Plant Abundances after Clearcutting and Stripcutting in Central Labrador

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ABSTRACT

We compared plant abundances between clearcuts ($n = 10$) and stripcuts ($n = 6$) on former *Picea mariana* sites harvested in the mid-1970s and mid-1990s in central Labrador, Newfoundland, and Labrador, Canada. Redundancy analysis (RDA) found logging methods an important determinant of conifer abundance for 1990s logging, showing *P. mariana* associated with clearcuts and *Abies balsamea* associated with stripcuts. Our RDA of the years combined found logging methods unimportant, but the year of logging was the most important factor followed by pH and drainage. The size distribution of trees, with the exception of *Alnus rugosa*, increased with stand age. *Geocaulon lividum* and *Cladina arbuscula* were associated with 1970s logging and coarse woody debris, *Vaccinium vitis-idaea*, and *Cornus canadensis* were associated with 1990s logging. *Sphagnum* spp. was positively associated with imperfectly drained sites and high pH, and *Pleurozium schreberi* was positively associated with moderately drained sites. Our results suggest only a short-term effect of logging methods on regeneration, and similarities may have resulted from the small opening sizes and irregular shapes of our clearcuts. We suggest that stripcutting to promote *P. mariana* regeneration may offer little, if any, benefit over clearcutting when distances between forest canopies within clearcuts are typically 300 m or less.

Keywords: *Abies balsamea*, boreal forest, logging, *Picea mariana*, regeneration

Clearcutting is the most common logging practice in Canadian boreal forests, e.g., in 2002, it comprised 90.5% of all harvesting (Canadian Council of Forest Ministers 2004). Clearcutting is attractive to forest companies because it maximizes timber extraction while minimizing road construction costs (Johnson and Smyth 1987, Hansen et al. 1995). However, to maintain the long-term economic viability of stands, clearcuts must regenerate to species that yield merchantable volumes within reasonable time frames (Jeglum 1990). To maintain biodiversity, it is desirable for clearcuts to regenerate species similar to that maintained by natural disturbance (Hunter 1993, McRae et al. 2001). However, clearcutting *Picea mariana* stands, a dominant boreal forest type, often results in increased proportions of *Abies balsamea* and broad-leaved trees (Richardson 1974, Brumelis and Carleton 1988, Jeglum 1990, Viereck and Johnston 1990, Carleton and MacLellan 1994, McRae et al. 2001, Simon and Schwab 2005). This conversion of species composition results in stands of lower commercial value and that differ in composition from wildfire origin stands (McRae et al. 2001, Simon and Schwab 2005). To increase *P. mariana* regeneration, clearcuts often require a seed source and expensive site preparation, such as scarification (Jeglum 1990, Viereck and Johnston 1990). In addition, widespread opposition to clearcutting exists from the public. It is considered aesthetically offensive and is negatively associated with deforestation and environmental degradation (Bliss 2000, Lieffers et al. 2003).

Stripcutting has been considered an alternative to clearcutting *P. mariana* forests because seed trees in the adjacent uncut strips can increase regeneration (van Nostrand 1971, Pothier 2000). Stripcutting also can have environmental advantages over clearcutting: re-

duced soil erosion and runoff, while generating diverse forest structure, edge effect, and aesthetic appeal (Jeglum 1990, Gove et al. 1992, Pothier 2000, Doyon et al. 2005). The abundance of some understory species, e.g., *Pleurozium schreberi* and *Sphagnum* spp., and the survival of *A. balsamea* seedlings often is lower in large openings (Hannerz and Hånell 1997, McLaren and Janke 1996, Jalonen and Vanha-Majamaa 2001), suggesting that the smaller openings in stripcuts may increase the abundance of these species. However, stripcutting can be less economical than clearcutting because less timber is removed and more roads are constructed (Johnson and Smyth 1987). The larger road network negatively impacts both terrestrial and aquatic ecosystems through direct mortality of organisms by vehicle collisions, altering animal movements and increasing hunter access (Simon et al. 1999, Trombulak and Frissell 2000, Haeussler and Kneeshaw 2003). The greater edge effect in stripcutting also can increase the susceptibility of windthrow for shallow-rooted species such as *P. mariana* (Wilton 1964, Ruel 1995).

