled or the plantation is overgrazed (Sharrow 1994, Newsome *et al.* 1995, Foster 1998).

Conifer regeneration is most susceptible to browsing and mechanical damage during the bud flush/elongation period (Sharrow 1994, Newsome *et al.* 1995, BCMFR 2000) but can be browsed at any time depending on availability of other forage. Palatability of conifers to sheep varies by species (Table 2) and changes throughout the growing season—seedlings become less palatable as they harden off (Newsome *et al.* 1995, Foster 1998). Pine species are very palatable to sheep and thus these plantations are not recommended for sheep grazing treatments without a very experienced shepherd (Foster 1998). Sharrow (1994) also noted that yearling ewes are more likely to browse shrubs and conifer seedlings than are older ewes or lambs.

The palatability and height of the target vegetation also changes throughout the growing season and is affected by drought or frost (BCMFR 2000). Sheep prefer succulent new vegetation early in the growth cycle as well as regrowth on vegetation previously grazed (BCMFR 2000). The palatability of some common non-crop species is shown in Table 3. The height of the competing vegetation affects treatment success and should be no taller than 1 m for sheep (Newsome 1996).

Multiple grazing entries, 40 to 70 days apart, during a single growing season seem more effective than single annual treatments, and resulting vegetation regrowth is generally more palatable and nutritious for wildlife (Foster 1998, BCMFR 2000). Depending on the target competitive species, repeated treatments over several years may be necessary to achieve effective control.

Unfortunately, very little data documenting the effect of vegetation management using sheep on the survival and growth of boreal conifer species are available. Some data from the United States show increased growth following treatments applied to Douglas-fir plantations (Sharrow *et al.* 1989, 1992). However, pilot studies in Northeastern Ontario in 1991 and 1992 reported that jack pine, black spruce, and white spruce seedlings showed no response to grazing (Vasiliauskas and Luke 2000). The authors concluded that sheep grazing did not appear to be a suitable vegetation management tool for Northeastern Ontario. Opio *et al.* (2001) concluded that the use of sheep in forest vegetation management in British Columbia has been limited by the availability of agricultural infrastructure to support sheep farms, the need for regular

Table 2. Relative susceptibility of conifer seedlings to sheep browsing[a] (adapted from Newsome *et al.* 1995 and Foster 1998).

Tree species	Sheep preference for conifer seedlings	Seedling Growth Stage				
			Seedlings > 1 year but <1 m tall		Large seedlings > 1 year and >1 m tall	
		Seedlings < 1 year	Flushing	Hardened	Flushing	Hardened
Black spruce	very low[e]	?	?	?	?	?
Spruce	low[b]	3[c]	3	1	2	1
Grand fir[d]	low	1	1	1	1	a
Western red cedar[d]	low	?	2	N/A	?	N/A
Balsam fir[e]	low	?	?	?	?	?
Interior Douglas-fir	moderate	?	3	3	2 or 4	2
Lodgepole pine	high	3	5	3	?	?
Jack pine	high	?	?	?	?	?
Western white pine[d]	high	?	4	?	?	?

[a]A number of provincial studies and one American study have been used to develop this table: Ellen (1988), Lousier (1990), Lousier and Lousier (1991), Bancroft (1992a, 1992b), Sutherland *et al.* (1992), Ken Gilbert (Silviculture Technician, BC Ministry of Forests, Horsefly, BC, personal communication 1993). (All cited in Newsome *et al.* 1995). Leininger and Sharrow (1983a,b,c).
[b]Indicates the relative preference for sheep to browse on different conifer species
[c]Susceptibility ratings: 1 – low (minimal damage); 2 – moderately low (minor lateral damage); 3 – Moderate (minor lateral and leader damage); 4 – Moderately high (major lateral damage); 5 – High (major lateral and leader damage); ? – No information available; N/A – Not applicable
[d]Very limited data
[e]Foster (1998)

Table 3. Palatability of boreal non-crop vegetation to sheep (Newsome *et al.* 1995, Foster 1998, BCMFR 2002).

High	Medium	Low	Unpalatable	Poisonous
Aster	Bluebead lily	Blueberry	Bull thistle	Bog, sheep and alpine laurel
Bindweed	Bunchberry	Labrador tea	Canada thistle	Chokecherry
Blue-joint grass	Fireweed	Rushes	Mosses	Field horsetail
Clover	Raspberry[b]	Sarsaparilla[b]	Rose twisted stalk	Arrowgrass
Honeysuckle	Sedge[b]	Sweetfern	Woodland horsetail	Mountain-death camas
Mountain ash	Skunk currant	Yarrow	Oregon grape	Columbian monkshood
Mountain maple	Starflower	Violet	Red elderberry	Tall larkspur
Pin cherry	Twinflower	Thimbleberry	Spirea species	Western water hemlock
Serviceberry	White birch[b]	Green alder	White-flowered Rhododendron	Indian Hellebore
Trembling aspen	Wild rose	Twinberry	Hawkweed	Labrador tea
Vetch	Willow	Bitter cherry	Bracken fern[a,b]	Rhododendron
Grasses		Indian Hellebore		
		Beaked hazel		
		Big leaf maple		

[a]Bracken consumed only in early frond stage, but mature plants can be controlled by trampling.
[b]Palatability particularly variable.

grazing opportunities, and farmer perceptions of the profitability of grazing for this purpose. However, it appears that although there are a limited number of local sheep farmers in British Columbia, certified sheep have been successfully transported from Alberta to meet the demand of BC's very successful and organized vegetation management program[6]. The biggest limitation to the program according to Boateng was finding large areas or aggregates of closely located areas that are suitable for sheep brushing. Other challenges mentioned include misconceptions by prescribing foresters regarding the use and effectiveness of this treatment as well as administrative issues and requirements (e.g., animal health issues, animal health monitoring, and concerns relating to domestic sheep and wildlife interaction). Boateng concluded that these requirements require lots of experience and time that can limit silvicultural use of sheep for brushing.

Chemical and biological spray treatments

A number of herbicides and one fungus are currently registered for forestry use in Canada. The product label for herbicides provides instructions on the proper use, storage, and restrictions, with the most current information provided on the pesticide label search website maintained by Health

[6]Jacob Boateng, BC Ministry of Forests and Range, Scientist Emeritus, Personal Communication, Dec. 21, 2010

Canada[7]. Forest managers must carefully read and follow the product label directions, precautions, and restrictions because applying a herbicide for a purpose or by a method other than what is indicated on the label is illegal and possibly hazardous (McLaughlan *et al.* 1996). Table 4 provides a list of the most commonly used herbicides registered for forestry use in Canada and includes their target vegetation group, application method, and mechanism of absorption.

Chemical and biological control treatments will not compact soil or increase the risk of erosion, do not create favourable seedbeds for windborne seed, and do not bring buried seed to the soil surface (Campbell *et al.* 2001). Herbicide treatments also generally provide longer-term control than other vegetation management treatments because they kill the roots of competing plants, preventing or reducing resprouting (Campbell *et al.* 2001, Fu *et al.* 2008). The associated positive crop tree responses in terms of survival, height, diameter, and volume growth to herbicide treatments are well documented (Pitt *et al.* 1999b, 2000, 2004; Pitt and Bell 2005; Dampier *et al.* 2006) and discussed in Bell *et al.* 2011a (this issue).

The sensitivity of a plant species to herbicide depends on its condition and age, season of application, application rate, soil type, and weather conditions. An overview of the sensitivity of boreal plant species (both conifer and deciduous) to various herbicides is provided in Table 5. As with other vegetation management treatments, the timing of application influences the effectiveness of the treatment and potential damage to crop trees (McLaughlan *et al.* 1996, Harper *et al.* 2005, Bell and Pitt 2007).

[7]http://www.hc-sc.gc.ca/cps-spc/pest/registrant-titulaire/tools-outils/label-etiq-eng.php

Table 4. Herbicides (and biological control option) registered in Canada for use in forestry (adapted and updated from Boateng 2002)

Common name of herbicide/ biological control option	Product examples	Target vegetation group	Method of absorption by plants[a]	Application method[c]
Glyphosate	Vision®	Annual and perennial weeds, woody plants	Foliage, cut surfaces	G,A, CS, I
	Forza™	Annual and perennial weeds, woody plants	Foliage, cut surfaces	G,A, CS, I
	Vantage® Forestry	Annual and perennial weeds, woody plants	Foliage, cut surfaces	G,A, CS, I
	EZject® Herbicide capsules	Woody brush and trees	Stems, root crowns, cut (stump) surfaces	I, RI
Hexazinone	Velpar® L	Annual, biennial and perennial weeds and grasses; hardwoods	Foliage, Roots	G, A, ST
	Pronone® 10G	Grasses and herbaceous species, woody deciduous plants	Roots	G, ST
MSMA	Glowon®	Conifers	Cut surfaces	I
Simazine	Princep Nine-T® Simanex 80W	Grasses, broadleaved and germinating plants	Roots	G
2,4-D ester	Esteron® 600	Shrubs, broadleaved forbs, hardwood trees	Stem, foliage, cut surface	G, A, CS, I, B
	2,4-D Ester LV 600®		Foliage	G, A
	2,4-D Ester 600		Stem, foliage, cut surface	G, A, CS, I, B
	2,4-D LV 600®		Foliage	G, A
2,4-D amine	Formula™ 40F Liquid Forestry Herbicide	Shrubs, broadleaved forbs, hardwoods Cut stump – red alder and willow	Foliage, cut surface	G, CS, I
Triclopyr	Release®	Shrubs and broadleaved forbs, hardwoods	Stem, foliage, cut surface	G, A, CS, B
Picloram[b]	Tordon® 22K	Noxious weeds: knapweed, field bindweed, leafy spurge, Canada thistle, etc.	Foliage	G, ST
Imazapyr	Arsenal®	Grasses and broadleaved forbs, shrubs and hardwoods (aspen)	Foliage, Roots	G, ST
Chondrostereum purpureum	Chontrol Paste (strain PFC2139 10^5 to 10^7) Chontrol Peat Paste (strain PFC2139 10^5 to 10^7)	Red and Sitka alder	Cut stump surfaces	CS

Note: In the event of any discrepancy between contents of this table and manufacturers' label, preference is given to the product label.
[a]Based on methods of application
[b]Registered only for use on forest rangeland, not for silviculture
[c]A = Aerial broadcast; G = Ground broadcast; B = Basal (stem, bark); I = stem injection/frill; CS = cut stump application; ST = Spot; RI = root injection

