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Regeneration Behaviour of Four Competing Plants of NW Ontario after Clear Cutting:

Efficacy of Conifer Release Treatments

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This file report is an unedited, unpublished report submitted as partial fulfilment of NODA/NFP Project #4009, "Efficacy of release treatments on regeneration strategies of major competing species of Northwestern Ontario".

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REGENERATION BEHAVIOUR OF FOUR COMPETING PLANTS OF NW ONTARIO AFTER CLEAR CUTTING: EFFICACY OF CONIFER RELEASE TREATMENTS

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Abstract

This study was completed in two parts. In the first part regeneration strategies of major competing plants of northwestern Ontario forests such as trembling aspen (*Populus tremuloides* Michx.), pin cherry (*Prunus pensylvanica* L.f.), green alder (*Alnus viridis* spp. *crispa* (Aiton) Turril) and beaked hazel (*Corylus cornuta* Marsh.) were studied in a seven year-old clear cut previously occupied with mature Jack pine (*Picea banksina* Lamb.). The second part of the study involved in determining the efficacy of conifer release treatments by brush cutting and Vision herbicide to control the competing plants. Growth response of planted jack pines and floristic richness and diversity to these treatmets were also studied.

Regeneration strategies and population dynamics of trembling aspen, pin cherry , green alder and beaked hazel were studied were studied by determining their crown diameter, stem density, stem height, stem age, depth of sprouting center, inter-sprout distance, oven-dry weight of shoots, roots plus rhizomes by nondestructive and destructive sampling. Efficacy of three conifer release treatments with i) single application of Vision herbicide (a.i. glyphosate- 1.5 kg a.e./ha), ii) multiple application of Vision and manual brush cutting was studied in controlling competing plants in a seven year old jack pine (*Picea banksina* Lamb.) plantation near Atikokan, northwestern Ontario, Canada.

Stem density of trembling aspen and pin cherry in 1992 was 4 580 and 3 600 stems per ha. Much higher stem density was obtained in green alder and beaked hazel during the same time, 27 580 and 14 600 stems per ha, respectively. Substantial reduction in stem density was recorded in trembling aspen (45%) and pin cherry (69%) over two years, 1992 - 1994. However, reduction in stem density of green alder and beaked hazel for that period was very little (6 and 2% respectively). Comparison of species' clonal characteristics of above- and below-ground components indicates that trembling aspen and pin cherry possess similar vegetative regeneration strategies that differ from those of green alder and beaked hazel. Ordination of the results of canonical variate analysis of the eight vegetative parameters of the four species arranged the species into two significantly different groups. Based on species regeneration strategies, two potential competition strategies were identified: a Vertical Competition Strategy (VCS) and a Horizontal Competition Strategy (HCS). We propose that the degree and duration of competition can be predicted from the density and ratio of VCS and HCS plants on a site once sufficient empirical data on the species' competitive abilities are gathered. I is suggested that future studies should relate the regeneration strategies, population dynamics and competitive abilities of competing plants with competition tolerance of crop trees. This would refine the prediction about species interaction based on the present model and better justify the need for vegetation control intervention.

Both the single and multiple application of Vision was equally effective in controlling trembling aspen and pin cherry causing over 90% stem mortality. Brush saw treatment caused an initial decrease followed by an increase in stem density of these two species. A high degree of stem thinning by natural mortality in the untreated control plots was observed in trembling aspen (23 - 46 %) and pin cherry (41- 69 %) in four years. Stem mortality in green alder and beaked hazel was 45 % and 97 % respectively two years after the operational Vision treatment. As in trembling aspen and pin cherry stem density of green alder and beaked hazel was initially decreased and then increased following the brush saw treatment mainly due to resprouting. Stem thinning by natural mortality in these two species was low compared to aspen and pin cherry.

Competition index (CI, calculated from available photosynthetic light, % cover of competing plants and their proximity to the crop tree) was low (mean CI = 52, ranging from 18 to115) in all the plots including the untreated control. There was no significant difference in plant height and base diameter of jack pine seedlings in the control and the treated plots three years after the treatments. However, jack pine saplings in the brush saw and Vision treated plots were taller compared to that of control. Significantly lower species richness and diversity was recorded in the herbicide treated plots compared to the brush saw and control plots in the third growing season following the treatments.

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INTRODUCTION

Secondary succession following forest harvesting is initiated by the growth of herbs, shrubs and trees which eventually leads into mature forest. Regeneration of commercially important trees is often suppressed by undesirable plants (Campbell 1990; Jobidon 1991a; Lambert *et al.* 1969). Prolific growth of clonal shrubs and trees has been a major obstacle in conifer regeneration. These competing plants regenerate quickly by rhizomatous growth (Mallik 1993; Tappeiner *et al.* 1991), basal sprouting (Schier 1983), root suckering (Schier *et al.* 1985) and layering of branches (Mallik 1993). Control of these plants is often necessary to ensure conifer growth in young plantations. Efficiency of vegetation control methods can be enhanced by performing conifer release treatments during the initial regeneration phase of the competing species when they are most vulnerable. However, this requires knowledge of autecological characteristics of the competing plants as it relates to the type of disturbance. The potential for rapid vegetative growth often depends on the nature (type, intensity, timing) of disturbance which determines the survival of the plant propagules, plants' abilities to develop sprouts from dormant or adventitious buds, seedbed substrates, and the post-disturbance, near ground microclimatic conditions (Hobbs and Mooney 1991; Mallik 1986; Mallik and Gimingham 1985; Mallik *et al.* 1984). Wagner and Zasada (1991) emphasized the need for a better understanding of the autecology of `noncrop' species to enhance control of competing vegetation and silvicultural success. In northwestern Ontario, knowledge of the response of noncrop species to forest harvesting and silviculture treatments is limited (Bell 1991; Wagner 1993). Recently

Zasada *et al.* (1992) summarized the reproductive processes of boreal forest trees, some of which compete with conifers.

Traditionally, chemical herbicides have been used to control competing vegetation. However, due to public concerns regarding indirect effects of herbicides on wildlife and human health, use of herbicides in forestry has been criticized. Consequently, forest managers are faced with developing alternative methods of vegetation control (Jobidon 1991b; Wagner 1993). Vegetation control methods that are environmentally safe and economically feasible are considered more desirable. Knowledge of regenerative strategies and population dynamics of competing plants can provide useful clues concerning the timing of various types of vegetation control. We have studied the regeneration behavior and population dynamics of four major competing plants, trembling aspen (*Populus tremuloides* Michx.), pin cherry (*Prunus pensylvanica* L. Fil.), beaked hazel (*Corylus cornuta* Marsh.) and green alder (*Alnus viridis* spp. *crispa* (Aiton) Turrill) after clear cutting in a mid-Canadian boreal forest. An additional study on age-dependent clump dynamics of green alder was undertaken to determine their regeneration behavior in the pre- and post-harvest habitats. The results have led to the development of a conceptual model in which the regenerative characteristics of competing plants might be used to predict their competitive abilities. Future studies should concentrate on collecting empirical data that will compare regenerative strategies of the HCS and VCS plants with their competitive abilities. The present paper argues the need for a better understanding of autecological characteristics of competing plants particularly their regeneration properties following disturbance in vegetation management strategies.

STUDY SITE

The study site was located in Block 164 of the Seines River Forest Management Area, 58 km north of Atikokan, Ontario, (49°57'22" N; 92°02'05" W; and 49° 75'41" N; 92° 03'00" W) near the southwest shore of Clearwater West Lake. The soil is composed of a thin layer of organic matter (mean thickness = 4.2 cm) overlaying fresh, deep sand and cobbles. The site was previously occupied by mature jack pine (*Pinus banksiana* Lamb.) forest belonging to vegetation type V-17 (Sims *et al.* 1989). Jack pine was harvested from the site in 1987 using conventional cut and skid followed by site preparation using heavy drags of barrels and chains in the fall of 1987. In spring 1988 the site was planted with jack pine container stock at the rate of 3000 seedlings per hectare (1.8 x 1.8m spacing). At the time the study was initiated (summer of 1992) the 5-year-old jack pine seedlings were mixed with stems of trembling aspen, pin cherry, beaked hazel, green alder and white birch (*Betula papyrifera* Marsh.). Ground vegetation consisted of *Vaccinium angustifolium* Ait. , *V. myrtilloides* Michx., *Cornus canadensis* L., *Gaultheria hispidula* (L.) Muhl., *Aster macrophyllus* L., *Rubus ideaus* L., *Maianthemum canadense* Desf. , *Clintonia borealis* (Ait.) Raf., *Viola* spp. with occasional ferns, grasses and sedges. Competition from herbaceous plants did not seem to be high.

METHODS

Four 60 x 80 m plots were randomly located at the site. Within each plot, three 5 x 10m permanent sub-plots were marked out randomly. Competitive abilities of trembling aspen, pin cherry, green alder and beaked hazel were inferred by quantitative analyses of their stem density and the varous above- and below-ground vegetatively regenerating parameters.

Stem Density

The number of stems of trembling aspen and pin cherry were counted in each 5 x 10m sub-plot. For green alder and beaked hazel, the number of clumps in each sub-plot was counted first, then the mean number of stems per clump was determined by sampling five clumps in each sub-plot. A clump is defined as a group of stems arising from a common root-stock. In this particular site beaked hazel bushes were fairly isolated although the bush sizes were variable. If more than 50% of a bush fell outside a sampling plot, (which happened very rarely) it was not counted for that plot. The mean number of stems per clump was multiplied by the total number of clumps to obtain an estimate of stem density in the sub-plot. Stem density was determined annually in late summer of 1992-1994.

Vegetative Regeneration Strategies

The regenerative strategies of each species were determined by excavating rhizome and root systems. Crown diameter of the clump was determined before excavation. Clumps of trembling aspen, pin cherry, green alder and beaked hazel were marked randomly outside the permanent sub-plots. A total of 28 plants were excavated. For trembling aspen, pin cherry and green alder, eight clumps of each were excavated. Only four hazel clumps were excavated because of their complexity and intertwined rhizomes. The first three species were excavated by removing litter and organic matter from underneath the plants by hand. In the case of beaked hazel, plant litter and organic matter were removed by hand; this was followed by the application of high pressure water. To generate sufficient water pressure a hydraulic pump capable of releasing 250 L of water per minute through a 10 mm diameter nozzle was used. For each of the excavated clumps the following above- and below- ground parameters were measured: crown diameter, stem age, number of stems, depth of sprouting center, inter-sprout distance, oven-dry weights (65 C for 96 hrs.) of shoot and root plus rhizome. Depth of sprouting center was determined from the origin of the sprout on the rhizome, root sucker or stem base. Inter- sprout distance is defined as the distance between the two adjacent stems or sprouts which gives a measure of ramet spread. Before determining the oven-dry weight the plant samples were air dried for eight weeks in a glass house. Since the competitive ability of plants often depends on their above- and below -ground spread and biomass, these plant properties were tested for correlation. Stem age was determined by counting annual rings of stem sections taken at the stem base. Pre-harvest clump dynamics of competing plants may have implications for their success in the post-harvest condition. Green alder was studied in further detail to determine how the vegetative regeneration of an HCS-plant is related to pre- and post-harvest conditions. This was done by determining the age-related clump dynamics of green alder. Thirty alder clumps of various sizes were chosen randomly; the total number of new, mature and dead stems per clump was recorded and the age of three oldest stems of each clump was determined.

Statistical Analysis

Strength of the relationships among the various above- and below-ground parameters of the competing plants was determined by calculating Pearson product-moment correlation coefficient of the variables. The data on crown diameter, stem diameter, height, age and dry biomass and also dry biomass of rhizomes plus roots were log-transformed and subjected to a one way analysis of variance (ANOVA). Tuckey's HDS test was performed to determine significant difference (P= 0.05) between the means. Multivariate analysis of variance (MANOVA) and Canonical variate analysis (Chatfield and Collins 1980) were performed with seven main vegetative parameters by multiplying the matrix of the standardized discriminant function coefficients by the species vectors of the seven dependent variables. The six dependent variables were crown diameter, diameter of all stems in the clump, number of shoots per clump, shoot height and shoot dry biomass and biomass of roots plus rhizomes. In the case of trembling aspen, pin cherry and green alder eight coordinates were calculated while for beaked hazel only four coordinates were calculated. The formula for calculating the matrix of canonical variate was:

$$Z= A'X$$

where Z=matrix of canonical variate (CV1 and CV2) for each species and their means, A'= matrix of transformed discriminant function coefficients calculated by MANOVA and X= matrix of dependent variables of each species and their means.