The feasibility of using stripcutting to increase *P. mariana* regeneration depends on its regeneration success in clearcuts. Although poor *P. mariana* regeneration in clearcuts is common (Viereck and Johnston 1990, Carleton and MacLellan 1994, McRae et al. 2001), *P. mariana* restocking on clearcuts in central Labrador is typically high (Newfoundland and Labrador Department of Natural Resources, unpublished data, 2003) and generally exceeds that of natural disturbance (Richardson 1974, Simon and Schwab 2005). Increased broad-leaved tree competitors on clearcuts can reduce *P. mariana* regeneration (Jeglum 1990, Carleton and MacLellan 1994, McRae et al. 2001) but this does not appear problematic in central
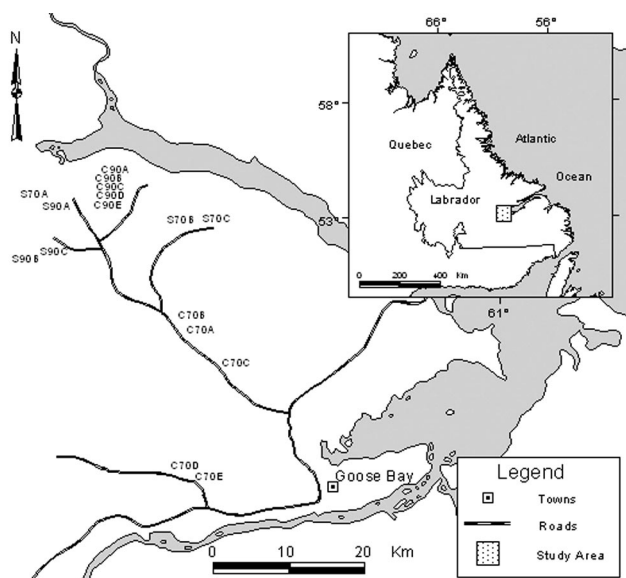
Figure 1. Map of study area. C, clearcut; S, stripcut; 70, 1970s logging; 90, 1990s logging.

Labrador (Simon and Schwab 2005). The large seed dispersal distances also can reduce regeneration within clearcuts (Hughes and Bechtel 1997, Greene et al. 1999) but the topography and high proportion of noncommercial *P. mariana* stands in Labrador cause clearcuts to be irregularly shaped. The high perimeter/area ratios of these clearcuts reduce the distance seeds have to disperse. Because of these differences, we compare regeneration among stripcuts and clearcuts in central Labrador. Logging method is evaluated within the context of time because disturbance and edaphic factors also influence plant communities. We predict *P. mariana* regeneration will be similar between clearcuts and stripcuts and the abundances of *A. balsamea, P. schreberi*, and *Sphagnum* will be higher on stripcuts.

Methods

Study Area

The study area is within 40 km of Goose Bay, Labrador (53°20′ N, 60°25′ W; Figure 1) and part of the Perhumid High Boreal ecoclimatic region (Canada Committee on Ecological Land Classification 1989). This region is characterized by intermittent bogs dominated by *Sphagnum* mosses among well-developed forest stands. *P. mariana* and *A. balsamea* are the most prevalent species and are commonly found on shallow upland soils (Lopoukhine et al. 1975). Other, less common, trees include *P. glauca*, *Betula papyrifera*, and *Populus tremuloides* (Lopoukhine et al. 1975, Canada Committee on Ecological Land Classification 1989).

Field Data Collection

In 2003, we randomly placed 1 transect, within accessible areas, in each of 16 treated areas: mid-1970s stripcuts ($n = 3$), mid-1990s stripcuts ($n = 3$), mid-1970s clearcuts ($n = 5$), mid-1990s clearcuts ($n = 5$). Our six stripcut sites were the only stripcuts in central Labrador large enough to encompass an entire transect. Transects consisted of 10, 5-m^2 plots, 20 m apart. The number of stems may not reflect adequately vegetation structure for species that have the potential to grow tall (i.e., conifer and broad-leaved trees). Therefore, we placed tree species into one of four basal diameter classes: 0–1 cm, more than 1–2 cm, more than 2–4 cm, and more than 4

cm. Ground vegetation cover, prostrate woody shrubs, forbs, mosses, lichens, and coarse woody debris were estimated using the method of Daubenmire (1968). Seven percentage classes were used for estimation within a 0.1-m^2 quadrat at the center of each plot: 0, more than 0–5, more than 5–25, more than 25–50, more than 50–75, more than 75–90, and more than 95–100. The midpoints of each class were used during data analysis.