Table 5. Sensitivity of boreal conifer and competitive species to commonly used herbicides and a biological control option (adapted from Coates *et al.* 1990, Buse and Bell 1992, Myketa *et al.* 1995, McLaughlan *et al.* 1996, Pitt *et al.* 1999, Boateng 2002, US Environmental Protection Agency 2005)

	Herbicide/biological control option						
Species	**Glyphosate**	**2,4-D**	**Hexazinone**	**Triclopyr**	**Simazine**	**Imazapyr**	***Chondros-tereum***
Conifers							
Black spruce	R	R	I-R	R	R	n.d.	n.d.
White spruce	R	R	I-R	R	R	n.d.	n.d.
Jack pine	I-R	R	S	I-R	R	n.d.	n.d.
Red pine	R	R	VR	R	R	n.d.	n.d.
White pine	R	R	I	R	I-R	n.d.	n.d.
Balsam fir	R	R	R	R	R	n.d.	n.d.
Subalpine fir	n.d.	n.d.	n.d. – foliar I-R – soil	n.d.	R	n.d.	n.d.
Douglas-fir	I-R	I-S	I-S – foliar I-S – soil	S	n.d.	n.d.	n.d.
Lodgepole pine	R	R	R – foliar I-S – soil	n.d.	R	n.d.	n.d.
Engelmann spruce	I-R	n.d.	I – foliar I-R – soil	n.d.	n.d.	n.d.	n.d.
Sitka spruce	R	R	n.d.	I	n.d.	n.d.	n.d.
Hardwoods							
Balsam poplar	S-I	S-R	S-I	S	n.d.	n.d.	n.d.
Black cottonwood	S	I-R	S	S	n.d.	n.d.	n.d.
Trembling aspen	S	S-I	S-I	S	n.d.	S	S-I
White birch	S-I	S	I	S	n.d.	n.d.	S
Red Maple	R	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Shrubs							
Mountain alder	S	S-I	n.d. – foliar I-R – soil	n.d.	n.d.	n.d.	S
Sitka/green alder	S	S-I	I-R – foliar I-S – soil	S	n.d.	n.d.	S
Speckled alder	I-R	S-I	R	S	n.d.	n.d.	S
Mountain maple	S-I	I-R	I	S	n.d.	S	S-I
Douglas maple	S	n.d.	S-I – foliar S-I – soil	n.d.	n.d.	S	n.d.
Beaked hazel	S-I	S	I-R	S-I	n.d.	n.d.	n.d.
Blueberry	S-I	S	VR	S	R	n.d.	n.d.
Currants	I-S	S	I-S - foliar I-R – soil	S	I-R	n.d.	n.d.
Labrador tea	R	S	n.d.	S	n.d.	n.d.	n.d.
Pin cherry	I	S	I	S	n.d.	n.d.	S
Prickly wild rose	S-I	I-R	I-S – foliar I-S – soil	S	R	S	n.d.

Table 5. *(continued)*

	Herbicide/biological control option						
Species	**Glyphosate**	**2,4-D**	**Hexazinone**	**Triclopyr**	**Simazine**	**Imazapyr**	***Chondros-tereum***
Red-osier dogwood	I-R	S-I	I-R – foliar I-S – soil	S	R	n.d.	n.d.
Red raspberry	S	R	S – foliar S – soil	S	R	S	n.d.
Service berry	S	S-R	I-S – foliar S – soil	S	n.d.	n.d.	n.d.
Highbush cranberry	S-I	I	I-R – Foliar R – soil	n.d.	n.d.	n.d.	n.d.
Devil's club	S	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Elderberry	S	S	S – foliar I-S – soil	S	n.d.	n.d.	n.d.
Dull Oregon Grape	S	n.d.	S	n.d.	n.d.	n.d.	n.d.
Huckleberry	S	I-S	I – foliar I – soil	S-I	I-R	n.d.	n.d.
Snowberry	S	S	n.d. – foliar S – soil	S	n.d.	n.d.	n.d.
Thimbleberry	S	I-R	S – foliar S-I – soil	S	n.d.	n.d.	n.d.
Black twinberry	S	n.d.	S – foliar n.d. – soil	S	n.d.	n.d.	n.d.
Soopolallie	n.d.	n.d.	n.d. – foliar S – soil	n.d.	n.d.	n.d.	n.d.
Rhododendron	S	I-R	R – foliar n.d. – soil	S-I	n.d.	n.d.	n.d.
Willows	I-R	S	I-S – foliar S – soil	S	R	n.d.	n.d.
Herbs, grasses and ferns							
Bracken fern	S-I	I-R	I-S – foliar n.d. – soil	I-R	n.d.	n.d.	n.d.
Canada blue-joint grass	I-S	R	S – foliar S-I – soil	R	S	S	n.d.
Pinegrass	S	n.d.	S	n.d.	S		n.d.
Fireweed	S	I-S	I-R – foliar S-I – soil	S	I	n.d.	n.d.
Grass spp	S	VR	S	R	S	n.d.	n.d.
Large-leaf aster	S-I	n.d.	S	n.d.	n.d.	n.d.	n.d.
Sedges	S-I	R	S	n.d.	S	n.d.	n.d.
Cow-parsnip	I	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Lady fern	S	R	n.d.	n.d.	n.d.	n.d.	n.d.
Sword fern	S-I	R	n.d. – foliar I – soil	I	n.d.	n.d.	n.d.
Forbs	S-I	S	S – foliar S-I – soil	S	n.d.	n.d.	n.d.

Note: VR = Very Resistant; R = Resistant; I-R = Intermediate to resistant; I = Intermediate; S-I = Susceptible to Intermediate; S = Susceptible; n.d. = no information. Above ratings are generalizations of vegetation response to herbicide application under many different conditions. Plant condition and age, season of application, application rate, soil type and weather conditions are among the factors that will cause results to vary. Boateng (2002) provides more specific potential damage information by treatment period for western conifer, hardwood, shrub, and herbaceous species.

Table 6. Methods, advantages, and disadvantages of various herbicide treatment application options. Compiled from Biring *et al.* (1996), Mallik *et al.* (1997) and Campbell *et al.* (2001).

Application type	Application methods	Advantages	Disadvantages
Broadcast - liquid - granules	• aerial (fixed-wing, helicopter)	• reduced site access issues • large areas treated quickly • application rates uniform	• relatively higher probability of off target deposit • detailed planning and implementation process • relatively low social acceptability
	• ground application • backpack sprayers • vehicle-mounted sprayers (boom, single/multiple nozzle or air blast sprayers) • slinger equipment (granules)	• relatively low probability of off-target deposit	• application rates can be uneven • herbicide drift possible • boom sprayers impractical for many forest sites (rough terrain, stumps, logging debris, residual trees)
Spot treatments - liquid - granules	• selectively applied to target vegetation • foliar sprays • basal stem treatments	• selective • relatively low probability of off-target deposit	• calibration difficult • can be wasteful of herbicide • potential for crop tree damage • vegetation less than 15 cm diameter required for effective basal stem treatments
Injection/hack and squirt	• herbicide injected into stem (e.g., EZject) or applied to cuts/frills in bark of target vegetation	• very selective • relatively very low probability of off-target deposit • minimal chance of damage to crop trees	• time-consuming • operationally unfeasible for large number of stems • only useful for controlling trees (e.g., aspen, poplar, birch, conifers) or shrubs with large stems (e.g., alder, cherry, willow)
Cut stump	• herbicide applied to cambium layer of stumps during or immediately after cutting using dabbing or spray equipment	• very selective • relatively very low probability of off-target deposit • minimal chance of damage to crop trees • reduced amount of herbicide required • biological control agents available (*Chondrostereum purpureum*)	• must be applied within 2 hours of cutting • stumps need to be free of sawdust, bark tears or other debris • impractical for large numbers of stems

Application methods

Herbicides can be applied as foliar or soil sprays (broadcast or spot treatments), basal bark sprays, injected into the stem, directly or using a hack and squirt approach, or applied to cut stumps (Table 6). Granular forms are spread over the soil as broadcast or spot treatments. Broadcast herbicides can be applied as a site preparation treatment prior to planting or as a post-planting release treatment. Chemical site preparation is ideal since crop tree damage is not a concern and treatments can be applied when target vegetation is most susceptible, higher application rates can be used, and competition during the first growing season after outplanting is reduced (Campbell *et al.* 2001). Stem injection treatments with glyphosate have provided complete control of Sitka and mountain alder (*Alnus incana ssp. tenuifolia* [L.] Moench), trembling aspen, balsam poplar, paper birch, cherry, willows, and various conifers (Biring *et al.* 1996). Cut stump applications with herbicides provide effective control of a variety of non-crop species (Williamson and Parker 1995, Mallik *et al.* 1997, Pitt *et al.* 1999a, Lindgren and Sullivan 2001, Jackson and Finlay 2007). Results from the application of the biological control agent *Chondrostereum purpureum* (Pers.) Pouzar have been generally successful but variable (Myketa *et al.* 1995, Pitt *et al.* 1999a, Conlin *et al.* 2000, De Jong 2000, Shamoun 2000, Uotila *et al.* 2006). Roy *et al.* (2010) observed that after four years, addition of a *C. purpureum*-based biological treatment does not significantly improve light availability and morphological parameters (height, diameter) of white spruce seedlings and thereby does not eliminate the need for repeated mechanical treatments. *C. purpureum* is currently registered for use only on Sitka and red alder (*Alnus rubra* Bong.) in Canada (Table 4). Other biological control agents investigated include *Sclerotina sclerotiorum* (Lib.) de Bary, *Ascochyta pteridium* Bres. (Myketa *et al.* 1995) and Cytospora canker (Mallik *et al.* 1997). However, little information about these fungi was found in the literature.

Conclusion

Vegetation management is essential to ensure that plantations provide the outcomes for which they are established. This review synthesizes the results of research that has been carried out in Canada and elsewhere for decades to identify the most effective and efficient vegetation management practices to control plants that compete with the growth and development of planted and natural Canadian boreal conifer species. However, silvicultural strategies must continue to be fine-tuned. For example, the effectiveness of treatments may need to be re-evaluated when new provincial strategies are developed and new guidelines are implemented such as retention of standing residual trees and downed woody debris, timing restrictions on operations, and road reclamation. These requirements could potentially affect the suite of vegetation management approaches that can be used on a site.