RESULTS AND DISCUSSION

Stem Density

Generally speaking, stem density of trembling aspen and pin cherry showed a continuous decline from 1992 to 1994 whereas that of green alder and beaked hazel showed little change over the same time period (Table 1). Aspen stem density decreased 23% from 1992 to 1993, which again decreased 30% from 1993 to 1994. Similarly, pin cherry stem density decreased 69% from 1992 to 1993 and showed a further decrease of 47% from 1993 to 1994. There was a 7% decrease in stem density of green alder from 1992 to 1993 which was followed by a 1% increase from 1993 to 1994. For beaked hazel stem density increased by 22% from 1992 to 1993 and this was followed by a 25% increase from 1993 to 1994 (Table 1). For the first two species, trembling aspen and pin cherry, the steady decline of stem density over time indicates strong natural self-thinning. Similar to our studies, Crouch (1983) reported results similar to those of our study, namely a rapid decline of aspen stem density in the first five years after logging; seven years after logging the loss of aspen stems was 77%. In addition to the plant's inherent property of self-thinning, sprout damage by snow compression and cattle trampling were attributed to the high stem mortality (Crouch 1983). High stem mortality in trembling aspen due to high stem density was also reported by Bella (1986). Perala (1984) reported that aspen stocking can decline as much as 43% within seven years by just self-thinning. He observed that an initial stem density of 128 000 stems per hectare was reduced to 73 000 stems per hectare. In comparison aspen stem density in our study site was much lower, 4 580 stems per hectare being reduced to 2 500 in two years. Different clones of aspen can vary in genetic attributes such as growth rate or ability to sucker (Perala 1972). Maini and Horton (1966) found different clones of trembling aspen to have up to 20-fold variation in the number of suckers after clear cutting. Significant difference in non-structural carbohydrates was observed in different aspen clones by Schier and Johnson (1971). In northern Minnesota, summer logging caused suckering delay until mid-summer of the following year, whereas winter cutting created abundant suckers the next year (Zehngraff 1946).

Green alder and beaked hazel had much higher stem densities (27 600 and 12 800 stems/ha, respectively) than did trembling aspen and pin cherry in our study site. Tappeiner (1971) reported 12 010 to 18 900 stems per hectare of hazel in red and white pine stands of northern Minnesota. Evidence of numerous dead shoots on roots of trembling aspen was reported by Tappeiner (1982) who concluded that few of the original shoots survive to maturity. Mortality rate and ratio of alive and dead stems of pin cherry, green alder and beaked hazel were not reported in the literature. In the present study tagging of individual stems in the sub-plots as used by Huenneke (1986) would have provided further detail on clump dynamics by accurate annual enumeration of dead stems and recruitment of new stems.

Vegetative Regeneration Strategies

A comparison of above- and below-ground properties of trembling aspen, pin cherry, green alder and beaked hazel indicates that trembling aspen and pin cherry have similar vegetative regeneration strategies that differs from those of green alder and beaked hazel. Crown diameter, number of shoots per clump, above- and below-ground biomass of trembling aspen and pin cherry were significantly different from those of green alder and beaked hazel (Table 2). Trembling aspen and pin cherry stems were significantly taller than those of green alder and beaked hazel. Pearson product-moment correlation coefficients of the growth parameters showed that the number of shoots or suckers of trembling aspen per ramet was positively correlated with their shoot biomass, root biomass and crown diameter (r= 0.69. 0.67 and 0.34 respectively. We define ramet as one or a group of aerial stems produced basally from buds or rhizomes, which have potential for independent survival. Shoot height of pin cherry was negatively correlated (r= -0.445) with inter-sprout distance, but positively correlated with shoot biomass, root biomass and crown diameter (r= 0.538, 0.799 and 0.767 respectively. For green alder, shoot height was correlated with the number of shoots per clump, shoot biomass, root plus rhizome biomass and crown diameter (r= 0.55, 0.69, 0.32 and 0.55 respectively. There also were strong positive correlations among these vegetative parameters of beaked hazel.

An ordination diagram of the canonical variate analysis of the seven vegetative parameters arranged the four species into two distinct groups (Fig.1). The 95 % confidence interval for each of the four means is represented by a circle with radius $r=2/\sqrt{n}$. Overlapping of the circles of species means indicates no significant difference between them. The group belonging to trembling aspen and pin cherry was significantly different from the group belonging to green alder and beaked hazel. These results corroborate those obtained by ANOVA of the vegetative parameters (Table 2).

It is suggested that the overtopping effects of trembling aspen and pin cherry due to increased height growth following their initial establishment reduces the amount of light that reaches the crop plants (Comeau *et al.* 1993). We propose calling this growth strategy, the Vertical Competition Strategy (VCS). Green alder and beaked hazel clumps consist of many short and massive stems above-ground and dense and robust roots and rhizomes below-ground. In this case competition within the with the crop plants is horizontal on the above-ground portion for space and light, and below-ground for rooting space, nutrients and moisture, a strategy we propose to call Horizontal Competition Strategy (HCS). If competing plants of both strategies are present in sufficient density in a site the crop plants would suffer long-term competition. We suggest that vegetation control methods should be developed based on stem density, proportion of VCS and HCS plants, and their population dynamics such as rate of clonal spread, height growth, stem mortality and recruitment. These characteristics of competing plants directly influence the survival and growth of planted seedlings. For example, if a nutritionally rich conifer regenerating site has a large amount of HCS-plants and the conifer seedlings are above the canopy height of the competing plants the site may not require any vegetation control treatment. It is likely that although initially the conifers will face some below-ground competition for growing space from the HCS-plants, they will eventually out-compete them due to their taller stature and other life form characteristics. On the other hand, if a conifer site has a large amount of hardwood species with VCS strategy, competition control may be necessary the four means is represented by a circle with radius $r=2/\sqrt{n}$. Overlapping of the circles of species means indicates no significant difference between them. The group belonging to trembling aspen and pin cherry was significantly different from the group belonging to green alder and beaked hazel. These results corroborate those obtained by ANOVA of the vegetative parameters (Table 2).

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Clonal Dynamics of Green alder

When the number of new, mature and dead stems of green alder clumps of varying sizes were compared with stem age it became apparent that after forest harvesting the plant expanded rapidly up to about five years with a high density of new and mature stems and this was followed by a decline in stem density (Fig. 2). Forest harvesting on this site occurred seven years previous to the commencement of this study. The high frequency of new and mature stems of ages between five and twelve years (i.e. seven years pre- and five years post-harvest) seems to indicate three things: i) the mature jack pine forest canopy may have been opening up creating micro-sites suitable for alder regeneration (Fig. 2a), ii) with the removal of the forest canopy alder clumps became vigorous due to rapid growth of pre-existing stems and newly recruited sprouts (Fig. 2b), and iii) increased mortality of alder stems was initiated due to self thinning (Fig. 2c). Furthermore, the presence of 23 to 30 year old alder stems in some clumps indicate that at the time of harvest these stems were 16 to 22 year old which means that alder clumps can perpetuate with reduced vigor in mature forests. Following a demographic study of speckled alder (*Alnus incana* ssp. *rugosa* (Duror) Clausen) Huenneke (1986) reported that long-term persistence of alder clumps is possible due to vegetative regeneration by basal sprouting. During her study she encountered no alder seedling recruitment nor did she observe death of an entire alder clump. In our study most of the stem recruitment occurred between the seven years pre- and five years post-harvest period. The high below-ground to above-ground biomass ratio of alder (Table 2) and a large number of sprouting centers at swollen stem bases indicate that the plant has a high potential for vegetative sprouting. The sprouts that were recruited immediately after forest harvesting remained most vigorous. There was a decline in alder stem density from two years after forest harvesting (Fig 3b). The decrease in the number of live stems and the concomitant increase in the number of dead stems was recorded between 1992 and 1993. In the following year (1994) however, the number of live stems was very similar to that of 1993 stem mortality was reduced (Table 1). For alder to remain vigorous it must recruit new vegetative sprouts or establish new seedlings. However, reduction in stem density in the clump does not necessarily mean reduced vigor or competitive ability of the plant since the remaining live stems can offer substantial competition if they have vigorous growth. Seedling regeneration in alder was not very common. We observed only five seedlings in twelve 5 x10 m plots during three years.

Excavation of alder clumps revealed swollen corm-like structures at the bases of stems from which new sprouts originate. Corms from large clumps showed decay of older parts and progressive growth in the newer parts, often with one or more daughter corm(s) connected with short (5-10 cm) horizontal rhizome buried under litter. The daughter corms and the living tissue of the parent corm were capable of producing new sprouts. This type of vegetative regeneration mechanism, where sprouts originate from swollen stem bases, is common in ericaceous plants such as *Calluna vulgaris* (L.) Hull, *Erica cinerea* L. and *Arctostaphylos uva-ursi* (L.) Sprengel, when subjected to periodic disturbance (Mallik and Gimingham 1985). Progressive growth and decay of alder corms with age may keep the alder clumps alive for a long time.

Clonal Dynamics of Beaked hazel

Due to the robust, extensive and intertwined nature of beaked hazel rhizome, it was not possible to excavate many hazel clumps. However, the study of four hazel clumps showed that the biomass of the below-ground component was almost equal to that of the above-ground component, indicating a good potential for vegetative sprouting (Table 2). Age of hazel stems varied from one to seven years with a mean value of four years, indicating that although hazel can perpetuate in mature forests (Tappeiner 1971), its stem density increases dramatically following forest harvesting. There was a decline in stem density of hazel from 1992 to 1994, i.e. seven to nine years after forest harvesting (Table 1). Spatial and temporal variation in height and stem density of hazel in undisturbed forests was reported from a 20-year study in central Minnesota by Kurmis and Sucoff (1989). They concluded that a shift in hazel stem density was unrelated to changes in overstorey but height and age increased with decreasing stem density. Hazel stem density in their six red pine stands varied from 5000 - 100 000 stems per ha. In five of these stands hazel stem density declined in the first three years of the study which was followed by an increase in the fourth year. They suggested that hazel stands are maintained by continual recruitment of new stems. Unlike green alder and beaked hazel, which are characterized by short stem height and high stem density, trembling aspen and pin cherry are characterized by taller stems and relatively less stem density. While alder and hazel may interfere with the establishment of conifers, aspen and pin cherry on the other hand, interfere with the growth of established seedlings. Zasada *et al.*(1992) presented a generalized diagram relating the ability of vegetative regeneration with age of aspen and balsam poplar (*Populas balsamifera* L.). We suggest that plants may have differential competition effects depending on their autecological characteristics, particularly their age and disturbance-related regeneration behavior. Assessing competitive ability of clonal plants based on one-time measurement of simple parameters such as abundance, percent cover, leaf area index or stem density may lead to an erroneous conclusion. To properly assess competitive ability we need to know life history attributes, particularly regeneration responses and population dynamics following various disturbance regimes.

Management Implications

Data on regeneration strategies and population dynamics of competing plants can provide useful insights in predicting their competitive abilities. Density and proportion of plants belonging to VCS and HCS groups identified in the present study can determine the nature and duration of competition on a site. Age-related clump dynamics of the major competing plants can tell us how long they will remain as viable competitors. Self-thinning of stems by natural mortality, age-related sprouting ability and vigor of clonal competing plants are important phenomena to consider before applying any vegetation control intervention. In the present study we have shown that although different competing plants respond differently following forest harvesting, based on their vegetative regeneration characteristics they can be broadly classified into two categories, HCS and VCS plants. The HCS and VCS plants also differ in terms of decline in stem density over time. Green alder's regeneration response to pre- and post-harvest conditions reveals it's unique ability to persist in undisturbed and disturbed habitats. What are the implications to a forester in terms of vegetation management? In an integrated forest vegetation management program decisions can be made based in part on the HCS-VCS concept (see Fig.3). The following four hypothetical post-harvest situations will serve to illustrate how the forester might use the HCS- VCS concept in the process of deciding which is the most appropriate vegetation control method to apply: i) if the site experiences competition mostly from low- growing HCS plants, such as herbs and grasses, manual or mechanical mulching may be appropriate for competition control, ii) if the site is dominated mostly by taller HCS plants (e.g., alder) or VCS plants (e.g., pin cherry and trembling aspen) manual cutting by brushsaw or ground application of herbicides with single stem application may be feasible, ii) if the site is dominated by approximately an equal proportion of high density HCS and VCS plants then the broadcast method of herbicide treatment (usually aerial application) may be necessary to release the planted seedlings from competition, and iv) if the site experiences competition mostly from the HCS plants that are known to undergo rapid stem thinning over a short period of time then it may not require any vegetation control treatment since, with time, competition will be reduced by natural thinning of competing plants. Besides considering the proportion and stem density of the HCS and

VCS plants one must also consider the degree of tolerance of crop plants to the vegetation changes occurring in this critical phase of secondary succession. Classifying competing plants on the basis of the HCS-VCS concept may lead to a better scientific approach in decision making and it also may facilitate communication with the public.