A soil pit was excavated to the top of the C layer, and the depth of each preceding layer was recorded. Drainage was classified using the six ordinal classes of the Agriculture Canada Expert on Soil Survey (1987): very poor, poor, imperfect, moderate, well, or rapid. Very poor and rapid drainage classes did not occur on our sites; poor drainage classes did not occur in the 1990s. Slope, aspect, pH, and thickness of the organic layer were recorded for each subplot and averaged per transect. Aspect was combined with slope in an index of radiation such that north-facing aspects produced high positive values, which increased with slope (northness = COS[aspect] × TAN[slope]; adapted from Beers et al. [1966]). Soil and topographic features by logging method and year of logging are shown in Table 1.

Statistical Analysis

We used redundancy analysis (RDA) performed using CANOCO version 4 (Microcomputer Power, Ithaca, NY) (ter Braak and Šmilauer 1999), to examine the effect of logging method, year of logging, and edaphic features on plant abundances. RDA is an ordination technique that directly compares two data sets (direct gradient analysis; Legendre and Legendre [1998]). In direct gradient analysis, the matrix of explanatory variables intervenes in the calculation producing the ordination of response variables (plant abundances), such that the vectors in the response variables are maximally related to the explanatory variables (Legendre and Legendre 1998). Because the vegetation data contained two different measures of abundance, percent cover and number of stems, we standardized our vegetation data by dividing the abundance of each plant species by the maximum value recorded for that species (Legendre and Legendre 1998). Because RDA is inappropriate for data across unimodal gradients with many zeros, we used the Hellinger distance transformation on our species data before analyses (Legendre and Gallagher 2001). Logging method, year of logging, and drainage were analyzed as a category using dummy variables (Legendre and Legendre 1998). The number of dummy variables required to code for ordinal or categorical variables is equal to the number of states minus one (Legendre and Legendre 1998). Thus, logging method and year of logging were each represented by one variable, and drainage was represented by three variables. We used Monte Carlo permutation tests in a stepwise fashion to determine the statistical significance of environmental variables (ter Braak and Šmilauer 1999), retaining those with $P < 0.15$ for final ordination. Logging year is likely to have the greatest effect on regeneration, potentially masking differences in logging methods or edaphic features so we performed RDA on the entire data set and on each age group separately.

Results

A total of 42 vegetation variables, representing 29 plant species, were recorded (Table 2). For the RDA on the combined years, we retained year of logging, pH, and drainage for final ordination (Figure 2). All canonical axes were statistically significant ($F = 1.60$; $P = 0.005$) and explained 44.4% of the variance in the vegetation data;

Table 1. Soil and topographic features by logging method and year of logging.

		1970		1990	
Variable	Type	Clearcut	Stripcut	Clearcut	Stripcut
Drainage[a]	Ordinal	4	4	4	4
Humic layer (cm)	Continuous	2.93	2.24	2.47	2.63
pH	Continuous	4.49	4.39	4.45	4.33
Slope (degrees)	Continuous	3.22	2.07	2.30	3.89
Northness	Continuous	0.06	0.03	0.02	0.00

[a] Drainage is expressed as median, and classified as very poor (1), poor (2), imperfect (3), moderate (4), well (5), and rapid (6); remaining variables are expressed as mean.