Acknowledgements

Financial support from the Agricultural Research Institute of Ontario through the Canadian Ecology Centre – Forestry Research Partnership's project *Silvicultural effectiveness and consequences of using vegetation management alternatives in boreal and temperate coniferous forests*, Domtar Inc., and FORREX Forum for Research and Extension in Natural Resources Society's Ecosystem Legacy Fund is gratefully acknowledged. We acknowledge the contributions of Manuel Mariotto, Mike Irvine, Teresa Newsome, Phil Comeau, Steven Kiiskila, Richard Kabzems and Chris Hollstedt in the preparation of this paper. They provided direction to relevant Web sites, supplied literature, and provided advice that helped us prepare this synthesis. We would also like to thank Lisa Buse, OFRI, and an anonymous reviewer for editing previous versions of this manuscript.

References

Arnup, R.W., B.J. Downsley, L.J. Buse and F.W. Bell. 1995. Field Guide to Autecology of Selected Crop Trees and Competitor Species in Northeastern Ontario. Ontario Ministry of Natural Resources, Northeast Science and Information, South Porcupine, ON. NESI FG-005. 152 p.

Ball, W.J. and V.S. Kolabinski. 1986. Performance of bareroot and container seedlings on prescribed burns in Saskatchewan. Canadian Forest Service, Northern Forestry Centre, Edmonton, AB. Information Report NOR-X-283. 18 p.

Balandier, P., C. Collet, J.H. Miller, P.E. Reynolds and S.M. Zedaker. 2006. Designing forest vegetation management strategies based on the mechanisms and dynamics of crop tree competition by neighbouring vegetation. Forestry 79(1): 3–27.

Balandier, P., H. Frochot and A. Sourisseau. 2009. Improvement of direct tree seeding with cover crops in afforestation: Microclimate and resource availability induced by vegetation composition. For. Ecol. Manage. 257(8): 1716–1724.

Bancroft, B. 1989. Response of aspen suckering to pre-harvest stem treatments: a literature review. B.C. Ministry of Forests, Research Branch, Victoria, BC. FRDA Report 087. 59 p. Available at http://www.for.gov.bc.ca/hfd/pubs/Docs/Frr/Frr087.htm.

Bancroft, B. 1992a. Sheep browsing as a silvicultural vegetation control method: an operational trial, Sable Creek, BC. Second year report. Madrone Consultants Ltd., Victoria, B.C. Unpublished report. 22 p. (Cited in Newsome *et al.* 1995).

Bancroft, B. 1992b. Sheep browsing for vegetation control: an operational trial, Sumas Mountain. Establishment information and second year results. Madrone Consultants Ltd, Victoria, B.C. Unpublished report. 39 p. (Cited in Newsome *et al.* 1995).

[BCMF] British Columbia Ministry of Forests 1997. Operational summary for vegetation management: Mixed-shrub complex. BC Ministry of Forests and Range, Forest Practices Branch. Victoria, BC. 11 p. Available at http://www.for.gov.bc.ca/hfp/publications/00048/mixshrub.pdf.

[BCMFR] British Columbia Ministry of Forests and Range. 2000. Sheep grazing in forestry. BC. Ministry of Forests and Range, Silviculture Practices Section, Victoria BC. Silviculture Note 26.

_____. 2002. Forest vegetation management using sheep – Species palatability tables for sheep. BC Ministry of Forests and Range, Forest Practices Branch, Victoria, BC. 4 p. Available at http://www.for.gov.bc.ca/isb/forms/lib/FS234S.pdf.

Bedford, L. and R.F. Sutton. 2000. Site preparation for establishing lodgepole pine in the sub-boreal spruce zone of interior British Columbia: the Bednesti trial, 10-year results. For. Ecol. Manage. 126(2): 227–238.

Bell, F.W. 1991. Critical silvics of conifer crop species and selected competitive vegetation in northwestern Ontario. Forestry Canada, Ontario Region, Sault Ste Marie, ON and Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. COFRDA Report 3310/NWOFTDU Technical Report 19. 177 p.

Bell, F.W., J. Dacosta, M. Penner, A. Morneault, A. Stinson, B. Towill, N. Luckai and J. Winters. 2011a. Longer-term volume trade-offs in spruce and jack pine plantations following various conifer release treatments. For Chron. 87(2): 235–250.

Bell, F.W., M. Kershaw, I. Aubin, N. Thiffault, J. Dacosta and A. Wiensczyk. 2011b. Ecology and traits of plant species that compete with boreal and temperate forest conifers: An overview of available information and its use in forest management in Canada. For Chron. 87(2): 161–174.

Bell, F.W., R.A. Lautenschlager, R.G. Wagner, D.G. Pitt, J.W. Hawkins and K.R. Ride. 1997. Motor manual, mechanical, and herbicide release affect early successional vegetation in Northwestern Ontario. For. Chron. 73: 61–68.

Bell, F.W. and D.G. Pitt 2007. Seasonal susceptibility of boreal plants: red raspberry phenology as a bioindicator of optimum within-season timing of glyphosate applications. For. Chron. 83(5): 733–741.

Bell, F.W., D.G. Pitt, A.E Morneault and S.M. Pickering. 1999. Response of immature trembling aspen to season and height of cut. North. J. Appl. For. 16(2): 108–114.

Bell, F.W., N. Thiffault, K. Szuba, N. Luckai and A. Stinson. 2011c. Synthesis of silviculture options, costs, and consequences of alternative vegetation management practices relevant to boreal and temperate conifer forests: Introduction. For Chron. 87(2): 155–160.

Bella, I.E. 1986. Logging practices and the subsequent development of aspen stands in east-central Saskatchewan. For. Chron. 62(2): 81–83.

Biring, B.S., P.G. Comeau and J.O. Boateng. 1996. Effectiveness of forest vegetation control methods in British Columbia. BC Ministry of Forests, Research Branch, Victoria, BC. FRDA Handbook 011. 58 p.

Boateng, J.O. 2002. Herbicide Field Handbook (Revised). BC Ministry of Forests, Forest Practices Branch, Victoria, BC. FRDA Handbook 006 [Revised]. 90 p. Available at http://www.llbc.leg.bc.ca/public/PubDocs/bcdocs/357529/Frh006.pdf.

Boateng, J.O. and G. Ackerman. 1990. A guide to vegetation control equipment. BC Ministry of Forests and Forestry Canada, Victoria, BC. FRDA handbook 005. 123 p.

Boateng, J.O., J.L. Heineman, L. Bedford, G.J. Harper, and A.F. Linnell Nemec 2009. Long-term effects of site preparation and post planting vegetation control on Picea glauca survival, growth and predicted yield in boreal British Columbia. Scand. J. For Res. 24(2): 111–129.

Boateng, J.O., J.L. Heineman, J. McClarnon and L. Bedford. 2006. Twenty year responses of white spruce to mechanical site preparation and early chemical release in the boreal region of northeastern British Columbia. Can. J. For. Res. 36(10): 2386–2399.

Buse, L.J. and F.W. Bell. 1992. Critical silvics of selected crop and competitor species in Northwestern Ontario. Ontario Ministry of Natural Resources. Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. 144 p.

Campbell, R.A., J.E. Wood, D.G. Thompson and E. Iskra. 2001. Site preparation – chemical. *In* R.G. Wagner and S.J. Colombo (eds.). Regenerating the Canadian Forest: Principles and Practices for Ontario. pp. 221–239. Fitzhenry and Whiteside Ltd, Markham, ON.

Coates, D., S. Haeussler and J. Mather. 1990. A guide to the response of common plants in British Columbia to management treatments. BC Ministry of Forests and Forestry Canada, Victoria, BC. FRDA Handbook 008. 142 p.

Cody, W.J. and C.W. Crompton. 1975. The biology of Canadian Weeds. 15. *Pteridium aquilinum* (L.) Kuhn. Can. J. Plant Sci. 55(4): 1059–1072.

Conference Board of Canada. (Updated October 2008). Environment. Use of forest resources [online]. Available at http://www.conferenceboard.ca/HCP/Details/environment/use-of-forest-resources.aspx [Accessed Aug. 31, 2009].

Conlin, T., G.J. Harper and P.G. Comeau. 2000. Evaluation of the effectiveness of *Chondrostereum purpureum* for the control of mechanically brushed trembling aspen (*Populus tremuloides* Michx.) suckers in a 2-year-old conifer plantation: Third-year results (MOF EP 1135.05). BC Ministry of Forests, Research Branch, Victoria, BC. Extension Note EN-49. 4 p.

Cyr, G. and N. Thiffault. 2009. Long-term black spruce plantation growth and structure after release and juvenile cleaning: A 24-year study. For. Chron. 85(3): 417–426.

Dampier J, F.W. Bell, M. St-Amour, D.G. Pitt and N.J. Luckai. 2006. Cutting versus herbicides: tenth-year volume and release cost effectiveness of sub-boreal conifer plantation. For Chron 82(4): 521–528.

Day, K., C. Koot and A.M. Wiensczyk. 2011a. The shelterwood silvicultural system in British Columbia – A practitioners' guide. Part 1: Implementation Considerations. BC Journal of Ecosystems and Management (in press).

Day, K., C. Koot and A.M. Wiensczyk. 2011b. The shelterwood silvicultural system in British Columbia – A practitioners' guide. Part 3: Applying the shelterwood system. BC Journal of Ecosystems and Management (in press).

De Jong, M.D. 2000. The BioChon story: deployment of *Chondrostereum purpureum* to suppress stump sprouting in hardwoods. Mycologist 14(2): 58–62.

Devine, W.D. and C.A. Harrington. 2007. Influence of harvest residues and vegetation on microsite soil and air temperatures in a young conifer plantation. Agric. For. Meteorol. 145(1–2): 125–138.

Dey, D.C. and G.B. MacDonald. 2001. Chapter 9: Overstory manipulation. *In* R.G. Wagner and S.J. Colombo (eds.). Regenerating the Canadian Forest: Principles and Practices for Ontario. pp. 157–175. Fitzhenry and Whiteside Ltd, Markham, ON.

Ellen, G. 1988. Clearwater agroforestry trials 1985–1988. BC Ministry of Forests, Clearwater, B.C. Unpublished Report (cited in Newsome *et al.* 1995).

Evans, C. 2005. Mechanical site preparation equipment review. Canadian Silviculture Magazine. Summer 2005.

Feller, M.C. 1996. Use of prescribed fire for vegetation management. *In* P.G. Comeau, G.J. Harper, M.E. Blache, J.O. Boateng, and L.A. Gilkeson. (eds.). Integrated Forest Vegetation Management: Options and Applications. Proceedings of fifth BC forest vegetation management workshop. Nov 29–30, 1993. Richmond, BC. pp. 17–34. FRDA report 251.