II. Efficacy of brush cutting and Vision herbicide treatments in vegetation control of a seven year-old jack pine plantation in northwestern Ontario, Canada

INTRODUCTION

In northwestern Ontario forest harvesting by clear cutting often results prolific regrowth of hardwood species from basal sprouting and root suckering. Success of conifer plantations is often predicated upon the control of these competing plants which affect the growth and yield of the crop species and thereby cause a potential increase in the rotation time (Sutton 1969; Radosevich and Osteryoung 1987). Although a number of conifer release treatments are available to reduce competing plants the use of herbicide remains the predominant one. In the last three decades conifer release with herbicides has become increasingly common in northern ecosystems (Kuhnke and Brace 1986; Maass 1989; Campell 1990). Ontario has the largest aerial herbicide program in Canada where 430,000 ha of forests were sprayed with herbicides from 1983 to 1990. However, despite the high treatment efficacy and cost effectiveness of herbicides (Campbell 1984; Bell *et al.* 1997) public concerns about their presence in the environment (Johnson et al. 1995), their toxicity effects on human health and the potential of changing wildlife habitat (Lautenschlager 1993; Runciman and Sullivan 1996; Environics Research Group 1992) has led to the development of Vegetation Management Alternative Program (VMAP) in Ontario (Wagner 1993). Although mechanical brush cutting and manual brush cutting using hand-held power saws provide alternative vegetation management techniques they have not been adequately studied. Comparisons between these non-chemical methods and the commonly used herbicide methods are necessary. Apart from their high costs (Bell et al. 1996) the non-chemical brush cutting may have the disadvantage of stimulating sprouting of certain broadleaf trees and shrubs (Campbell 1984; Hobbs and Mooney 1985; Wagner 1993).

An experimental trial was established to compare the efficacy of Vision (glyphosate -1.5 a.e./ha) treatments and brush saw treatment to control the competing vegetation, such as trembling aspen, pin cherry, green alder and beaked hazel in a seven year old jack pine (*Picea banksina* Lamb.) plantation near Atikokan, northwestern Ontario. The specific objectives of this study were to i) determine the response of competing plants and planted jack pines to the conifer release treatments, ii) study the relationships among the competing species cover, their competition index, available light (PAR) and jack pine growth, and iii) determine the changes in floristic diversity and composition following the release treatments.

STUDY SITE AND EXPERIMENTAL DESIGN

This study was conducted in the same site as described in the previous section. A randomized block design with four treatments and four replications per treatment was used for monitoring the efficacy of the release treatments (Fig. 4). Each of the treatment plots was 60 x 80 m. The four treatments were 1) brush sawing, where the competing vegetation was cut at the ground level after maximum leaf flush from late June to early July; 2) an operational single aerial treatment with Vision at the rate of 1.5 kg a. e./ ha from a fixed wing aircraft in late August 1992; 3) a non-operational multiple Vision treatment, consisting of the operational single Vision treatment followed by annual backpack Vision treatments in September 1993 and August 1994 and 4) control , where the post logging vegetation was kept undisturbed. Pre-treatment data collections were done in August 1992, followed by one, two and three year post-treatment data collection in August-September 1993, 1994 and 1995 respectively.

METHODS

Within each 60 x 80 m treatment plot, three 5 x 10 m permanent sub-plots were marked out.. Population dynamics and competitive ability of trembling aspen, pin cherry, green alder and beaked hazel were studied by determining density, mortality and recruitment of stems.

Stem Density and Height

The number of stems of trembling aspen and pin cherry were counted in each 5 x 10 m sub-plot from which stem density per hector was determined. For green alder and beaked hazel, the number of clumps in each sub-plot was counted first, then the mean number of stems per clump was determined by sampling five clumps in each sub-plot. The mean value per clump was multiplied by the total number of clumps to obtain an estimate of stem density in the sub-plot. Mean stem height of trembling and pin cherry of each sub-plot was determined from individual stem heights taken from ground level to the tip. For green alder and beaked hazel stem heights were determined by taking the mean of five random stems per bush.

Assessment of Competition

In the second growing season following the treatments (August 1994), within each 5 x 10 m sub-plot percent cover of all vascular and non-vascular plants was determined visually from three randomly located seedling-centered circular quadrats (Brand 1986). Radius of the seedling-centered quadrats was 1.41 m (area 6.24 m^2). To assess the level of competition induced by trembling aspen, pin cherry, green alder and beaked hazel percent cover and proximity i.e. distance of the competing plants to crop tree stem was determined.

Competition Index

A competition index (CI) was calculated by the following formula (Brand 1986):

$$CI = (Hb/Ht)(((Rb/Rt)+1)^{-1})(C)$$

where H_b is the mean height of the brush species, H_t is the sample crop tree height, R_b is the mean distance to the brush foliage from the sample tree stem, R_t is the crop tree crown radius and C is the % cover of the competing brush species around the sample tree.

This competition index is a function of the relative height of the competing vegetation to the tree, the relative distance to the competitor's foliage as a ratio to crown width, and the ground cover of competitors around the 1.14 m radius of the crop tree (Brand 1986).

Photosynthetically Active Radiation (PAR)

The fraction of the full sunlight reaching the top of each crop tree seedling was determined by measuring the PAR. A sunfleck ceptometer (Model SF-80, Decagon Device Inc., Pullman, WA) was used to measure the PAR transmission. The sunflec septometer is a battery-operated device which measures instantaneous fluxes of light intensity in the PAR wave band (400-700 nm). The ceptometer has 80 light sensors placed at 1 cm interval along a 80 cm long probe, attached to a battery-powered digital data logger. A microprocessor scans the 80 photodiodes on demand and calculates the arithmetic average (Decagon Devices 1992). The ceptometer was placed horizontally on top of the crop tree seedling and two readings were taken at right angle to each other keeping the leader of the seedling at the center. Four readings were taken at the half canopy level from the edges of the canopy outward in four directions. PAR readings were taken at five jack pine seedlings marked in each sub-plot. The light measurements were taken on cloudless days between 11 am and 2 pm in mid-September, 1994. Total PAR was determined on open ground. The percent PAR transmission (PT) for individual jack pine seedling was calculated using the following formula:

$$PT = (I_g/I_o) \times 100$$

where I_o is the total incoming PAR in open ground and I_g is the transmitted PAR around the seedling. For each jack pine seedling the mean I_g value was determined by averaging the top crown and mid-crown PAR readings.

Response of Alder and Aspen to Stem Cutting

A greenhouse experiment was performed to compliment the field studies on trembling aspen and green alder response to brush cutting. Seeds of trembling aspen and green alder were germinated in a growth chamber. When the seedlings were about 15 cm high they were transplanted into pots with 1:1 peat-vermiculite mixture. Subsequently, 50 five month old, 40 cm high aspen seedlings and 50 six month old 30 cm high alder seedlings were used for a decapitation experiment. Five treatments were applied; batches of ten seedlings were cut at 5, 10, 15 and 20 cm above ground and another ten seedlings of each species were left as uncut control

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Jack pine Response After Release Treatments

Five jack pine seedlings were randomly marked in each of the 5 x 10 m sub-plots. Their stem height, current years leader length, base diameter and crown diameter were measured.

Floristic Changes After Release Treatments

Species richness (N0), diversity (N1) and evenness (E1) were calculated by using importance values (IV) of the species occurring in each treatment plot in September 1995. The importance values were calculated by adding the percent cover and frequency of each species.

Statistical Analysis

Differences in stem density and height of trembling aspen, pin cherry, green alder and beaked hazel in the three treatments and control plots were compared using a non-parametric Kruskal-Wallis test followed by a non-parametric multiple comparison procedure (Zar 1984). Differences between height and basal diameter of *Pinus banksiana* and between Hill's diversity and species richness and evenness were also analysed using the above procedures.

RESULTS

Stem Density

Stem density of trembling aspen and pin cherry decreased significantly ($P = 0.035$) following both the Vision treatments compared to the control and brush saw treatments. After the brush saw treatment stem density of aspen and pin cherry was increased compared to the control. However, the increases were not significant (Table 3). The operational single Vision treatment was as effective as the experimental multiple Vision treatment causing over 85 % stem mortality in aspen and 65 % stem mortality in pin cherry one year after the treatment. In the second and third year after the treatments stem mortality was mostly over 90 % in either the single or the multiple Vision treatment plots (Table 3). The brush saw treatment caused 66 % decrease in stem density on e year later. By the third year after the treatment stem base sprouting increased the stem density close to the pre-cut level. Pin cherry stem density was reduced by 25 % in the first year after cutting. In the second and third year the stem density was increased by 5 and 8 % respectively compared to the pre-cut condition (Table 3).

Green alder stem density was decreased following the above treatments but the decreases were not significant one year after the treatments. In the second year after the treatments stem density of green alder was decreased significantly compared to the control. No significant change in alder stem density was obtained due to the brush saw treatment (Table 3). Stem density of beaked hazel was significantly reduced due to both the single and multiple Vision treatments. However, the decreases in stem density were not significant following the multiple Vision treatment. The brush saw treatment caused 57 % decrease in ader stem density in the first growing season after the treatment. Enhanced sprouting two years after the treatment resulted an increase in stem density close to the pre-cut level. Similarly, hazel stem density was reduced by 37 % one year after the treatment followed by a 65 % increase two years after the treatment (Table 3)

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Stem Height

Brush saw treatment caused a significant reduction in stem height of trembling aspen and pin cherry. In the Vision treated plots stem height of these plants were not significantly different compared to that of control. In the subsequent years however, the stem heights were significantly less in all the treatment plots compared to the control (Fig. 5).

No significant difference in stem height of alder was obtained one year after the treatments but two and three years after the treatments the stem height was significantly reduced. In the case of hazel the brush saw treatment did not cause any significant decrease in stem height but both the Vision treatments caused significant reduction in stem height particularly in the second year afer the treatments.

Response of Aspen and Alder to Stem Cutting

The number of leaves was significantly reduced due to the decapitation of aspen. Highest number of leaves and shoots per plant were produced at the end of three months in plants that were cut 20 cm above ground (Fig. 5). After cutting, aspen shoots released buds closest to the clipping ends. In the first two months of the cutting experiment there was no significant difference (P = 0.380) in the number of open buds among the different cutting treatments.

Following stem cutting at all heights, the number of dormant as well as open buds, leaves and shoots of alder were increased with time (Fig. 6). More open buds were produced in the first month after cutting than in the following two months. Green alder produced relatively less leaves compared to aspen after the cutting treatments (Fig. 6).

Plant Cover, Competition Index and PAR

In the study site, mean percent cover of competing plants was 52 + 4.1 and their competition index (CI) was 41+3.17 (Table 4). Although there was a large variability in CI, ranging from 18 to

115, the low values of cover and competition index indicate that the site did not experience a high level of brush competition, at least up to 1994. Significant linear relationships between % cover and PAR of brush species were found on control and single Vision treated plots (R^2 from 0.39 to 0.63; P from 0.001 to 0.05) (Fig. 8). No significant linear relationship was found between % cover of competing plants and PAR in the brush saw and multiple Vision treated plots (P = 0.627).

The percent PAR of the top half crown of jack pine seedlings in min-September ranged from 0.22 to 0.99. Most of the jack pine seedlings (80 %) received more than 50 % PAR transmission in the control plots. Higher PAR transmission was received by the jack pine seedlings with reduced competition index following the release treatments (Table 4). On the single and multiple Vision treated plots significant correlation was found between % PAR and CI ($P = 0.526$) (Fig.9).