Table 2. Mean abundance of vegetation within regenerating stripcuts and clearcuts.[a]

		Stripcut				Clearcut			
		1970		1990		1970		1990	
Species/diameter	Mnemonic	Avg	SE	Avg	SE	Avg	SE	Avg	SE
Conifers									
A. balsamea (0–1 cm)	Abi.bal1	0.32	0.12	0.46	0.09	0.48	0.11	0.28	0.11
A. balsamea (1–2 cm)	Abi.bal2	0.18	0.05	0.33	0.07	0.60	0.14	0.20	0.08
A. balsamea (2–4 cm)	Abi.bal4	0.10	0.04	0.05	0.04	0.22	0.08	0.04	0.02
A. balsamea (>4 cm)	Abi.bal5	0.53	0.15	0.80	0.22	0.12	0.05	0.52	0.18
P. mariana (0–1 cm)	Pic.mar1	1.81	0.26	0.37	0.07	1.06	0.19	0.68	0.19
P. mariana (1–2 cm)	Pic.mar2	1.27	0.24	0.21	0.06	1.38	0.23	0.36	0.12
P. mariana (2–4 cm)	Pic.mar4	0.31	0.07	0.02	0.01	0.52	0.11	0.02	0.02
P. mariana (>4 cm)	Pic.mar5	2.25	0.36	0.82	0.17	0.88	0.19	2.40	0.40
Broad-leaved trees									
A.s rugosa (0–1 cm)	Aln.rug1	0.24	0.09	0.46	0.25	0.98	0.43	0.00	0.00
A. rugosa (1–2 cm)	Aln.rug2	0.10	0.05	0.28	0.13	0.08	0.04	0.00	0.00
A.s rugosa (>2 cm)	Aln.rug3	0.07	0.04	0.12	0.07	0.24	0.10	0.00	0.00
B. papyrifera (0–1 cm)	Bet.pap1	0.24	0.11	0.00	0.00	0.12	0.06	0.04	0.04
B. papyrifera (1–2 cm)	Bet.pap2	0.06	0.03	0.01	0.01	0.34	0.11	0.00	0.00
B. papyrifera (>2 cm)	Bet.pap3	0.14	0.05	0.07	0.04	0.00	0.00	0.08	0.05
Salix spp. (0–1 cm)	Sal.spp1	0.04	0.02	0.04	0.04	0.04	0.02	0.58	0.22
Salix spp. (1–2 cm)	Sal.spp2	0.06	0.03	0.06	0.07	0.04	0.02	0.70	0.27
Salix spp. (>2 cm)	Sal.spp3	0.07	0.03	0.00	0.00	0.06	0.04	0.50	0.13
Shrubs/herbs									
Clintonia borealis	Cli.bor	0.78	0.47	0.00	0.00	0.38	0.30	0.00	0.00
C. canadensis	Cor.can	4.75	1.11	7.05	1.55	4.70	1.24	15.00	2.55
Empetrum nigrum	Emp.nig	5.66	1.33	1.14	0.97	2.16	1.10	0.00	0.00
G. hispidula	Gau.his	9.22	1.88	6.37	1.36	8.60	2.26	14.45	3.52
G. lividum	Geo.liv	1.63	0.77	0.00	0.00	1.50	0.50	0.00	0.00
Kalmia polifolia	Kal.pol	0.52	0.29	0.00	0.00	1.76	0.88	0.00	0.00
Ledum groenlandicum	Led.gro	3.94	1.06	1.91	0.87	3.60	0.83	0.60	0.42
Linneae borealis	Lin.bir	0.16	0.17	3.19	1.56	2.20	1.10	0.00	0.00
Maianthemum canadense	Mai.can	0.21	0.17	0.00	0.00	1.10	0.51	0.00	0.00
R. chamaemorous	Rub.cha	0.61	0.45	0.64	0.45	4.10	1.24	0.35	0.30
S. trifolia	Smi.tri	0.50	0.29	0.02	0.02	1.50	0.84	0.34	0.30
V. angustifolium	Vac.ang	16.94	2.09	9.58	1.99	20.08	3.06	0.04	0.04
V. vitis-idaea	Vac.vit	2.00	0.58	1.17	0.37	0.90	0.43	3.95	1.09
Mosses/lichens/liverworts									
Cladina alpestris	Cla.alp	5.87	1.91	0.16	0.17	0.00	0.00	0.00	0.00
C. arbuscula	Cla.arb	2.53	0.80	0.00	0.00	2.20	1.10	0.54	0.31
Cladina	Cla.mit	4.36	1.10	2.30	0.96	7.75	2.47	2.20	0.92
Cladina spp.	Cla.spp	2.02	0.86	0.02	0.03	0.75	0.32	2.70	0.72
Dicranum polysetum	Dic.pol	2.44	1.24	3.90	1.18	4.40	1.77	19.00	4.32
D. scoparium	Dic.sco	6.63	1.61	5.58	1.74	10.85	2.38	4.05	1.42
Lycopodium annotinum	Lyc.ann	1.16	0.71	0.02	0.03	2.75	1.13	0.80	0.75
Peltigera spp.	Pel.spp	1.08	0.61	0.36	0.24	0.35	0.30	0.95	0.75
P. schreberi	Ple.shr	58.30	3.60	33.31	3.70	51.85	5.29	24.45	3.49
P. crista-castrensis	Pti.cri	0.77	0.33	5.75	1.74	6.85	2.21	0.75	0.42
Sphagnum spp.	Sph.spp	5.08	2.17	13.20	3.13	13.65	3.90	10.30	3.73
Other									
Coarse woody debris	CWD	3.94	0.78	27.02	3.31	1.45	0.58	12.90	1.88