Foster, R.F. 1998. Grazing animals for forest vegetation management. Northwest Science and Technology. Technical Note TN-40 *In* F.W. Bell, M. McLaughlan and J. Kerley (compilers). Vegetation management alternatives – A guide to Opportunities. Ontario Ministry of Natural Resources. Thunder Bay, ON. Available at http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@nwsi/documents/document/mnr_e005371.pdf.

Fowells, H.A. 1965. Silvics of forest trees of the United States. USDA Forest Service, Agricultural Handbook No. 271. Washington, DC. 762 p.

Frey, B.R., V.J. Lieffers, S.M. Landhausser, P.G. Comeau and K.J. Greenway. 2003a. An analysis of sucker regeneration of trembling aspen. Can. J. For. Res. 33(7): 1169–1179.

Frey, B.R., V.J. Lieffers, A.D. Munson and P.V. Blenis. 2003b. The influence of partial harvesting and forest floor disturbance on nutrient availability and understory vegetation in boreal mixedwoods. Can. J. For. Res. 33(7): 1180–1188.

Fu, S. F.W. Bell and H.Y.H. Chen 2007. Long-term effects of intensive silvicultural practices on productivity, composition, and structure of northern temperate and boreal plantations in Ontario, Canada. For. Ecol. Manage. 241(1–3): 115–126.

Fu, S., Chen, H.Y.H., F.W. Bell, M. Sharma, J.R. Delaney and G. Peterson. 2008. Effects of timing of glyphosate application on jack pine, black spruce and white spruce plantations in northern Manitoba. For. Chron. 84(1): 37–45.

Haeussler, S. 1991. Prescribed fire for forest vegetation management. Synopsis. BC Ministry of Forests, Victoria, BC. FRDA Memo No 198. 19 p.

Haeussler, S., D. Coates and J. Mather. 1990. Autecology of common plants in British Columbia: A literature review. FRDA report 158. Available at http://www.for.gov.bc.ca/hfd/pubs/Docs/Frr/Frr158.pdf.

Hall, I.V., L.E. Aalders, and C.F. Everett. 1976. The biology of Canadian Weeds. 16. *Comptonia peregrina* (L.) Coult. Can. J. Plant Sci. 56(1):147–156.

Hall, I.V., L.P. Jackson, and C.F. Everett. 1973. The biology of Canadian Weeds. 1. *Kalmia angustifolia* L. Can. J. Plant Sci. 53(4): 865–873.

Harper, G.J., P.G. Comeau and B.S. Biring. 2005. A comparison of herbicide and mulch mat treatments for reducing grass, herb, and shrub competition in the BC Interior Douglas-fir zone – ten-year results. West. J. Appl. For. 20(3): 167–176.

Hart, D. and P.G. Comeau. 1992. Manual brushing for forest vegetation management in British Columbia: A review of current knowledge and information needs. BC Ministry of Forests Land Management Report No 77. Victoria, BC. 36 p.

Harvey, E.M., F.W. Bell, and J.O. Boateng. 1998. Manual, motor manual and mechanical brushing tools for conifer release. Northwest Science and Technology Technical Note TN-42 *In* F.W. Bell, M. McLaughlan and J. Kerley (compilers). Vegetation management alternatives – A guide to Opportunities. Ontario Ministry of Natural Resources. Thunder Bay, ON. Available at http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@nwsi/documents/document/mnr_e005369.pdf.

Hayes, A. 2001. Regeneration strategies as a proactive approach to vegetation management. Northwest Science and Technology TN-46 *In* F.W. Bell, M. McLaughlan and J. Kerley (compilers). Vegetation management alternatives – A guide to Opportunities. Ontario Ministry of Natural Resources. Thunder Bay, ON. Available at http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@nwsi/documents/document/mnr_e005365.pdf.

Iverson, R.D. 1984. Planting-stock selection: meeting biological needs and operational realities. *In* M.L. Duryea and T.D. Landis (eds.). Forest Nursery Manual: Production of Bareroot seedlings. pp. 261–266. Martinus Nijhoff/Dr W. Junk Publishers. The Hague/Boston/Lancaster, for Forest Research Laboratory, Oregon State University. Available at http://www.rngr.net/Publications/fnm/Chapter%2024/view.

Jackson, D.R. and J.C. Finlay. 2007. Herbicides and forest vegetation management; Controlling unwanted trees, brush, and other competing forest vegetation. Penn State College of Agricultural Sciences, Agricultural Research and Cooperative Extension. 20 p. Available at http://pubs.cas.psu.edu/freepubs/pdfs/UH174.pdf.

Jobidon, R. 1997. Stump height effects on sprouting of mountain maple, paper birch and pin cherry – 10 year results. For. Chron. 73(5): 590–595.

Jobidon, R. and L. Charette. 1997. Effets, après 10 ans, du dégagement manuel simple ou répété et de la période de coupe de la végétation de compétition sur la croissance de l'épinette noire en plantation. Can. J. For. Res. 27(12): 1979–1991.
Jobidon, R., L. Charette, and P.Y. Bernier. 1998. Initial size and competing vegetation effects on water stress and growth of *Picea mariana* (Mill.) BSP seedlings planted in three different environments. For. Ecol. Manage. 103(2–3): 293–305.
Jobidon, R., V. Roy and G. Cyr. 2003. Net effect of competing vegetation on selected environmental conditions and performance of four spruce seedling stock sizes after eight years in Québec (Canada). Ann. For. Sci. 60(7): 691–699.
Kiiskila, S. 1999. The effect of seedling size on field performance. Notes from the Field – articles. Pacific Regeneration Technologies Inc. Prince George, BC. 6 p. Available at http://www.prt.com/sites/prtgroup/uploads/1237820326003.pdf.
Lamhamedi, M.S., P.Y. Bernier, C. Hébert and R. Jobidon. 1998. Physiological and growth response of three sizes of containerized *Picea mariana* seedlings outplanted with and without vegetation control. For. Ecol. Manage. 110(1–3): 13–23.
LandOwner Resource Centre. 1994. Cover crops help tree seedlings beat weed competition. LandOwner Resource Centre, Manotick, On. Extension Note. 6 p. Available at http://www.lrconline.com/Extension_Notes_English/pdf/cvrcrps.pdf.
LandOwner Resource Centre. 1997. Mulches help trees beat weed competition. LandOwner Resource Centre, Manotick, On. Extension Note. 8 p. Available at http://www.lrconline.com/Extension_Notes_English/pdf/mlchs.pdf.
Leininger, W.C. and S.H. Sharrow. 1983a. Livestock grazing and forest regeneration: The status of our knowledge. *In* S.H. Sharrow and W.C. Leininger (eds.). Forage preferences of herded sheep as related to brush control and seasonal browsing damage to Douglas-fir regeneration. pp. 1–58. Final Report 1980–1983. U.S. Department of Agriculture, Forest Service, Alsea Ranger District, Siuslaw Natural Forest, Oregon.
Leininger, W.C. and S.H. Sharrow. 1983b. Seasonal food habits of herded sheep grazing cut-over Douglas-fir forests of western Oregon. *In* S.H. Sharrow and W.C. Leininger (eds.). Forage preferences of herded sheep as related to brush control and seasonal browsing damage to Douglas-fir regeneration. pp. 73–94. Final Report 1980–1983. U.S. Department of Agriculture, Forest Service, Alsea Ranger District, Siuslaw Natural Forest, Oregon.
Leininger, W.C. and S.H. Sharrow. 1983c. Seasonable browsing of Douglas-fir regeneration by sheep in the coast range. *In* S.H. Sharrow and W.C. Leininger (eds.). Forage preferences of herded sheep as related to brush control and seasonal browsing damage to Douglas-fir regeneration. pp. 95–116. Final Report 1980–1983. U.S. Department of Agriculture, Forest Service, Alsea Ranger District, Siuslaw Natural Forest, Oregon.
Lindgren, P.M.F. and T.P. Sullivan 2001. Influence of alternative vegetation management treatments on conifer plantation attributes: Abundance, species diversity, and structural diversity. For. Ecol. Manage. 142(1–3): 163–182.
Lousier, J.D. 1990. Using sheep to control competing vegetation on Vancouver Island, impacts on seedlings, competing vegetation and water quality: Glenora Creek, Duncan Forest District, first year report. W.F.S. Enterprises Ltd., Nanaimo, B.C. Unpublished report. 19 p. (cited in Newsome *et al*. 1995).
Lousier, J.D. and M. Lousier. 1991. Using sheep to control competing vegetation on Vancouver Island, impacts on seedlings, competing vegetation and water quality: Glenora Creek, Stocking Creek, and Banon East, Duncan Forest District. W.F.S. Enterprises Ltd., Nanaimo, B.C. Unpublished report. 22 p. (cited in Newsome *et al*. 1995).
Luke, A.B., D.J. Archibald, R.W. Arnup and N.L. Wood. 2000. Prescribed fire as a vegetation management tool. Northwest Science and Technology Technical Note TN-45 *In* F.W. Bell, M. McLaughlan and J. Kerley (compilers). Vegetation management alternatives – A guide to Opportunities. Ontario Ministry of Natural Resources. Thunder Bay, ON. Available at http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@nwsi/documents/document/mnr_e005366.pdf.
Macadam, A., R.F. Sutton, and L. Bedford. 2001. Site preparation for establishing lodgepole pine on backlog sites in the sub-boreal spruce zone. BC Ministry of Forests, Silviculture Practices Section, Victoria, BC. Silviculture Note 27. 6 p. Available at http://www.for.gov.bc.ca/hfp/publications/00128/SN27.pdf.
MacKinnon, A., L. Bedford, and J. Maxwell. 1987. A guide to the use of mechanical site preparation equipment in North Central British Columbia. 2nd edition. BC Ministry of Forests, Research Branch, Victoria, BC. FRDA Report 002. Available at http://www.for.gov.bc.ca/hfd/pubs/Docs/Frh/Frh002.pdf.
Mallik, A.U. 1991. Cutting, burning, and mulching to control *Kalmia*: results of a greenhouse experiment. Can. J. For. Res. 21(3): 417–420.
Mallik, A.U., K. Wood, C. Hollstedt and M.S. McLaughlan. 1997. Cut stump herbicide treatments to reduce sprouting and root suckering. Northwest Science and Technology Technical Note TN-39 *In* F.W. Bell, M. McLaughlan and J. Kerley (compilers). Vegetation management alternatives – A guide to Opportunities. Ontario Ministry of Natural Resources. Thunder Bay, ON. Available at http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@nwsi/documents/document/mnr_e005372.pdf.
McDonald, P.M. and G.O. Fiddler. 1996. Mulching: A persistent technique for weed suppression. *In* P.G. Comeau, G.J. Harper, M.E. Blache, J.O. Boateng and L.A. Gilkeson (eds.).Integrated Forest Vegetation Management: Options and applications. Proceedings of the 5th BC forest vegetation management workshop, Nov 29–30, 1993, Richmond BC. pp. 51–57. BC Ministry of Forests, Victoria, BC. FRDA report 251.
McDonald, P.M., G.O. Fiddler, and R. Henry. 1994. Repeated manual release in a young plantation: effect on Douglas-fir seedlings, hardwoods, shrubs, forbs, and grasses. Pacific Southwest Research Station. USDA Forest Service, Albany, CA. Research Paper PSW-RP-221.
McLaughlan, M.S, D. Myketa and F.W. Bell. 1996. Managing vegetation with herbicides: A review of glyphosate, 2,4-D, Hexazinone, Triclopyr and Simazine. Northwest Science and Technology, TN-37. *In* F.W. Bell, M. McLaughlan and J. Kerley (compilers). Vegetation management alternatives – A guide to Opportunities. Ontario Ministry of Natural Resources. Thunder Bay, ON. Available at http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@nwsi/documents/document/mnr_e005375.pdf.
McMinn, R.G. 1982. Size of container-grown seedlings should be matched to site conditions. *In* J.B. Scarratt, C. Glerum and C.A. Plexman (eds.). Proceedings of the Canadian Containerized Tree Seedling Symposium. Sept 14–16, 1981, Toronto, Ontario. pp. 307–312. COJFRC Symposium proceedings O-P-10. Canadian Forest Service, Great Lakes Forest Research Centre, Sault Ste Marie, ON.
McRae, D.J., M.G. Weber and P.C. Ward. 2001. Site preparation – prescribed fire. *In* R.G. Wagner and S.J. Colombo (eds.).Regenerating the Canadian Forest: principles and practices for Ontario. pp. 201–219. Fitzhenry and Whiteside Ltd, Markham, ON.
Mohammed, G., G.R. McLeod, P.A. Menes and V.R. Timmer. 2001. A comparison of bareroot and container stock. *In* R.G. Wagner and S.J. Colombo (eds.). Regenerating the Canadian Forest: principles and practices for Ontario. pp. 343–348. Fitzhenry and Whiteside Ltd, Markham, ON.
Moore, R.J. 1975. The biology of Canadian weeds. 13. *Cirsium arvense* (L.) Scop. Can. J. Plant Sci. 55(4): 1033–1048.
Myketa, D. and M.S. McLaughlan. 1996. The shelterwood silvicultural system as related to vegetation management. Northwest Science and Technology Development Unit. Technical note TN-35. *In* F.W. Bell, M. McLaughlan and J. Kerley (compilers). Vegetation management alternatives – A guide to Opportunities. Ontario Ministry of Natural Resources. Thunder Bay, ON. Available at http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@nwsi/documents/document/mnr_e005377.pdf.