Jack pine Response After Release Treatments

Three years after the release treatments no significant difference was found in height and base diameter of jack pine between the control and treated plots (Table5). However, jack pines in the multiple Vision and brush saw treated plots were taller than that in the control and multiple Vision treated plots. Base diameter of jack pine was highest in the multiple Vision treated plots followed by the brush saw, single Vision and control plots (Table 5).

Species Diversity, Evenness and Richness

In the third growing season following the release treatments floristic diversity (Hill's diversity) was significantly less in the Vision treated plots compared to that of control. No significant difference in Hill's diversity was obtained between the brush saw and control plots (Fig.10). Species evenness was significantly lower in the herbicide treated plots compared to the control and brush saw treated plots. There was no significant difference in species evenness between the control and brush treated plots. Species richness was not significantly different from the control and the release treatment plots

Floristic Composition

Plant species composition of control and brush saw treated plots were similar. But cover of certain species for example green alder, beaked hazel, trembling aspen, pin cherry, paper birch (*Batula papyrifera*), blueberry (*Vaccinium angustifolium* and *V. myrtilloides*) and bracken fern (*Pteridium aquilinum*) were progressively declined due to brush saw, single Vision and multiple Vision treatments. On the other hand cover and frequency of *Rubus ideaus*, *Meianthemum canadense* and grasses were increased following the Vision treatments (Table 6). *Epigaea repens* and several lichen species found in the control and brush saw treated plots were not found in the herbicide treated plots, where as *Pinus resinosa*, certain ferns and *Aster* spp. found in the herbicided plots were not found in the control and brush treated plots.

DISCUSSION

Stem Density

Single and multiple Vision treatments caused high stem mortality (66 to 97 %) of aspen, pin cherry, and hazel and caused more than 45 % reduction in alder stem density one year after the treatments. By the second growing season after the single herbicide application stem mortality in the first three species was over 90 % . Sprouting ability of pin cherry, trembling aspen and beaked hazel were also reduced significantly two years after the herbicide treatment. However, green alder still produced new shoots two years after herbicide application indicating that alder was less susceptible to the herbicide treatments than trembling aspen, pin cherry and beaked hazel. Results of the effects of multiple application of Vision on hazel showing less stem mortality than that of the single application of Vision is difficult to explain. To start with hazel in these plots had a high stem density and the bushes were robust. Perhaps their high root biomass and numerous shoots at its vigorous growth stage may have diluted the active ingredient of the herbicide receiving in the rhizome system. Other studies have reported similar results showing that response of alder to foliar sprays of Vision has been variable, ranging from moderate to severe depending on the age and size of these plants (Conard and Emmingham 1984a, b; Boateng and Herring 1990). The vigorous growth phase of the plant between the ages of 7 to 12 may be more resistant to the treatments than the decline growth phase over the age of 15 years.

First and second year sprouts were numerous after brush saw cutting. Other studies also reported that the response of the four species is generally proportional to the degree of cutting (Watson et al. 1980; Aldous 1972; Fawellus 1965; Aldous 1952). If all the sprouts grow well and the sprouting continues over the next few years after brush saw treatment, the level of competition between established sprouts may increase following this treatment. Response of aspen and alder to cutting at different heights in the greenhouse experiment suggests that the cut shoots released buds closet to the cut ends and sprout production decreased with increasing distance from the clipped end. Wilson and Kelty (1994) obtained similar results. Our results suggest that in the case of brush saw treatment in the field, stems cut at heights between 10 and 20 cm would have no significant difference in the number of sprouts while those cut at or below 5 cm would produce fewer new sprouts.

Clonal Characteristics

Significant number of mature stems of all the four competing species had been killed after herbicide application, indicating that Vision was effective in controlling these species. These results agree with that obtained by others (Sutton 1978, 1994; Haeussler and Coates 1986). Brush saw cutting of the competing plants enhanced their rapid vegetative regeneration by means of basal sprouting. Schier et al (1985) reported that when suckers are extremely numerous after clear-cutting, the number of suckers rapidly declines over time due to self-thinning and other damaging factors including insect attack and animal browsing.

Competition Assessment

When neighbouring vegetation occur in sufficient density, cover and height, it can seriously affect the survival and growth of tree seedlings through competition for light, water, or nutrients. As a basis for competition models, a consistent method is required for describing the degree of competition to which crop seedlings are exposed to. Several competition indices (CI) are proposed to described and assess competition (Brand 1986, DeLong 1991, Wanger and Radosevich 1991). The competition index proposed by Brand (1986) was used in this study to assess the level of competition imposed by neighbouring competing species to crop trees. In the control plots, about 80 % jack pine seedlings received more than 50 % PAR transmission and no significant correlation was found between PAR transmission and competition index (Fig. 6). This indicates that the level of competition in the study site was not severe. In the control plots, competition index ranged from 18 to 115 near the crop tree seedlings, which also implies a low level of competition. Comeau et al. (1993) suggested that any need for vegetation control is required only when CI is more than 150.

However, the substantial variability in both transmittance (% PAR transmission) and jack pine seedling growth have occurred at levels below 150. Results of this study suggest that when the level of competition is not severe, competition index is not an effective tool to predict interspecific competition. Cover of competing species alone seems to be a more effective parameter to predict brush competition since a significant linear relationship between % PAR transmission and % cover of brush species was found in the control plots (Fig. 8). DeLong (1991) also recommended % cover of competing brush species as a useful tool to predict light transmission through the canopy.

In the case of brush saw treatment, since the vegetative sprouts have not reached the height of crop tree seedlings, using the present competition index and % PAR transmission may not accurately predict the level of competition. On aerial treatment plots, significant correlation was obtained between % PAR and CI and % PAR and % cover of competing species. A high percentage of aerial shoots of the competing species was killed by the herbicide treatments allowing more light to penetrate to the tree seedlings. The jack pine seedlings on the multiple Vision treated plots were completely free from the competing plants and shade (low PAR) was no longer restricting their growth.

Jack pine Response After Release Treatments

Three years after the release treatments no significant increase in jack pine growth was observed between the control and the treated plots. However, some increase in height and base diameter of jack pine in the treated plots indicates that the crop plants are starting to respond to the release treatments. The absence of linear relationships between % cover of competing plants, competition index and jack pine seedling growth on the control and release treatment plots implies that the level of competition in the control plots was not seriously restricting the growth of jack pine. However, the removal of any level of competition should improve jack pine growth in the long run

Floristic Changes After Release Treatments

Vision treatments killed large amounts of woody species. However, substantial recovery of some of the herbaceous angiosperms was evident on some spray plots. Freedman et al (1993) reported that no plant taxa was completely eliminated 6 years after the silviculture spraying of Vision®, but here were substantial changes in their relative abundances. In this study, white birch, green alder, poplar, pin cherry, beaked hazel, bracken fern and blueberry plants were declined by the release treatments whereas both cover and frequency of red raspberry, large leaved aster and grasses were increased in the treated plots. Species evenness was lower on the herbicide treated plots than on the control and brush saw treated plots.

CONCLUSIONS

Based on the above- and below-ground regeneration beheaviour of major competing plants of northwestern Ontario this study identified two competition strategies, HCS (horizontal competition strategy) and VCS (vertical competition strategy) in post-harvest environment. The plants belonging to the HCS such as green alder and beaked hazel have many short and massive stems above-ground and dense and robust roots and rhizomes below-ground. These plants compete with the crop trees horizontally above-ground for growing space, light and below-ground for rooting space, nutrients and moisture. The VCS plants (e.g. trembling aspen and pin cherry) on the other hand affects the crop trees by overtopping them due to their rapid height growth. However, their stem densities declined over time. In an integrated forest vegetation management program decisions can be made based in part on the HCS-VCS concept since regeneration characteristics of these competing plants directly influence the survival and growth of planted seedlings.

Green alder's regeneration response to pre- and post-harvest conditions reveals it's unique ability to persist in undisturbed and disturbed habitats. To properly assess competitive ability of the competing plants we need to know their life history attributes, particularly their regeneration responses and population dynamics following various disturbance regimes such as clear cutting and fire. Classifying competing plants on the basis of the HCS-VCS concept will lead to a better scientific approach in vegetation management and it will also help facilitate communication with the public.

Both the single and multiple application of Vision was equally effective in controlling trembling aspen and pin cherry causing over 90% stem mortality. Brush saw treatment caused an initial decrease followed by an increase in stem density of these two species. Stem mortality in green alder and beaked hazel was 45 % and 97 % respectively two years after the operational Vision treatment. As in trembling aspen and pin cherry, stem density of green alder and beaked hazel was initially decreased and then increased following the brush saw treatment mainly due to resprouting. Stem thinning by natural mortality in these two species was low compared to trembling aspen and pin cherry.

Competition index was low in all the plots including the untreated control and there was no significant difference in plant height and base diameter of jack pine seedlings in the control and the treated plots three years after the treatments. However, jack pine saplings in the brush saw and Vision treated plots were taller compared to that of control.

Significantly lower species richness and diversity was recorded in the herbicide treated plots compared to the brush saw and control plots in the third growing season following the treatments.

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FIGURE CAPTIONS

Figure 1. Canonical scores and means of vegetative parameters of four competing species: aspen (▲), cherry (■), alder (□) and hazel (△). The 95% confidence interval for each species mean is represented by a circle. Overlapping of the circles indicate no significance difference between them.

Figure 2. Age-dependent clump dynamics of green alder in a seven year-old clear cut. Note that the clumps between the ages of five and twelve years have the maximum number of new and mature stems. This coincides with the time between ten year pre- and five year post-harvest period.

Figure 3. A potential integrated approach in forest vegetation management strategy following the proposed HCS-VCS concept.

Figure 4. Geographic location and distribution of the experimental plots with control (C), brush saw (B), single Vision (SV) and multiple Vision (MV)treatments in the study site near Clearwater West Lake, Atikokan, Ontario.

Figure 5. Effect of brush saw and Vision treatments on stem height of trembling aspen, pin cherry, green alder and beaked hazel.

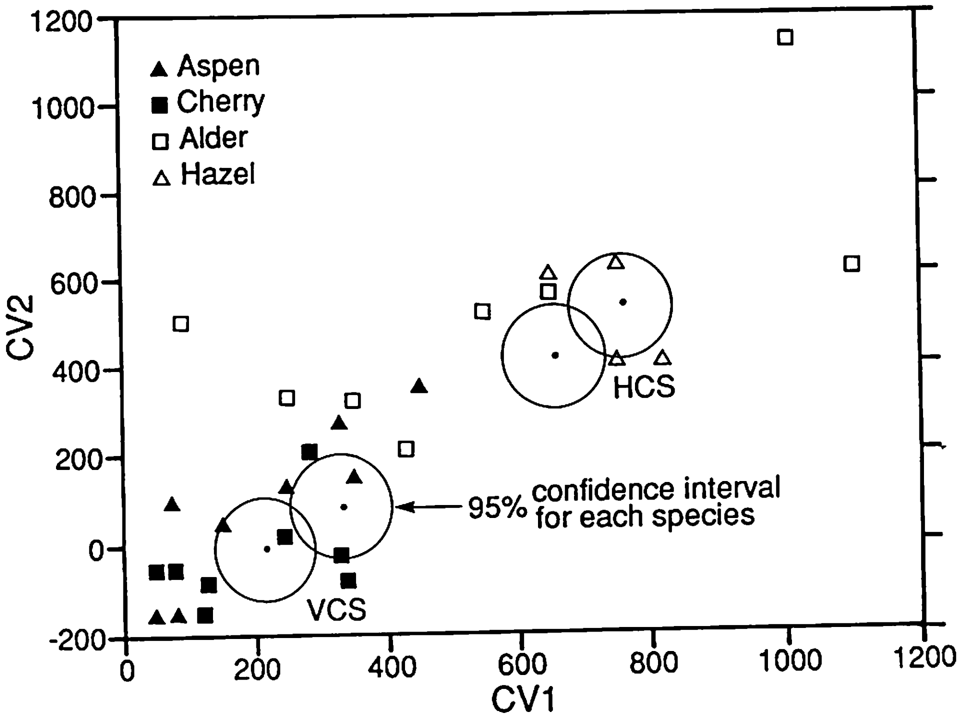
Figure 6. Vegetative regeneration of trembling aspen following stem cutting at 5, 10, 15 and 20 cm above ground in the greenhouse.