[a] Abundances of conifers and broad-leaved trees were expressed as the number of stems/5 m^2; all remaining species were expressed as percent cover.
Avg, average.

the variance explained by the first and second axes were 20.4 and 8.7%, respectively. Coarse woody debris and conifer and broad-leaved tree species, 0–1 cm in diameter, were positively associated with 1990s logging, except *Alnus rugosa*, which was associated with 1970s logging. *P. mariana*, *A. rugosa*, and *B. papyrifera*, more than 2 cm in diameter, were positively associated with 1970s logging. *A. balsamea*, 0–1 cm in diameter, were moderately associated with 1990s logging and those more than 4 cm were moderately associated with 1970s logging. *Geocaulon lividum* and *Cladina arbuscula* were associated with 1970s logging and *Vaccinium vitis-idaea* and *Cornus*
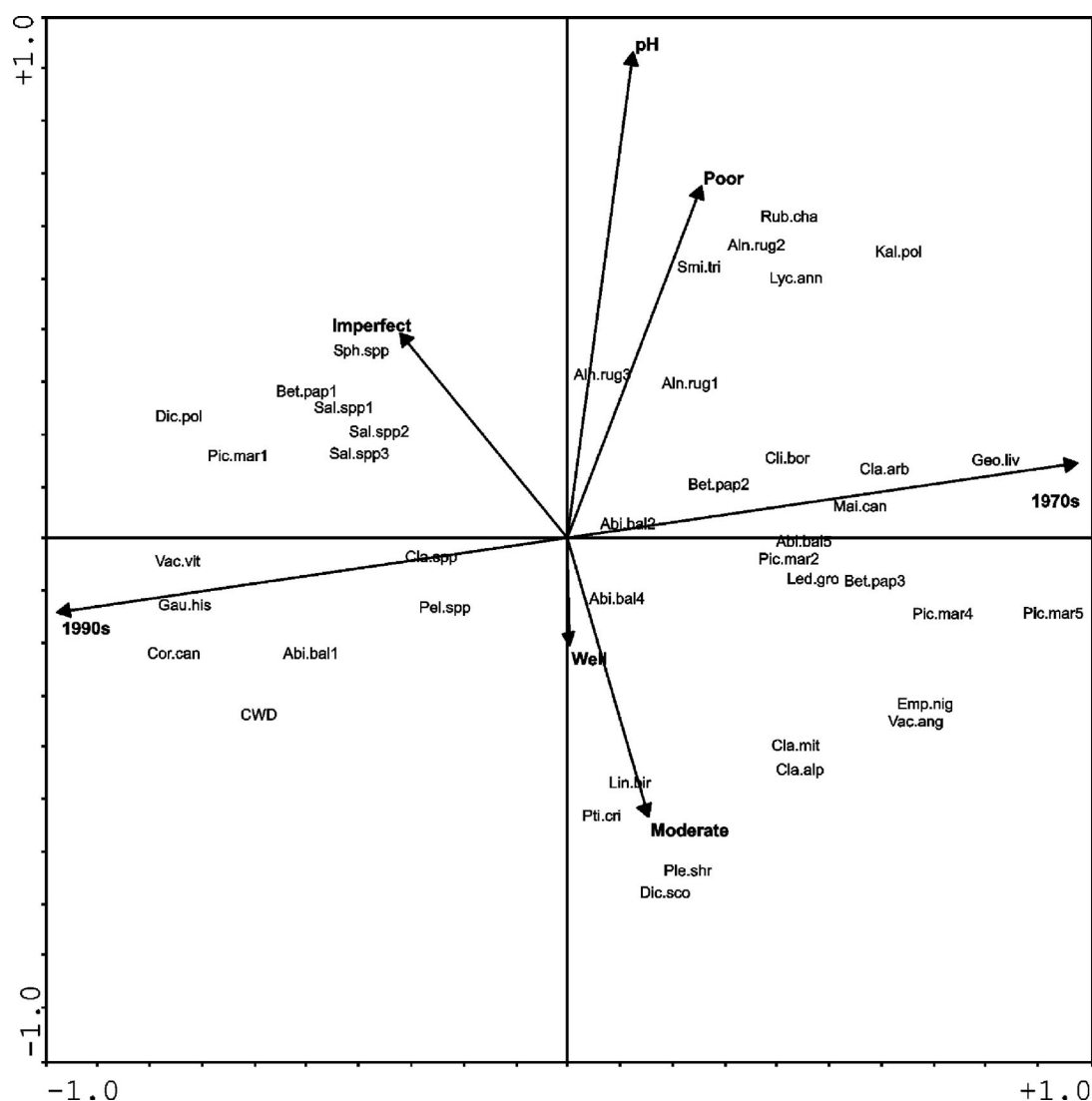
Figure 2. RDA biplot relating plant species abundance with environmental variables. Environmental codes are given in Table 1 and vegetation codes are given in Table 2.