Myketa, D., M. McLaughlan and F.W. Bell. 1995. Fungi and plant toxins for forest vegetation management. Northwest Science and Technology Technical Note TN-33. *In* F.W. Bell, M. McLaughlan and J. Kerley (compilers). Vegetation management alternatives – A guide to Opportunities. Ontario Ministry of Natural Resources. Thunder Bay, ON. Available at http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@nwsi/documents/document/mnr_e005379.pdf.

Myketa, D, R. Whaley, and B. Polhill. 1998. Harvesting practices and their implications for vegetation management. Northwest Science and Technology. Technical Note TN-43. *In* F.W. Bell, M. McLaughlan and J. Kerley (compilers). Vegetation management alternatives – A guide to Opportunities. Ontario Ministry of Natural Resources. Thunder Bay, ON. Available at http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@nwsi/documents/document/mnr_e005368.pdf.

Negrave, R. and R. Kabzems. 1996. Use of replacement vegetation for control of competing vegetation in spruce plantations in the BWBS. *In* P.G. Comeau, G.J. Harper, M.E. Blache, J.O. Boateng and L.A. Gilkeson (eds.). Integrated Forest Vegetation Management: Options and applications. Proceedings of the 5th BC forest vegetation management workshop, Nov 29–30, 1993, Richmond BC. pp. 127–129. BC Ministry of Forests, Victoria, BC. FRDA report 251.

Newsome, T. 1996. The use of sheep in forest vegetation management. *In* P.G. Comeau, G.J. Harper, M.E. Blache, J.O. Boateng and L.A. Gilkeson (eds.). Integrated Forest Vegetation Management: Options and applications. Proceedings of the 5th BC forest vegetation management workshop, Nov 29–30, 1993, Richmond BC. pp. 67–74. BC Ministry of Forests, Victoria, BC. FRDA report 251.

Newsome, T., B. Wikeem and C. Sutherland. 1995. Sheep grazing guidelines for managing vegetation on forest plantations in British Columbia. BC. Ministry of Forests Research Program. Land Management Handbook 34.

Norberg, A. 2000. Steam treatment of forest ground vegetation to improve seedling establishment and growth. PhD thesis – Swedish University of Agricultural Sciences. Umea, Sweden.

Norberg, A., A. Jäderlund, O. Zackrisson, T. Nordfjell, D.A. Wardle, M.-C. Nilsson and A. Dolling. 1997. Vegetation control by steam treatment in boreal forests: a comparison with burning and soil scarification. Can. J. For. Res. 27(12): 2026–2033.

Nova Scotia Department of Lands and Forests. 1989. Control of hardwood competition by injection of glyphosate or girdling. Nova Scotia Department of Lands and Forests, Truro, NS. Forest Research Report No 15. 7 p.

Nyland, R.D. 2002. Silviculture: Concepts and Applications. McGraw-Hill.

[OMNR] Ontario Ministry of Natural Resources. 1997. Silvicultural guide to managing for black spruce, jack pine, and aspen on boreal forest ecosites in Ontario. Book 1: Silviculture in Ontario. Version 1.1. Ontario Ministry of Natural Resources, Queen's Printer for Ontario, Toronto, ON.

Opio, C., N. Jacob, and D. Khasa. 2001. Factors affecting a sheep vegetation management system in British Columbia, Canada. Agrofor. Syst. 53(3): 305–312.

Örlander, G., P. Gemmel and J. Hunt. 1990. Site Preparation: A Swedish Overview. British Columbia Ministry of Forests. FRDA Report. 105. Victoria, BC.

Pacific Regeneration Technologies Inc. 2000. McGregor Interior Spruce Stock Type Trials – 24 year results. Notes from the field – Trials. PRT Red Rock, Prince George BC. 4 p. Available at http://\www.prt.com/sites/prtgroup/uploads/1237576357896.pdf.

Perry, J. 1987. An assessment of manual brush control in the Cariboo Forest Region. B.C Ministry of Forests, Williams Lake, BC. Unpublished Report. 20 p.

Pitt, D.G., and F.W. Bell. 2005. Juvenile response to conifer release alternatives on aspen-white spruce boreal mixedwood sites. Part I: Stand structure and composition. For. Chron. 81: 538–547.

Pitt, D.G., M.T. Dumas, R.E. Wall, D.G. Thompson, L. Lanteigne, W. Hintz, G. Sampson and R.G. Wagner. 1999a. *Chondrostereum purpureum* as a biological control agent in forest vegetation management. I. Efficacy on speckled alder, red maple, and aspen in Eastern Canada. Can. J. For. Res. 29(7): 841–851.

Pitt, D.G., C.S. Krishka, F.W. Bell and A. Lehela. 1999b. Five-year performance of three conifer stock types on fine sandy loam soils treated with hexazinone. Northern Journal of Applied Forestry 16(2):72–81.

Pitt, D.G., A.E. Morneault, P. Bunce and F.W. Bell. 2000. Five years of vegetation succession following vegetation management treatments in a jack pine ecosystem. North. J. Appl. For. 17(3):100–109.

Pitt, D.G., R.G. Wagner, and W.D. Towill. 2004. Ten years of vegetation succession following ground-applied release treatments in young black spruce plantations. North. J. Appl. For. 21(3):123–134.

Prescott, C.E., J.W. Kumi and G.F. Weetman. 1995. Long-term effects of repeated N fertilization and straw application in a jack pine forest. 2. Changes in the ericaceous ground vegetation. Can. J. For. Res. 25:1984–1990.

Prévost, M. and D. Dumais. 2003. Croissance et statut nutritif de marcottes, de semis naturels et de plants d'épinette noire à la suite du scarifiage : résultats de 10 ans. Can. J. For. Res. 33(11): 2097–2107.

Racey, G.D., T.S. Whitfield and R.A. Sims. 1989. Northwestern Ontario forest ecosystem interpretations. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, On. NWOFTDU Technical Report No. 46. 90 p.

Raymond, P., S. Bédard, V. Roy, C. Larouche and S. Tremblay. 2009. The irregular shelterwood system: review, classification, and potential application to forests affected by partial disturbances. J. For. 108(8): 405–413.

Robertson, S. and D. Myketa. 1998. The selection silvicultural system as related to vegetation management. Northwest Science and Technology. Technical Note TN-44. *In* F.W. Bell, M. McLaughlan and J. Kerley (compilers). Vegetation management alternatives – A guide to Opportunities. Ontario Ministry of Natural Resources. Thunder Bay, ON. Available at http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@nwsi/documents/document/mnr_e005367.pdf.

Robitaille, D. 2003. Protection des plantations de feuillus contre la végétation concurrente dans les friches herbacées : Plantation de Beaumont – résultats de sept ans. Ministère des Ressources Naturelles, de la Faune et des Parcs, Direction de la Recherche Forestière. Note de Recherche Forestière 142.

Rowe, J.S. 1983. Concepts of fire effects on plant individuals and species. *In* R.W. Wein and D.A. MacLean (eds.).The role of fire in northern circumpolar ecosystems. pp. 135–154. John Wiley and Sons Ltd. Available at http://globalecology.stanford.edu/SCOPE/SCOPE_18/SCOPE_18_1.8_Rowe.pdf.

Roy, V., D. Dubeau and I. Auger. 2010. Biological control of intolerant hardwood competition: Silvicultural efficacy of *Chondrostereum purpureum* and worker productivity in conifer plantations. For. Ecol. Manage. 259(8): 1571–1579.