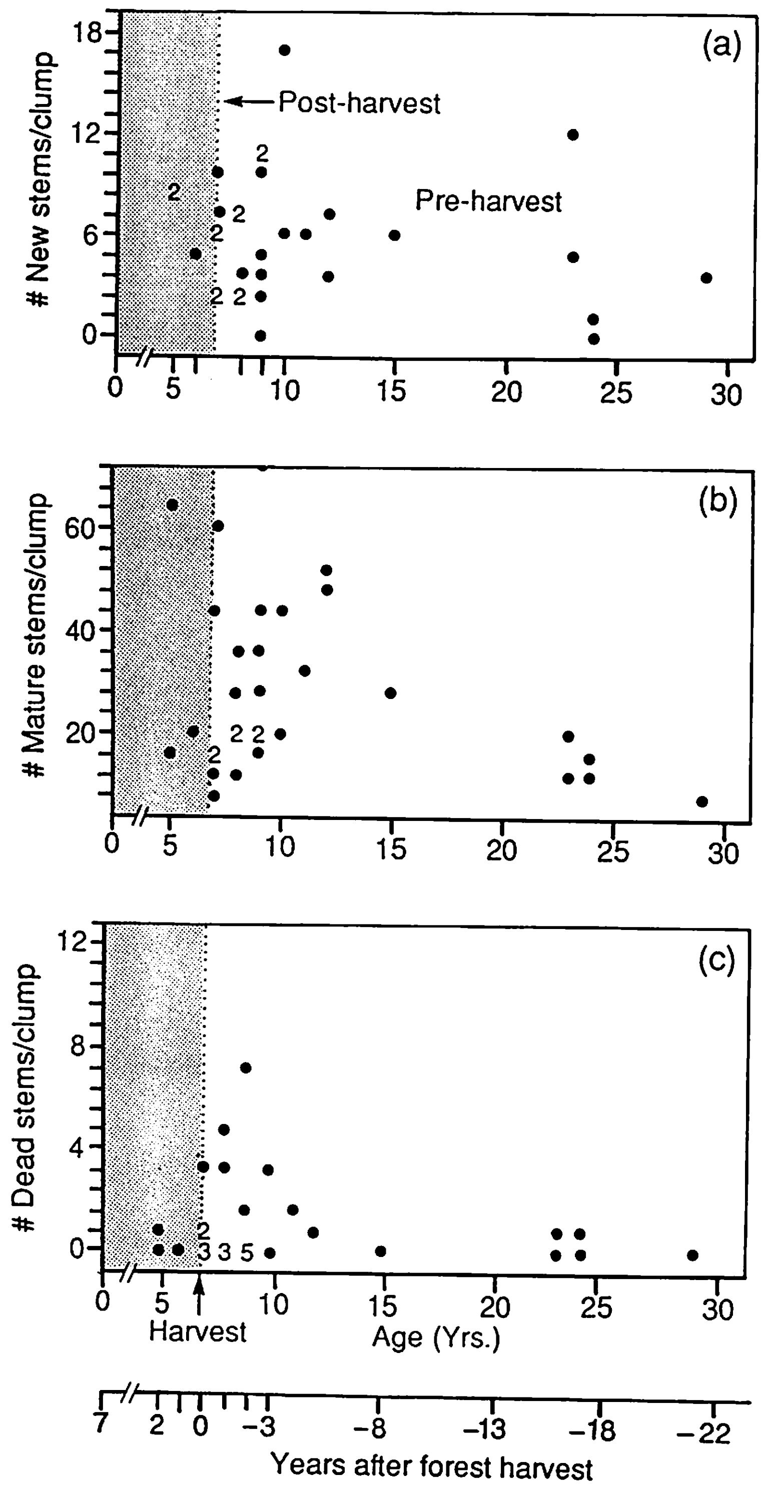
Figure 7. Vegetative regeneration of beaked hazel following stem cutting at 5, 10, 15 and 20 cm above ground in the greenhouse.

Figure 8. Relationship between cover of competing plants and light transmission (% PAR) in the control, brush saw and Vision treated plots.

Figure 9. Relationship between competition index and light transmission (% PAR)in the control , brush saw and Vision treated plots.

Figure 10. Diversity (Hill's index), richness and evenness of plant species in the control, brush saw, single Vision and multiple Vision plots three years after the treatments.


▲ Aspen
■ Cherry
□ Alder
△ Hazel
1200
1000
800
600
400
200
0
-200
CV2
0
200
400
600
800
1000
1200
CV1
HCS
VCS
95% confidence interval for each species



(a)
New stems/clump
18
12
6
0
Post-harvest
Pre-harvest
2
0
5
10
15
20
25
30
(b)
Mature stems/clump
60
40
20
(c)
Dead stems/clump
12
8
4
0
3 3 5
Harvest
Age (Yrs.)
7
2
0
−3
−8
−13
−18
−22
Years after forest harvest

Fig 2

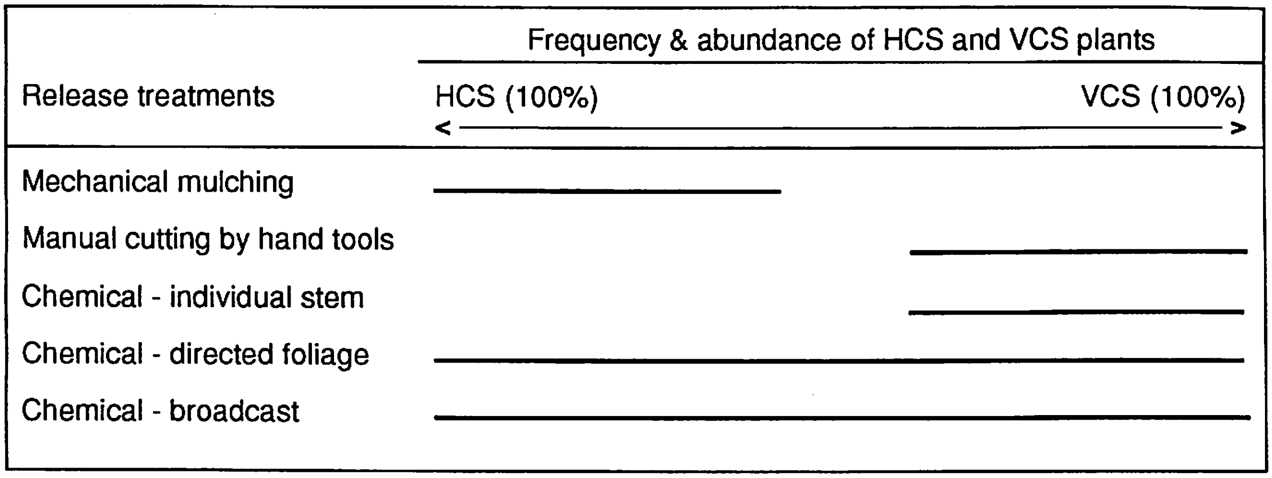

Frequency & abundance of HCS and VCS plants
Release treatments
HCS (100%)
VCS (100%)
Mechanical mulching
Manual cutting by hand tools
Chemical - individual stem
Chemical - directed foliage
Chemical - broadcast

Fig 3

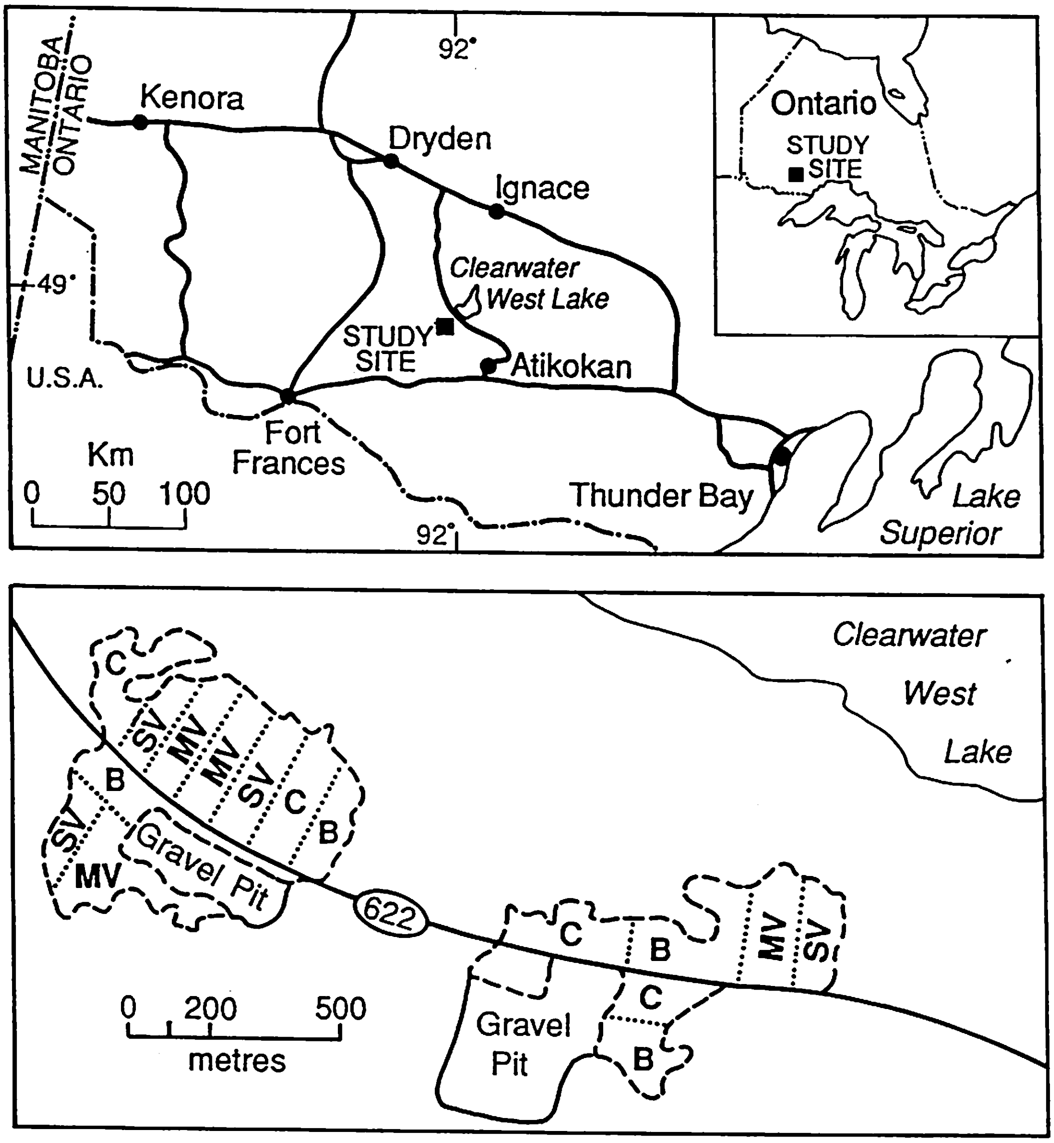

MANITOBA
ONTARIO
Kenora
92°
Dryden
Ignace
Clearwater
West Lake
STUDY SITE
Atikokan
49°
U.S.A.
Fort Frances
Km
0 50 100
Thunder Bay
92°
Lake Superior
Ontario
STUDY SITE
Clearwater West Lake
C
SV
MV
MV
SV
C
B
B
SV
MV
Gravel Pit
622
C
B
C
B
MV
SV
0 200 500
metres
Gravel Pit