Ryans, M. and D. Cormier. 1994. A review of mechanized brushcutting equipment for forestry. Forest Engineering Research Institute of Canada (FERIC), Special Report No. SR-101. 36 p.

Ryans, M. and B. Sutherland. 2001. Site Preparation – Mechanical. *In* R.G. Wagner and S.J. Colombo (eds.). Regenerating the Canadian Forest: principles and practices for Ontario. pp 177–199. Fitzhenry and Whiteside Ltd, Markham, ON.

Sachs, D., J Heineman, J. Mather, M. Curran and S. Simard. 2009. Expert System for Site Preparation and Vegetation Management in Southern Interior British Columbia [online]. Available at http://www.myacquire.com/spvegman/expertsystem/ [Accessed Sept. 2, 2009].

Shamoun, S.F. 2000. Application of biological control to vegetation management in forestry. *In* N.R. Spencer (ed.). Proceedings of the X International Symposium on Biological Control of Weeds. July 4–14, 1999, Montana State University, Bozeman, Montana. pp. 87–96.

Sharrow, S.H. 1994. Sheep as a silviculture management tool in temperate conifer forest. Sheep and Goat Research Journal. Special Issue: 1994; "The Role of Sheep Grazing in Natural Resource Management". pp. 97–104.

Sharrow, S.H., W.C. Leininger and K.A. Osman. 1992. Sheep grazing effects on coastal Douglas-fir growth: a ten-year perspective. Forest Ecology and Management 50(1–2): 75–85.

Sharrow, S.H. W.C. Leininger, and B. Rhodes. 1989. Sheep grazing as a silvicultural tool to suppress brush. J. Range Manage. 42(1): 2–4.

Smith, D.M. 1962. The Practice of Silviculture. 7th Edition. John Wiley and Sons, New York, NY. 573 p.

Steneker, G.A. 1976. Guide to the silvicultural management of trembling aspen in the prairie provinces. Canadian Forest Service Information Report NOR-X-164. 6 p.

Stewart, R.E., L.L. Gross, and B.L. Honkela (compilers). 1984. Effects of competing vegetation on forest trees: a bibliography with abstracts. USDA For. Serv., Washington, DC. Gen. Tech. Rep. WO-43. 260 p.

Stewart, R.E., 1987. Seeing the forest for the weeds: a synthesis of forest vegetation management. *In*.J.D. Walsted and P.J. Kuch (eds.). Forest vegetation management for conifer production. pp. 431–480. John Wiley and Sons, New York.

Stone, R.N. and C.D. Chase. 1962. Forest plantations of northern lower Michigan. USDA For. Serv., Lake States Forest Exp. Stn., St Paul, Minnesota. Stn. Pap. 102. 30 p.

Sutherland, B.J., and F.F. Foreman. 1995. Guide to the use of mechanical site preparation equipment in northwestern Ontario. Can. For. Serv., Sault Ste. Marie, On. NODA/NFP Project 4113.

Sutherland B.J. and F.F. Foreman. 2000. Black spruce and vegetation response to chemical and mechanical site preparation on a boreal mixedwood site. Can. J. For. Res. 30(10): 1561–1570.

Sutherland, C., T. Newsome, N. Daintith and J. Perry. 1992. Sheep grazing: a biological tool for controlling competing vegetation in spruce plantations. *In* C.E. Dorworth and S.G. Glover (eds.). Biocontrol of forest weeds: proceedings of a workshop held at the western international forest disease conference, Vernon, BC. pp. 21–29. Forestry Canada, Pacific Forestry Centre, Victoria, BC.

Sutton, R.F. 1985. Vegetation management in Canadian forestry. Govern. Can., Can. For. Serv., Great Lakes For. Res. Cen., Sault Ste Marie, ON. Inf. Rep. 0-X-369. 34 p.

Sutton, R.F., L. Bedford, L. Stordeur and M. Grismer. 2001. Site preparation for establishing interior spruce in British Columbia: trials at Upper Coalmine and Mackenzie. West. J. Appl. For. 16(1): 9–17.

Sutton, R.F. and T.P. Weldon. 1993. Jack pine establishment in Ontario: 5-year comparison of stock types ± Bräcke scarification, mounding, and chemical site preparation. For. Chron. 69(5): 545–553.

Swift, K.I. and F.W. Bell. 2011. What are the environmental consequences of using silviculturally effective forest vegetation management treatments? For Chron. 87(2): 201–216.

Swift, K. and J. Turner. 2004. Southern Interior Forest Region – Part 3: Vegetation complex stand establishment aids. BC J. Ecosys. Manage. 5(1): 11–21. Available at http://www.forrex.org/publications/jem/ISS25/vol5_no1_art3.pdf.

Thiffault, N. 2006. Remise en production des stations à éricacées: résultats de 15 ans d'un essai sylvicole sur la Côte-Nord. Ministère des Ressources Naturelles, de la Faune et des Parcs, Direction de la Recherche Forestière. Note de Recherche Forestière 132.

Thiffault, N., G. Cyr, G. Prégent, R. Jobidon and L. Charette. 2004. Artificial regeneration of an ericaceous black spruce stand – Effects of scarification, fertilization and plant type 10 years later. For. Chron. 80(1): 141–149.

Thiffault, N. and R. Jobidon. 2005. Existe-t-il une interaction entre le type de plants et le scarifiage? Le cas des PMD et des PFD d'épinettes. Ministère des Ressources Naturelles, de la Faune et des Parcs, Direction de la Recherche Forestière. Note de Recherche Forestière 129. 14 p. Available at http://www.mrnf.gouv.qc.ca/publications/forets/connaissances/recherche/Thiffault-Nelson/Note129.pdf.

Thiffault, N. and R. Jobidon. 2006. How to shift unproductive *Kalmia angustifolia – Rhododendron groenlandicum* heath to productive conifer plantation. Can. J. For. Res. 36(10): 2364–2376.

Thiffault, N., R. Jobidon and A.D. Munson. 2003. Performance and physiology of large containerized and bare-root spruce seedlings in relation to scarification and competition in Québec (Canada). Ann. For. Sci. 60(7): 645–655.

Thiffault, N. and V. Roy. 2011. Living without herbicides in Québec (Canada): Historical context, current strategy, research and challenges in forest vegetation management. Eur. J. For. Res. 130(1): 117–133.

Thiffault, N., B.D. Titus and M.T. Moroni. 2010. Silviculture and planted species interact to influence reforestation success on a *Kalmia*-dominated site – a 15-year study. For. Chron. 86(2): 234–242.

Thiffault, N., B.D. Titus and A.D. Munson. 2005. Silvicultural options to promote seedling establishment on *Kalmia–Vaccinium*-dominated sites. Scand. J. For. Res. 20(2): 110–121.

Thompson, C.F., P. Bauer, M.V. Ketcheson and G. Mowat. 1996. Seeding cover crops to inhibit vegetation development and encourage seeding growth in Interior Cedar–Hemlock and Engelmann spruce–Subalpine fir forests. B.C. Ministry of Forests, Victoria, BC. FRDA Report No. 263. 27 p.

Thompson, C.F. and M.V. Ketcheson. 1996. Grass and legume seeding for vegetation control in the Nelson Forest Region – species screening trial on a low impact burn. *In* P.G. Comeau, G.J. Harper, M.E. Blache, J.O. Boateng and L.A. Gilkeson (eds.). Integrated Forest Vegetation Management: Options and applications. Proceedings of the 5th BC forest vegetation management workshop, Nov 29–30, 1993, Richmond BC. pp. 139–140. BC Ministry of Forests, Victoria, BC. FRDA report 251.

Thompson, C.F. and S. Steen. 1996. Cover crops for forest vegetation management. *In* P.G. Comeau, G.J. Harper, M.E. Blache, J.O. Boateng and L.A. Gilkeson (eds.). Integrated Forest Vegetation Management: Options and applications. Proceedings of the 5th BC forest vegetation management workshop, Nov 29–30, 1993, Richmond BC. pp. 43–50. BC Ministry of Forests, Victoria, BC. FRDA report 251.

Thompson, D.G. and D.G. Pitt. 2003. A review of Canadian forest vegetation management research and practice. Ann. For. Sci. 60(7): 559–572.

Thorpe, S. 1996. Chemical and manual treatment in the Northern Interior. *In* P.G. Comeau, G.J. Harper, M.E. Blache, J.O. Boateng and L.A. Gilkeson (eds.). Integrated Forest Vegetation Management: Options and Applications. Proceedings of the 5th BC forest vegetation management workshop, Nov 29–30, 1993, Richmond BC. pp. 61–65. BC Ministry of Forests, Victoria, BC. FRDA report 251.

[USEPA] United States Environmental Protection Agency. Updated March 2005. *Chondrostereum purpureum* strain HQ1 (081309) fact sheet [online]. Available at http://www.epa.gov/pesticides/biopesticides/ingredients/factsheets/factsheet_081309.htm#usesites [Accessed Aug. 31, 2009].

Uotila, A., H. Penttinen and G. Salingre. 2006. *Chondrostereum purpureum* a potential biocontrol agent of sprouting. *In* Forest Pathology research in the Nordic and Baltic countries 2005. Proceedings from the SNS meeeting in Forest Pathology at Skogbrukets Kursinstitutt, Biri, Norway, 28–31. August 2005. Skogforsk Aktuelt fra skogforskning 1/06: 77–78. Available at http://www.skogogland-skap.no/filearchive/uotilaa-2006-1-4.pdf.

Vasiliauskas, S and A. Luke. 2000. Testing sheep grazing as a vegetation management tool in northeastern Ontario. OMNR, Northeast Science and Technology, NEST Technical Report TR-041 34 p.

Vincent, A.B. 1953. Mountain maple. Canada Department of Resources and Development, Division Forest Research Silviculture Leaflet No. 80. (cited in Myketa *et al* 1998).

Von der Gonna. M.A. 1992. Fundamentals of Mechanical site preparation. Canadian Forest Service, Pacific Forestry Centre, Victoria, BC and B.C. Ministry of Forests, Research Branch, Victoria BC. FRDA Report No. 178. 28 p. Available at http://www.for.gov.bc.ca/hfp/publications/00084//FRDA178.pdf.

Wagner, R.G., F.W. Bell, and R.A. Campbell. 2001. Vegetation management. *In* R.G. Wagner, and S.J. Colombo (eds.).Regenerating the Canadian Forest: principles and practices for Ontario. pp. 431–457. Fitzhenry and Whiteside Ltd, Markham, ON.
Wagner, R.G., K.M. Little, R. Richardson and K. Mcnabb. 2006. The role of vegetation management for enhancing productivity of the world's forests. Forestry 79(1): 57–79.
Walstad, J.D., M. Newton and D.H. Gjerstad. 1987. Overview of vegetation management alternatives. *In* J.D. Walstad and P.J. Kuch (eds.). Forest Vegetation Management for Conifer Production. pp. 157–200. John Wiley and Sons, New York.
Waters, I, S. Kembel, J-F. Gingras and J. Shay. 2004. Short-term effects of cut-to-length versus full-tree harvesting on conifer regeneration in jack pine, mixedwood, and black spruce forests in Manitoba. Can. J. For. Res. 34(9): 1938–1945.
Whaley, R. and B. Polhill. 1998. The clearcut silviculture system as related to vegetation management. Northwest Science and Technology. Technical Note TN-41. *In* F.W. Bell, M. McLaughlan and J. Kerley (compilers). Vegetation management alternatives – A guide to Opportunities. Ontario Ministry of Natural Resources. Thunder Bay, Ontario. Available at http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@nwsi/documents/document/mnr_e005370.pdf.
White, R.G. 2004. Mechanical site preparation and vegetation management. Northwest Science and Information. Technical Note TN47. *In* F.W. Bell, M. McLaughlan and J. Kerley (compilers). Vegetation management alternatives – A guide to Opportunities. Ontario Ministry of Natural Resources. Thunder Bay, Ontario. Available at http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@nwsi/documents/document/mnr_e005364.pdf.
Wiensczyk, A.M. 2008. Tour discusses managing mixedwood. LINK 10(2): 27–28.
Williamson, M. and D. Parker. 1995. Low-impact, selective herbicide application for control of desert shrubs and trees. USDA Forest Service, Southwest Region Field Guide. 4 p.
Wurtz, T.L. and J.C. Zasada. 2001. An alternative to clear-cutting in the boreal forest of Alaska: a 27-year study of regeneration after shelterwood harvesting. Can. J. For. Res. 31(6): 999–1011.
Zackrisson, O., G. Norberg, A. Dolling, M.-C. Nilsson, and A. Jäderlund. 1997. Site preparation by steam treatment: effects on forest vegetation control and establishment, nutrition and growth of seeded Scots pine. Can. J. For. Res. 27(3): 315–322.

Appendix 1. Responses of the main competing species found in Canada to disturbance by selected vegetation management treatments.

	Response to Disturbance				
		Fire			
Life form/species[a]	**Overstory removal**	**Low intensity**	**Medium to high intensity**	**Cutting**	**Mechanical site preparation**
Trees					
Red maple *Acer rubrum*	• Growth increases	• Sprouts vigorously		• Stump sprouts	
Sugar maple *Acer saccharum*	• Growth increases immediately • May develop epicormic sprouts Regenerates and grows best in small openings			• Stump sprouts	
Yellow birch *Betula alleghaniensis*	• Prefers small openings • Seeds in • In large openings, excess exposure may cause post-logging decadence	• Readily colonizes burned seedbeds		• Stump sprouts (small stems only). Sprouting from large stems poor.	• Increased seeding in on exposed mineral soil
Paper birch *Betula papyrifera*	• Increases in abundance via sprouting and seeding in	• Sprouts from root crowns • Seeds in abundantly	• Sprouting reduced	• Sprouts – sprouting more vigorous if cut during growing season except May–June – sprouts less. • Young trees sprout more than older ones • Ground level cutting more effective • Girdling effective during growing season	• Mineral soil exposure or mixed soil ideal seedbed • Sprouts from damaged stems
Balsam poplar *Populus balsamifera* ssp. *balsamifera* / ssp. *trichocarpa*	• Root suckering increases, summer logging + • Seeding on exposed mineral soil.	• Root suckering increases • Seeds in on burned areas • Mature trees are resistant	• Sprouting reduced	• Sprouting or suckering, winter – vigorous, growing season – less.	• Promotes suckering • Increased seeding on mineral soil • Branch fragments will regenerate
Black cottonwood *Populus balsamifera* ssp. *trichocarpa*	• Seeding in • Stump sprouts, may sucker	• Highly susceptible, sprouting stimulated	• High intensity fires may reduce sprout vigour.	• Vigorous sprouting; 25 times increase in stem numbers. • Cutting mid-June to mid-August may reduce number of sprouts.	• Seeding in on mineral soil • Stem and root fragments will regenerate

	Response to Disturbance				
		Fire			
Life form/species[a]	**Overstory removal**	**Low intensity**	**Medium to high intensity**	**Cutting**	**Mechanical site preparation**
Trembling aspen *Populus tremuloides*	• Root suckering, some stump sprouting • Winter logging 4× more suckers • Regeneration from seed on exposed mineral soil • Vigorous sprouting when organic layer disturbed but not removed and root systems not damaged	• Adapted to environment with recurring fires • Regenerates from suckers • Spring fires – increased regeneration		• Sprout from stump or suckers • Cutting in June – lower number of suckers • Sucker production proportional to degree of cutting • Girdling during growing season effective	• Surface treatment will increase sucker production • Seeding in on mineral soil is minimal • High cultivation treatments may control aspen
Shrubs					
Douglas maple *Acer glabrum*	• Minimal to slight increase in cover	• Moderate tolerance • Sprouts and can increase in cover	• Mortality	• Vigorous sprouting • Slight increase in foliar density	• Damaged stems sprout • Seeds in on disturbed areas
Mountain maple *Acer spicatum*	• Spreads rapidly	• Sprouts	• Kills meristem • Decrease in abundance	• Temporary increase in stem density, grows in clumps	• Shallow rooted – treatments that uproot entire plant successful. Treatments that bend over, trample or sever at root collar will result in increased biomass.
Mountain alder *Alnus incana* ssp. *tenuifolia* (L.) Moench	• Increase in abundance and growth especially on wet sites	• Often favoured by burning.	• Set back by moderate to severe fires	• Resprouts – spring and winter – rapid sprouting; July/August – less sprouting and slower growth.	• Seeds in to exposed mineral soil
Sitka/green alder *Alnus viridis – Alnus crispa*	• Increase in stem numbers • Stimulated more by winter than summer logging.	• Often favoured by burning; Killing cambium at ground level will kill plant. If only stem killed will resprout from stumps.	• Control	• Increase in stem numbers through stump sprouts; July and August – least sprouting and height growth	• Treatments that remove roots – greater success • Seeds in to disturbed sites
Speckled alder *Alnus rugosa*	• Promotes growth – spring and winter cutting – rapid sprouting; July/August – less sprouting and slower growth	• Vigorous reproduction	• Increase	• Winter and spring – rapid sprouting; July and August – thinnest stands and least height growth	• Stems bent but not severed will resprout vigorously; stems in contact with or partially covered by soil will produce aerial shoots along length; stems completely severed will die
Saskatoon *Amelanchier alnifolia*		• Sprouts	• Reduced sprouting	• Sprouts; increases biomass	• Treatments that only sever aboveground portions will result in increased biomass

Life form/species[a]	Response to Disturbance: Overstory removal	Fire: Low intensity	Fire: Medium to high intensity	Cutting	Mechanical site preparation
Bog rosemary *Andromeda glaucophylla*	• Encouraged by canopy removal				
Scrub birch (bog birch) *Betula glandulosa*		• Sprouts			
Leatherleaf *Chamaedaphne calyculata*	• Encouraged by canopy removal	• Increase in cover			
Red-osier dogwood *Cornus sericea* *Cornus stolonifera*	• Enhanced, especially on wetter sites	• Stimulates sprouting • Increases germination of stored seed.	• Reduces sprouting • Reduces germination of stored seed.	• Increase twig production; prone to rooting when cut during dormant season; early to mid-summer produces shorter and narrower sprout clumps than winter cutting. • Vigour can be reduced with multiple cuttings	• Sprout/sucker from stems/roots • Germination of buried seed stimulated by exposure of mineral soil
Beaked hazel *Corylus cornuta*	• Increases stem vigour and growth; stimulates fruit production, sprouts rapidly after winter harvesting	• Increases	• Reduced sprouting • Stimulates sprouting and suckering – less if cut late in growing season • Vigour unaffected by repeated cutting	• Underground stems sprout if not removed or destroyed	• Deep scarification or disking can reduce sprouts and suckers
Bush honeysuckle *Diervilla lonicera*	• Increased abundance	• Regenerates rapidly	• Decrease	• Sprouts less vigorously in summer-treated than in fall-treated plots	
Sheep laurel *Kalmia angustifolia*	• Increased growth and development of reproductive phase	• Regenerates quickly from rhizomes • Control with repeated fall burning (3 years in a row)	• High intensity: set back/eliminate	• Sprouts from rhizomes • Encourages lateral growth and spread	• Some control with intense treatments –ploughing stimulated growth, cuts rhizomes into pieces which then form a new plant. • Toxic to sheep, goats and cattle
Bog laurel *Kalmia polifolia*	• Prolific resurgence	• Little change			
Common juniper *Juniperus communis*		• Slow post-fire establishment			
Black twinberry *Lonicera involucrate*	• Moderate increase in density and growth, especially on moist, rich sites.	• Vigorous sprouting	• Set back/eliminate	• Sprout	• Increase in cover