Fig. 4

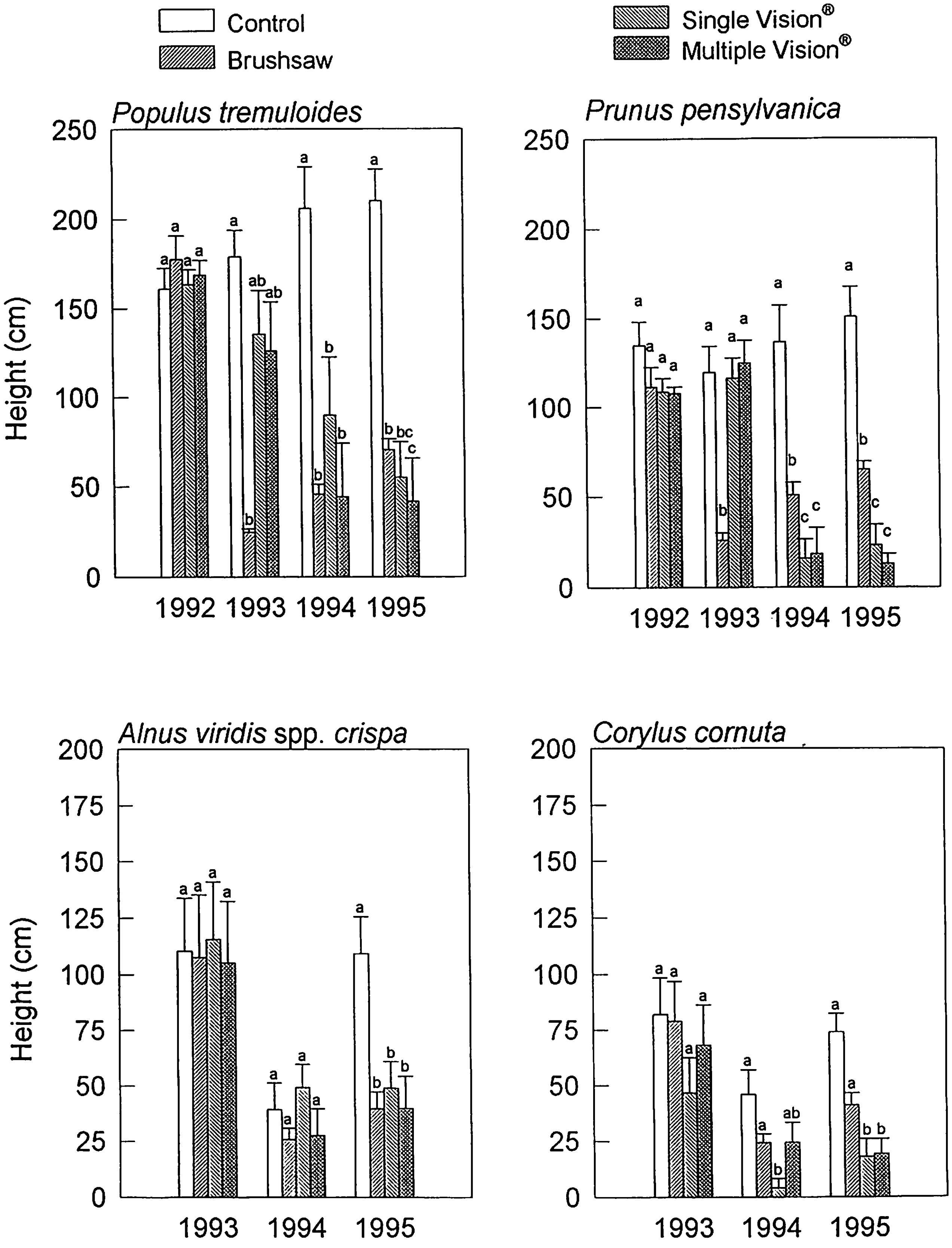

Control
Brushsaw
Single Vision®
Multiple Vision®
Populus tremuloides
Height (cm)
0
50
100
150
200
250
1992
1993
1994
1995
a a a a
a b ab ab
a b b b
a b bc c
Prunus pensylvanica
0
50
100
150
200
250
1992
1993
1994
1995
a a a a
a b a a
a b c c
a b c c
Alnus viridis spp. crispa
Height (cm)
0
25
50
75
100
125
150
175
200
1993
1994
1995
a a a a
a a a a
a b b b
Corylus cornuta
0
25
50
75
100
125
150
175
200
1993
1994
1995
a a a a
a a b ab
a a b b

Fig. 5

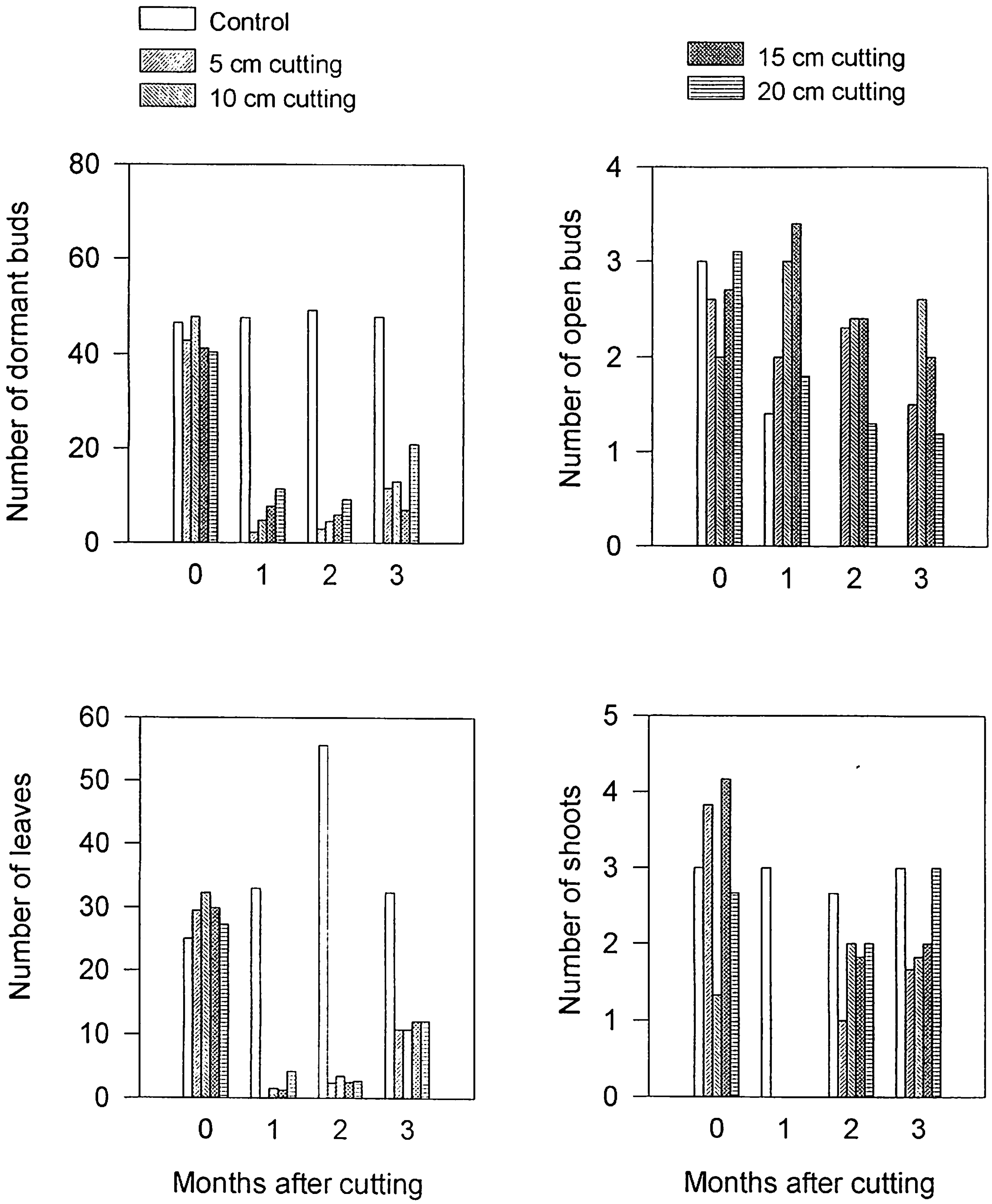
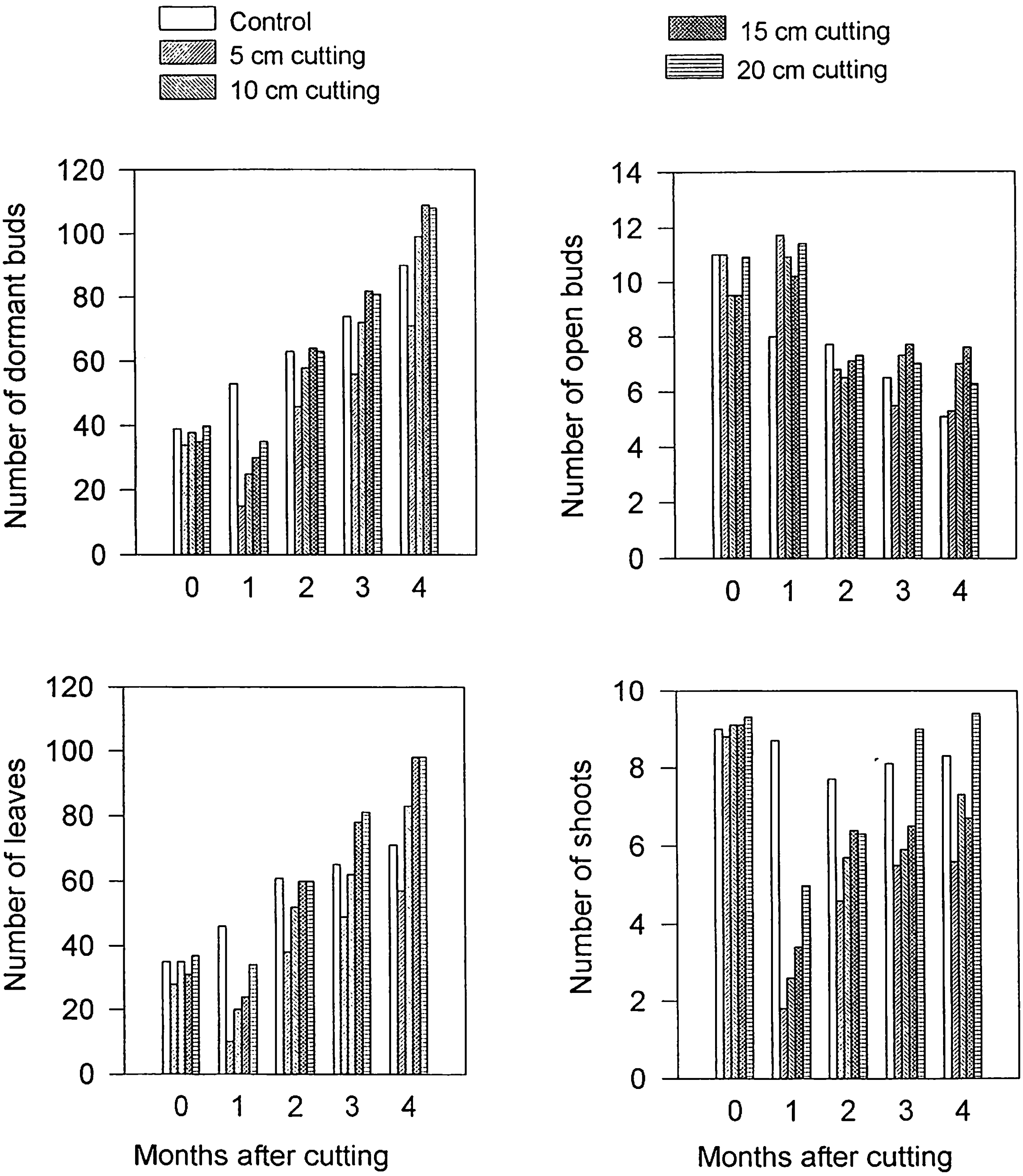

Control
5 cm cutting
10 cm cutting
15 cm cutting
20 cm cutting
Number of dormant buds
0
20
40
60
80
0 1 2 3
Number of open buds
0
1
2
3
4
0 1 2 3
Number of leaves
0
10
20
30
40
50
60
0 1 2 3
Months after cutting
Number of shoots
0
1
2
3
4
5
0 1 2 3
Months after cutting

Fig. 6



Control
5 cm cutting
10 cm cutting
15 cm cutting
20 cm cutting
Number of dormant buds
0
20
40
60
80
100
120
Number of open buds
0
2
4
6
8
10
12
14
Number of leaves
0
20
40
60
80
100
120
Number of shoots
0
2
4
6
8
10
0 1 2 3 4
Months after cutting
Months after cutting