Appendix 1. *(continued)*

Life form/species[a]	Overstory removal	Fire: Low intensity	Fire: Medium to high intensity	Cutting	Mechanical site preparation
Devil's club *Oplopanax horridus*		• Slow recovery			
Pin cherry *Prunus pensylvanica*	• Seeds in and seed-bank response. Summer logging – increase	• Increase		• Sprouts, stem density increases, should be cut at 15 cm from ground	• Increase
Choke cherry *Prunus virginiana*	• No data	• Frequency increases but% cover unchanged		• Sprouts readily	• Abundance and growth reduced by ploughing
White-flowered rhododendron *Rhododendron albiflorum*	• Season dependent – in winter – no effect. In summer – reduction and replacement by other species		• Reduction, slow to recover	• Slow initial response – sprouts	• Severe damage, slow to recover
Labrador tea *Rhododendron groenlandicum*	• Increased vigour and abundance	• Sprouts from stems. • Seeds into exposed mineral soil	• High intensity: set back/eliminate		• Some control with intense treatments
Currant/ gooseberry *Ribes* spp. *oxyacanthoides hudsonianum lacustre glandulosum*		• Seedbank • Sprouting from root crowns and rhizomes	• Decrease	• May sprout from root collar	• Increase in abundance • Damage to aerial portions stimulates sprouting
Prickly rose *Rosa acicularis*	• Unaffected or decreases due to competition from other species • Summer harvest increases abundance	• Sprouts	• Kills rhizomes, reduced abundance • Seed in on burned areas	• Rapidly re-establishes from rhizome sprouts; less if treatments applied in June–July	• Increase sprouting
Red raspberry *Rubus idaeus*	• Dense fields created from sprouts and seedbank Summer harvest increases abundance	• Increase in abundance – suckers, sprouts, seedbank, new seed	• Increase	• Regenerates rapidly from bud bank located along the root and at the base of the stem • Repeated heavy cutting will deplete food reserves and eventually reduce number and vigour of canes • Reducing density of canes increases vigour of remaining ones	• Stimulates suckering and fragmentation of roots = new plants
Thimbleberry *Rubus parviflorus*	• Increased cover and vigour, invades by stored or animal carried seed.	• Significant increase	• Recovery slow	• Stimulates sprouting; rapidly returns to pre-treatment cover levels • Cutting around time of full leaf development can provide limited control for one and maybe two growing seasons	• Increase in dominance and vigour • Invades exposed mineral soil

Appendix 1. *(continued)*

	Response to Disturbance				
		Fire			
Life form/species[a]	Overstory removal	Low intensity	Medium to high intensity	Cutting	Mechanical site preparation
Willow *Salix* spp.	• Increase in number and growth, seed into clearcuts – especially on wet sites	• Quick, hot fires – increase; slow burns reduce sprouting; receptive seedbeds; grows faster on burned sites		• Increased density, cutting/damage to stems, especially in winter, can stimulate prolific sprouting; 3–5 times increase in stem numbers; best controlled in late summer	• Reduced if entire root system removed; damage to stem – increase; • Buried branch parts = new shoots
Red elderberry *Sambucus racemosa*	• Slow increase in growth, vigour, and percent cover	• Mixed response, sprouts, seeding-in may occur • Can stimulate germination of stored seed.		• Sprouts rapidly • Repeated cutting effective control	• Increase, uprooted plants die • Damaged stems and rhizomes sprout vigorously, mineral soil exposure – increased seeding in.
Soopolallie *Shepherdia canadensis*	• No data	• Sprouts from root crowns • Seeds in from off site			
Spiraea spp. – *betulifolia* – *douglasii* ssp. *menziesii*	• Responds quickly	• Sprouts from rhizomes (5–13 cm below soil surface) and stem base		• Sprouts from rhizomes	• Small sections of rhizome capable of producing sprouts
Snowberry *Symphoricarpos albus*	• Increased cover, suckers, seedbank	• Sprouts and suckers, deep rooted • Seeds in • Light fires stimulate germination of stored seed	• Reduced suckering	• Sprout • Tolerant of heavy grazing	• Stimulates germination of stored seed
Blueberry *Vaccinium* spp. – *angustifolium* – *ovalifolium* – *myrtilloides* – *caespitosum*	• Stimulates root system and increases vigour, abundance and fruit yields	• Rhizome sprouts. Burning when plant in full leaf detrimental to new shoot and flower bud growth.	• Significantly reduced • Recovery slow	• Increase lateral branching and fruit production	• Varies with intensity – deep, severe MSP will inhibit regeneration • May increase if rhizomes cut
Black huckleberry *Vaccinium membranaceum*	• Increased cover, growth, frequency and fruit production	• Stimulates prolific sprouting	• Reduced stem density and cover	• Sprouts and suckers – growth slow	• Variable – plant removal – reduced cover • Discing stimulated rhizome sprouting.
Grouseberry *Vaccinium scoparium*	• Reduction in cover (due to soil disturbance)	• Decreases as fire severity increases (shallow rhizomes)			• Reduction in cover as level of disturbance increases
Highbush cranberry *Viburnum edule*	• Conflicting reports – some increase and some decrease in vigour and abundance. Summer logging increases abundance.	• Stimulates germination of buried seed • Stimulates vegetative reproduction	• Decrease	• Some sprouting; recovery slow	• Damaged stems will sprout • Soil disturbance stimulates seed germination.

	Response to Disturbance				
		Fire			
Life form/species[a]	**Overstory removal**	**Low intensity**	**Medium to high intensity**	**Cutting**	**Mechanical site preparation**
Herbs					
Baneberry *Actaea rubra*	• Slight increase in cover	• Vigorous resprouting from stumps			• Increased cover
Large-leaved aster *Aster macrophyllus*	• Rapid increase vegetatively, seeding on exposed mineral soil.	• Sprouts	• Seeds in from adjacent areas	• Stimulates rhizomes – increases density	• Root raking – stimulates rhizomes
Lady fern *Athyrium filix-femina*	• Overstory removal: little effect. Increases on wet sites, decreases on dry sites	• Increased cover, especially on wetter sites			• Effective control
Blue-joint grass *Calamagrostis canadensis*	• Increased growth and spread. Will seed in on exposed mineral soil – then spread rhizomatously	• Rapid colonizer, burning stimulates flowering, greatest increases on wet to moist sites		• Recovery slow; ability to recover greatest in May; repeated cutting will reduce biomass	• Stimulates growth and vigour, heavy cultivation will reduce cover temporarily; mounds capped thickly with mineral soil may inhibit
Reedgrass *Calamagrostis purpurascens*	• Increased growth and reproduction – rapid expansion of	• Increase growth and rapid expansion of cover		• Little impact	• Low to medium impact treatments favour development and growth cover
Pinegrass *Calamagrostis rubescens*	• Dramatic increase by rhizomes or seeding in	• Survives well and sprouts profusely after	• Severe fire may set it back	• Impact depends on summer rainfall. Repeated treatments required to be effective.	• Light to medium soil disturbance favours pinegrass – seeds in to disturbed areas. • Heavier disturbance provides longer control but also leads to increased abundance.
Sedges *Carex* spp. Northwestern sedge *Carex concinnoides*	• Increased abundance and vigour	• Develops well except after intense fire		• Reduce abundance and vigour	• Stimulates growth and vigour; treatments that cut up rhizomes increase abundance; exposed mineral soil provides suitable seedbed
Nodding woodreed *Cinna latifolia*	• Increased abundance and growth				
Canada thistle *Cirsium arvense*	• Mineral soil exposure could encourage seeding in	• Late spring burns (May – June) control, earlier – can increase sprouting • Will seed in on burned areas. (mixed information in literature)		• Sprouts • Repeated cutting needed to control – 3 times per season	• Soil disturbance favours establishment • Can use other crops (alfalfa and forage grasses) to control an infestation.

Appendix 1. *(continued)*

	Response to Disturbance				
		Fire			
Life form/species[a]	**Overstory removal**	**Low intensity**	**Medium to high intensity**	**Cutting**	**Mechanical site preparation**
Sweetfern *Comptonia peregrina*	• Stimulates growth	• Rapid colonization, increase in density		• Stimulates sprouting from dormant buds	
Field bindweed *Convolvulus arvensis*	• Seeds in on exposed mineral soil	• Seeding in encouraged			• Encouraged by mineral soil exposure
Bunchberry *Cornus canadensis*	• Vigorous regrowth	• Re-establishes quickly			
Spiny wood fern *Dryopteris expansa*	• Slight increase	• Sprouts from rhizomes rhizome survival depends on moisture in duff layer)			
Fireweed *Epilobium angustifolium*	• Aggressive invader of logged sites by seeding. Existing plants spread by rhizomes. Stimulated more by summer logging	• Low flammability, favoured by fire, invades moist to wet burned sites by seeding • Vegetative reproduction stimulated		• May stimulate sprouting and root sucker formation • Repeated cutting effective control	• Increase due to reduced competition from other species • Mineral soil exposure – increased seeding in
Fragrant bedstraw *Galium triflorum*	• Decrease in abundance	• Decrease in abundance			
Grasses *Graminaceae*	• Increased growth and development • Will seed in on exposed mineral soil	• Spreads from rhizomes and seeds in; encourages flowering		• Decreased biomass – recovery slow	
Cow-parsnip *Heracleum lanatum*	• Response variable, general increase	• Increase percent cover		• Decreased cover	
Ostrich fern *Matteuccia struthiopteris*	• Reduction (needs moist, shady sites)				
Bracken *Pteridium aquilinum*	• Vigour significantly enhanced • Will invade new areas by spores • Will expand in areas where it exists prior to harvesting from rhizomes	• Litter highly flammable; will invade recently burned areas via spores. Vigorously produces new fronds • Rhizomes spread quickly		• Single treatments ineffective • Sprouts and suckers vigorously • Frond density increases • Best controlled from mid-July onwards; repeated treatments necessary for control	• Rapid regrowth • Repeated deep ploughing required to be effective • Other species (greater birdsfoot trefoil, with alta fescue and creeping red fescue) can be used to outcompete bracken fern
Western meadowrue *Thalictrum occidentale* Information for T. *dioicum*		• May survive	• Likely results in mortality		

Appendix 1. *(continued)*

	Response to Disturbance				
		Fire			
Life form/species[a]	**Overstory removal**	**Low intensity**	**Medium to high intensity**	**Cutting**	**Mechanical site preparation**
Stinging nettle *Urtica dioica*	• May stimulate seed production	• Sprouts from rhizomes; – response depends on season of burn – fall burn – better control	• May kill rhizomes		• Encourages spread through rhizomes
Sitka valerian *Valeriana sitchensis*	• Increased vigour	• Recovers quickly	• Probable slow recovery	• Sprouts • Multiple treatments necessary	• Recovers in 1–2 years
American vetch *Vicia americana*	• Increased growth and cover	• Sprouts • Will seed in on burned areas.	• May kill rhizomes		

[a] Scientific authorities for all Latin species names in this table are as per the Canadensys Database of Canadian Vascular Plants (VASCAN) – http://data.canadensys.net/vascan/search/

Blank spaces in the table indicate a lack of available information.

Sources of information: Fowells 1965; Vincent 1953 cited by Myketa *et al.* 1998; Hall *et al.* 1973, 1976; Cody and Crompton 1975; Moore 1975; Coates *et al.* 1990; Haeussler *et al.* 1990; Bell 1991; Buse and Bell 1992; Arnup *et al.* 1995; BCMF 1997; Thompson and Pitt 2003; Swift and Turner 2004