Fig.7

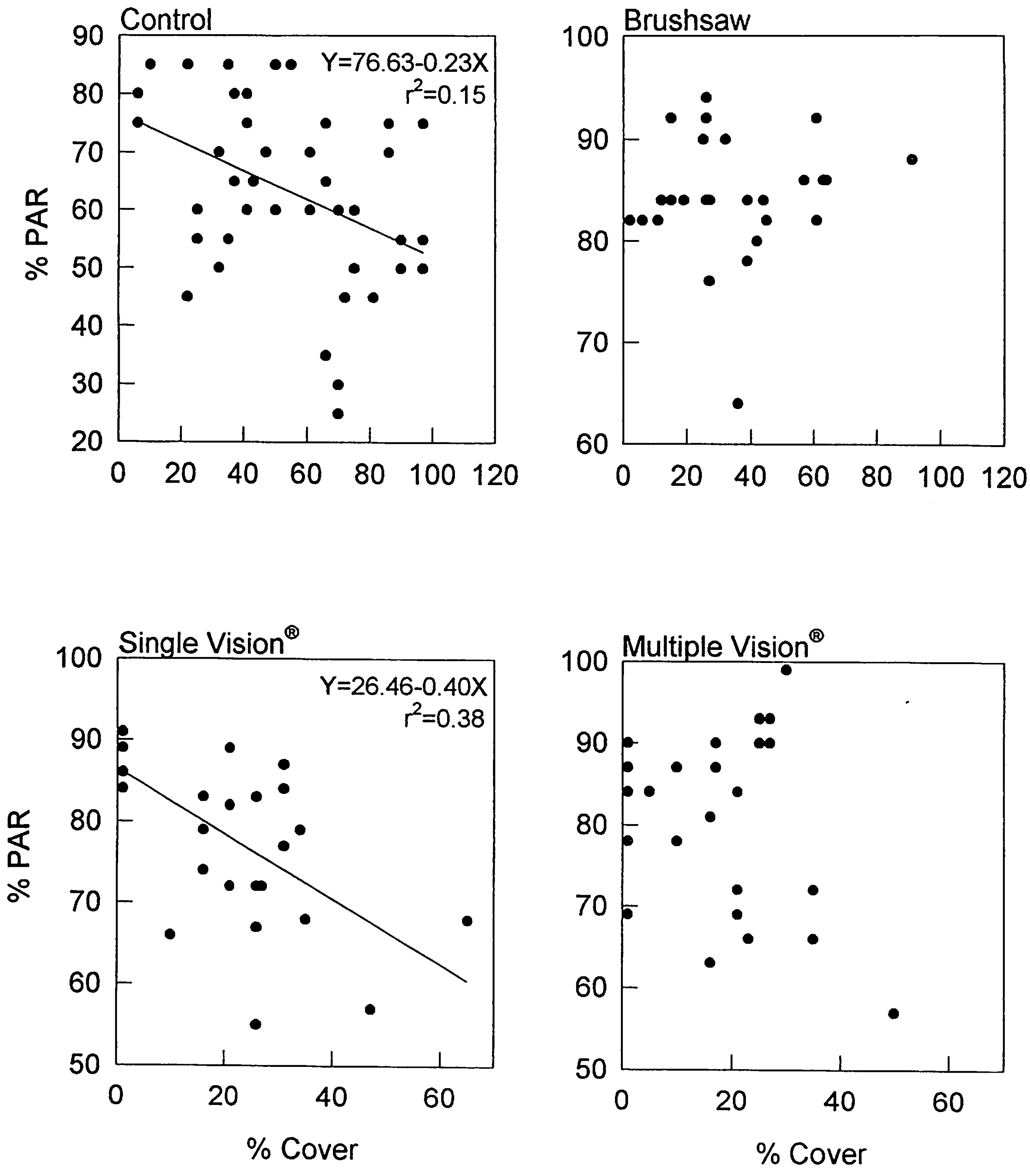

Control
Y=76.63-0.23X
r^2=0.15
90
80
70
60
50
40
30
20
0
20
40
60
80
100
120
% PAR
Brushsaw
100
90
80
70
60
0
20
40
60
80
100
120
Single Vision®
Y=26.46-0.40X
r^2=0.38
100
90
80
70
60
50
0
20
40
60
% PAR
% Cover
Multiple Vision®
100
90
80
70
60
50
0
20
40
60
% Cover

Fig 8

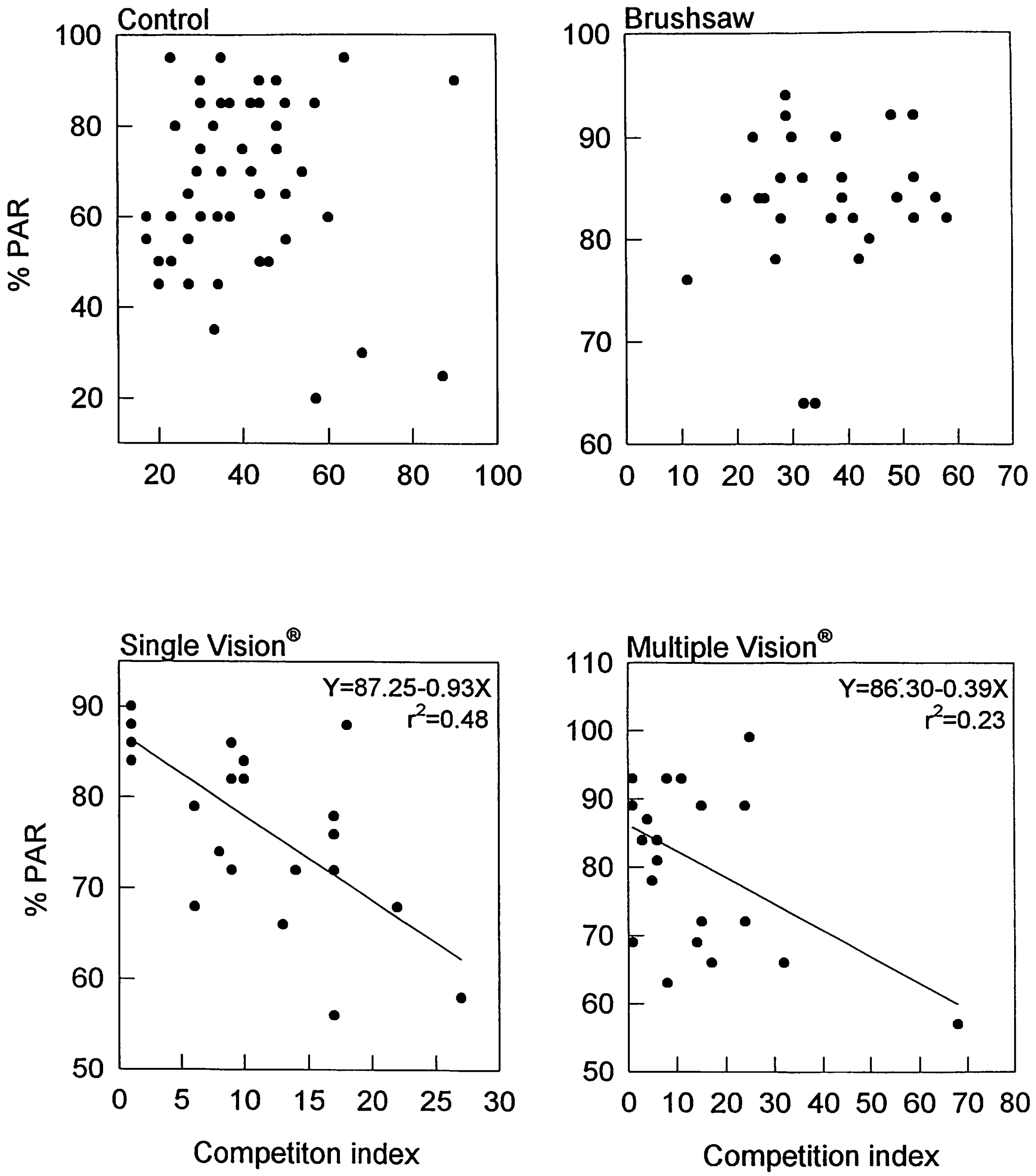

Control
100
80
60
40
20
% PAR
20
40
60
80
100
Brushsaw
100
90
80
70
60
0
10
20
30
40
50
60
70
Single Vision®
Y=87.25-0.93X
r²=0.48
90
80
70
60
50
% PAR
0
5
10
15
20
25
30
Competiton index
Multiple Vision®
Y=86.30-0.39X
r²=0.23
110
100
90
80
70
60
50
0
10
20
30
40
50
60
70
80
Competition index

Fig. 9

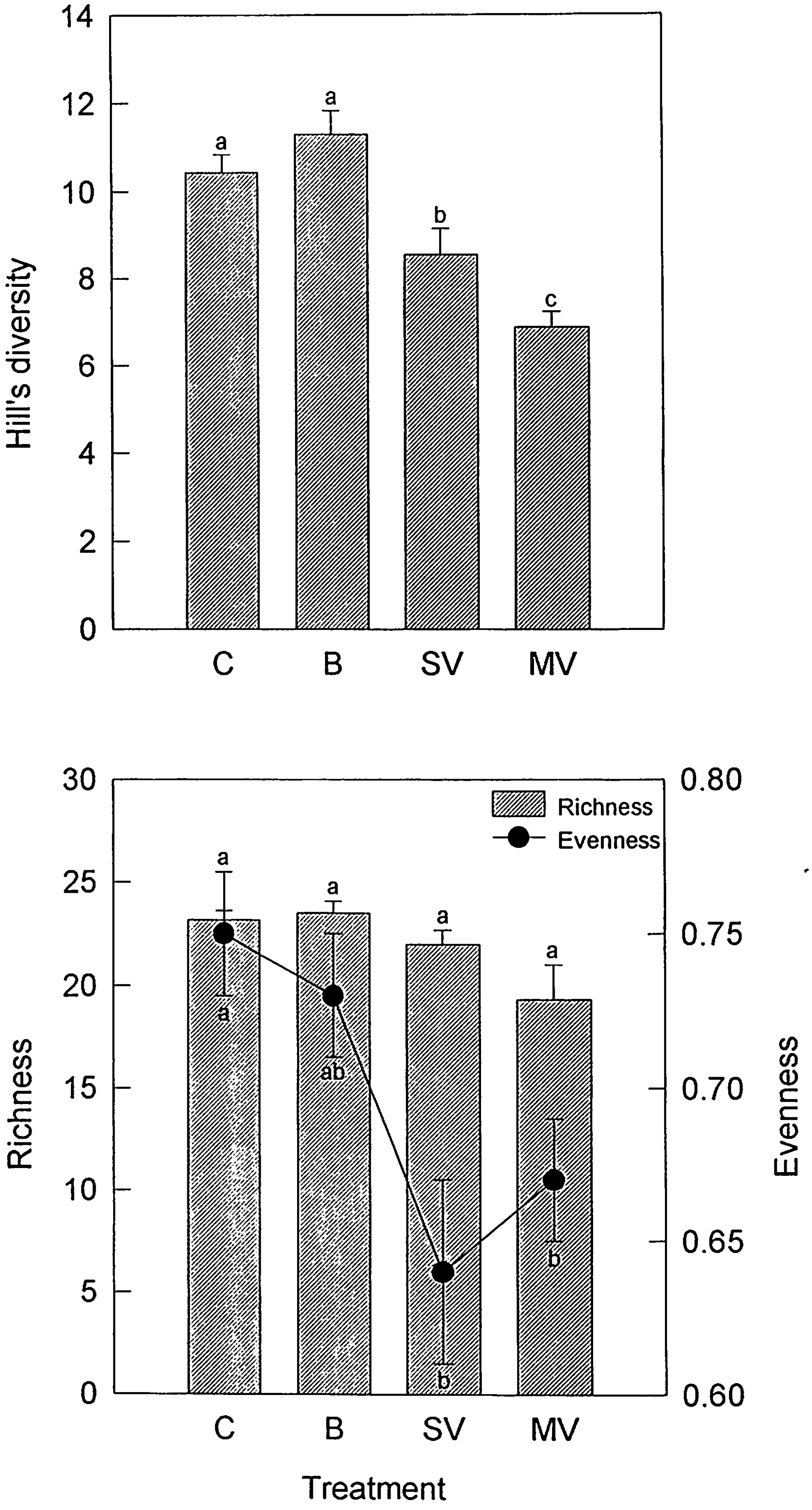

14
12
10
8
6
4
2
0
Hill's diversity
a
a
b
c
C
B
SV
MV
30
25
20
15
10
5
0
Richness
0.80
0.75
0.70
0.65
0.60
Evenness
▨ Richness
● Evenness
a
a
a
a
a
ab
b
b
C
B
SV
MV
Treatment

Fig.10

Table 1. Standing stem density (no./ha) of trembling aspen, pin cherry, green alder and beaked hazel, five, six and seven years after forest harvesting. Means ± standard error were determined by sampling 12 5x10 m permanent sub-plots during 1992-1994.

	Number of stems per hectare		
Species	1992	1993	1994
Trembling aspen	4 580 ± 1160	3 550 ± 440	2 500 ± 560
Pin cherry	3 600 ± 1200	2 120 ± 600	1 120 ± 240
Green alder	27 580 ± 7 720	25 600 ± 6 580	25 920 ± 7 720
Beaked hazel	14 600 ± 4 850	11 400 ± 4 500	1 436 ± 4 140

Table 2. Vegetative regeneration characteristics of trembling aspen, pin cherry, green alder and beaked hazel. Values and means ± standard error of eight clumps for each of the first three species and four clumps for hazel. Mean stem diameter for green alder and beaked hazel was measured at the root collar position, which often contained more than one aerial stem.

Species	Crown diameter (cm)	Mean stem diameter (cm)	Inter-sprout distance (cm)	Stem			Dry biomass	
				number (no./clump)	height (cm)	age (yrs)	rhizomes & roots (g)	stem (g)
Trembling aspen	77 ± 8.4 a	2.7 ± 0.4 a	61 ± 16 a	2.8 ± 0.4 a	184 ± 17 a	6.0 ± 1.1 a	410 ± 89 a	461 ± 93 a
Pin cherry	77 ± 12.4 a	1.4 ± 0.3 a	53 ± 20 a	2.3 ± 0.4 a	146 ± 14 a	6.0 ± 0.7 a	242 ± 46 a	238 ± 42 a
Green alder	140 ± 13.7 b	13.7 ± 1.5 b	-	14.0 ± 1.4 b	105 ± 14 b	5.0 ± 0.6 b	947 ± 142 b	624 ± 82 b
Beaked hazel	135 ± 41.3 b	3.2 ± 0.4 a	49 ± 8 a	8.0 ± 2.1 b	97 ± 18 b	4.0 ± 0.3 b	811 ± 145 b	873 ± 201 b

Note: Values with different letters within the same column are significantly different ($P \leq 0.05$) as determined by one-way ANOVA followed by Tukeys HDS test.

Table 3. Stem density (mean no/ha ± S.E.) of trembling aspen *(Populus tremuloides)*, pin cherry *(Prunus pensylvania)*, green alder *(Alnus viridis* spp. *crispa)* and beaked hazel *(Corylus cornuta)* in the control, brushsaw and Vision® treated plots.

	Treatment			
	Control	Brushsaw	Single Vision®	Multiple Vision®
Populus tremuloides				
1992 (pre-treatment)	4,588±1,160b	6,516±1,068ab	11,184±1,838a	10,984±1750a
1993	3,350±440a	2,218±500a	1,650±584a	1,716±690a
1994	2,500±560a	4,350±1096a	1,434±648b	34±22b
1995	3,400±858a	6,066±1,116a	366±1046	116±68b
Prunus pensylvania				
1992 (pre-treatment)	3,600±1,200a	2,984±590a	4,516±898a	3,934±818a
1993	2,120±600a	2,244±626a	1,550±330a	934±218a
1994	1,120±240a	3,484±922a	234±182b	300±204b
1995	1,150±808a	3,234±664a	184±94b	266±124b
Alnus viridis spp. *crispa*				
1993 (pre-treatment)	25,600±6,580a	28,272±9,094a	15,424±4,302a	10,324±3,088a
1994	25,920±7,720a	12,266±4,900a	8,434±2,286a	5,366±2,466a
1995	25,910±7,726a	27,144±10,056ab	6,670±3,614b	3,970±2,378b
Corylus cornuta				
1993 (pre-treatment)	14,578±4,850a	16,160±8,258a	13,818±7,550a	18,744±3,816a
1994	1,436±4,140a	10,234±5,890ab	484±484b	7,434±2,880ab
1995	14,360±4,134a	26,674±15,018ab	1,504±5,66b	15,826±7,114ab

Note: Species' means, within each year, followed by the same letter are not significantly different when ∝ = 0.05. For alder and hazel pre-treatment data were not collected.

Table 4. Mean ±SE percent cover and competition index (CI) and percent PAR transmission in the control and treated plots.

Treatment	Percent cover	CI	PAR
Control	52±2.1a	41±1.9a	67±1.3a
Brushsaw	34±1.9b	37±1.6a	82±0.7b
Single Vision	20±1.6c	11±1.6b	75±1.6b
Multiple Vision	15±1.3c	12±1.4b	29±0.9c

Note: Means with unlike letter indicates significant difference ($P = 0.001$).

Table 5. Mean (±S.E.) height and basal diameter of *P. banksiana* on the control and conifer release treated areas in 1995.

Treatment	Height (cm)	Basal diameter (cm)
Control	227.90±11.55a	3.13±0.28a
Brushsaw	242.05±9.12a	3.93±0.13a
Single Vision	236.95±14.43a	3.90±0.23a
Multiple Vision	207.04±18.04a	4.04±0.38a

Note: Means followed by the same letter are not significantly different when α=0.05.

Table 6. Mean % cover, frequency and importance value (IV) of the vascular and non vascular plants in the control, brush saw, single vision and multiple vision plots three years after the treatments.

	Control			Brushsaw			Single Vision			Multiple Vision		
Species	Mean	%Freq	IV	Mean	%Freq	IV	Mean	%Freq	IV	Mean	%Freq	IV
Acer spicatum	3.50	75.00	78.50	0.37	26.67	27.03	6.00	60.00	66.00	2.55	60.00	62.55
Achillea millefolium	0	0	0	0	0	0	1.00	60.00	61.00	0.60	20.00	20.60
Alnus viridis spp. crispa	23.92	81.85	105.78	10.98	54.07	65.05	9.18	48.89	58.07	1.20	36.00	37.20
Amelanchier spp.	0.68	24.17	24.84	1.60	42.50	44.10	0.68	22.50	23.18	0.60	20.00	20.60
Anaphalis margaritacea	0.27	31.48	31.75	0.83	57.58	58.41	0	0	0	0	0	0
Apocynum androsaemifoliu	0.91	31.11	32.03	1.64	41.90	43.55	1.87	62.50	64.37	0.79	55.56	56.35
Aralia nudicaulis	0.18	26.67	26.85	0	0	0	0	0	0	0.10	20.00	20.10
Aster ciliolatus	0.20	20.00	20.20	0	0	0	0	0	0	23.81	90.00	113.81
Aster macrophyllus	8.07	87.22	95.29	5.57	74.39	79.96	7.72	86.11	93.83	2.44	64.00	66.44
Aster spp.	0	0	0	0	0	0	10.25	85.00	95.25	8.87	73.33	82.21
Betula papyrifera	6.34	50.00	56.34	1.59	47.33	48.93	1.50	27.86	29.36	0.04	26.67	26.70
Carex spp.	0.69	68.89	69.58	1.15	56.00	57.15	11.00	100.00	111.00	0	0	0
Clintonia borealis	2.23	48.17	50.40	0	0	0	2.50	63.64	66.14	0.58	26.67	27.25
Chimaphila umbellata	0	0	0	0.60	40.00	40.60	0	0	0	0	0	0
Comptonia peregrina	9.71	66.88	76.58	20.27	90.00	110.27	20.20	46.67	66.87	0.82	57.14	57.96
Coptis trifolia	0.17	66.67	66.83	0.02	20.00	20.02	0.10	21.67	21.76	0.37	48.57	48.94
Cornus canadensis	15.56	96.25	111.81	19.29	92.50	111.79	26.39	89.58	115.98	15.70	91.67	107.37
Corydalis sempervirens	0	0	0	0	0	0	0	0	0	0.05	20.00	20.05
Corylus cornuta	16.68	69.07	85.76	4.31	37.33	41.65	0.82	39.76	40.58	4.48	56.67	61.15
Dicranum spp.	0.76	55.30	56.06	1.68	71.04	72.73	3.44	84.17	87.61	3.37	81.82	85.18
Diervilla lonicera	14.67	100.00	114.67	6.07	97.92	103.98	4.25	77.00	81.25	1.24	60.00	61.24
Dyphasiastrum digitatum	0.83	100.00	100.83	0.63	100.00	100.63	1.80	40.00	41.80	0	0	0
Epigaea repens	0.20	20.00	20.20	1.00	20.00	21.00	0	0	0	0	0	0
Epilobium angustifolium	0.60	37.62	38.22	0.60	37.22	37.83	5.36	63.18	68.55	1.42	60.00	61.42
Fern	0	0	0	0	0	0	4.00	80.00	84.00	2.95	60.00	62.95
Geranium bicknellii	0	0	0	0	0	0	0	0	0	1.00	100.00	101.00
Grass	13.38	72.67	86.05	11.91	76.46	88.37	28.83	86.67	115.50	25.51	90.00	115.51
Hieracium aurantiacum	0	0	0	0	0	0	0.06	25.00	25.06	0	0	0
Lichen	0.40	40.00	40.40	0.49	45.00	45.49	0	0	0	0	0	0
Linnaea borealis	1.39	65.37	66.76	1.67	58.50	60.17	1.45	75.00	76.45	0.63	45.00	45.63
Lycopodium dendroideum	1.54	65.00	66.54	1.31	55.56	56.87	1.94	56.67	58.60	1.67	67.50	69.17
Lycopodium spp.	0.16	20.00	20.16	0.68	50.48	51.15	0.40	20.00	20.40	0	0	0
Maianthemum canadense	2.44	83.89	86.33	2.54	77.96	80.50	2.60	88.61	91.21	5.61	88.33	93.94
Melampyrum lineare	0.52	51.33	51.85	0.43	42.92	43.35	0.47	49.00	49.47	0.98	54.29	55.27
Moss	0.40	30.00	30.40	0.83	74.33	75.16	2.38	80.00	82.38	1.49	77.14	78.64
Picea glauca	0	0	0	0.56	48.89	49.44	1.66	27.00	28.66	4.00	20.00	24.00
Pinus banksiana	12.81	78.48	91.29	18.75	78.18	96.93	19.52	83.18	102.70	21.60	87.50	109.10
Pinus resinosa	0	0	0	0	0	0	0	0	0	10.00	100.00	110.00
Polygonum cilinode	0	0	0	0.10	20.00	20.10	1.91	48.33	50.25	2.11	65.00	67.11
Populus tremuloides	18.36	73.33	91.70	4.46	73.33	77.79	1.70	42.22	43.92	0.30	40.00	40.30
Prunus spp.	8.07	66.53	74.60	2.90	51.81	54.71	2.21	38.57	40.79	0.45	42.50	42.95
Pteridium aquilinum	14.23	86.67	100.90	7.71	50.00	57.71	2.37	55.00	57.37	2.60	60.00	62.60
Rosa acicularis spp. sayi	0.83	36.67	37.50	0.10	20.00	20.10	4.60	60.00	64.60	0	0	0
Rubus idaeus	2.27	64.00	66.27	2.45	60.00	62.45	14.23	86.06	100.29	5.96	77.50	83.46
Salix spp.	5.54	54.17	59.71	3.78	51.36	55.14	4.95	38.75	43.70	4.80	60.00	64.80
Solidago spp.	0.37	26.67	27.03	0.63	47.50	48.13	0.14	28.75	28.89	2.20	40.00	42.20
Sphagnum spp.	1.31	66.88	68.18	4.73	83.75	88.48	3.63	81.67	85.30	0.93	66.67	67.60
Taraxacum officinale	0.25	25.00	25.25	0.16	22.50	22.66	0.10	20.00	20.10	0.11	20.00	20.11
Vaccinium angustifolium	7.75	79.58	87.33	8.04	71.81	79.85	2.88	72.58	75.46	0.31	40.00	40.31
Vaccinium myrtilloides	10.06	74.86	84.93	11.83	80.00	91.83	6.62	71.21	77.83	0.57	42.50	43.07
Viola spp.	0.73	80.00	80.73	0.54	65.76	66.30	0.85	76.21	77.06	1.20	78.00	79.20

Table 7. Mean (±S.E.) height and basal diameter of *P. banksiana* on the control and conifer release treated areas in 1995.

Treatment	Height (cm)	Basal diameter (cm)
Control	227.90±11.55a	3.13±0.28a
Brushsaw	242.05±9.12a	3.93±0.13a
Single Vision	236.95±14.43a	3.90±0.23a
Multiple Vision	207.04±18.04a	4.04±0.38a

Note: Means followed by the same letter are not significantly different when ∝ = 0.05.