canadensis were associated with 1990s logging. *Sphagnum* and all diameter classes of *Salix* spp. were positively associated with imperfect drainage and moderately associated with pH and 1990s logging. *Rubus chamaemorous*, and *Smilacina trifolia* were positively associated with poor drainage and pH, and *P. schreberi* and *Dicranum scoparium* were positively associated with moderate drainage.

Using only the 1970s logging data, no variables that we measured were statistically significant predictors of regeneration. Using only the 1990s logging data, we retained logging method and drainage for final ordination (Figure 3). All canonical axes were statistically significant ($F = 2.000$; $P = 0.005$) and explained 60.0% of the variance in the vegetation data; the variance explained by the first and second axis were 29.9 and 19.3%, respectively. *A. balsamea*, 0–4 cm in diameter, and all diameter classes of *A. rugosa* were positively associated with stripcuts. *P. mariana*, 0–4 cm in diameter, were positively associated with clearcuts. *Vaccinium angustifolium*, *Ledum groenlandicum*, and *Ptilium crista-castrensis* were positively associated with stripcuts. *Gaultheria hispidula*, *V. vitis-idaea*, and *C. canadensis* were positively associated with clearcuts. *A. balsamea*, more than 4 cm; all diameter classes of *Salix* spp.; and *B.*

papyrifera, 0–2 cm were positively associated with imperfect drainage.

The plots of mean conifer abundance showed slight logging effect on the abundances of *A. balsamea* (Figure 4). All diameter classes of *A. balsamea* were higher in stripcuts in the 1990s but were higher in clearcuts in the 1970s, except for the 0-to 1-cm diameter class. Estimates of means for *P. mariana* were relatively imprecise but showed a strong age effect with moderate differences between logging methods. In general, there was slightly more total *P. mariana* in the 1970s stripcuts, but the reverse was true for the 1990s. This difference was largely driven by diameter classes 2 cm or less. There were few trees more than 2 cm on the 1990s and there were more *P. mariana* more than 4 cm on the 1970s clearcuts.

Discussion

Stripcutting has been proposed to improve conifer regeneration over clearcutting and avoid planting costs (van Nostrand 1971, Johnson and Smyth 1987, Pothier 2000). Others have found more *P. mariana* regeneration on stripcuts than clearcuts because of the
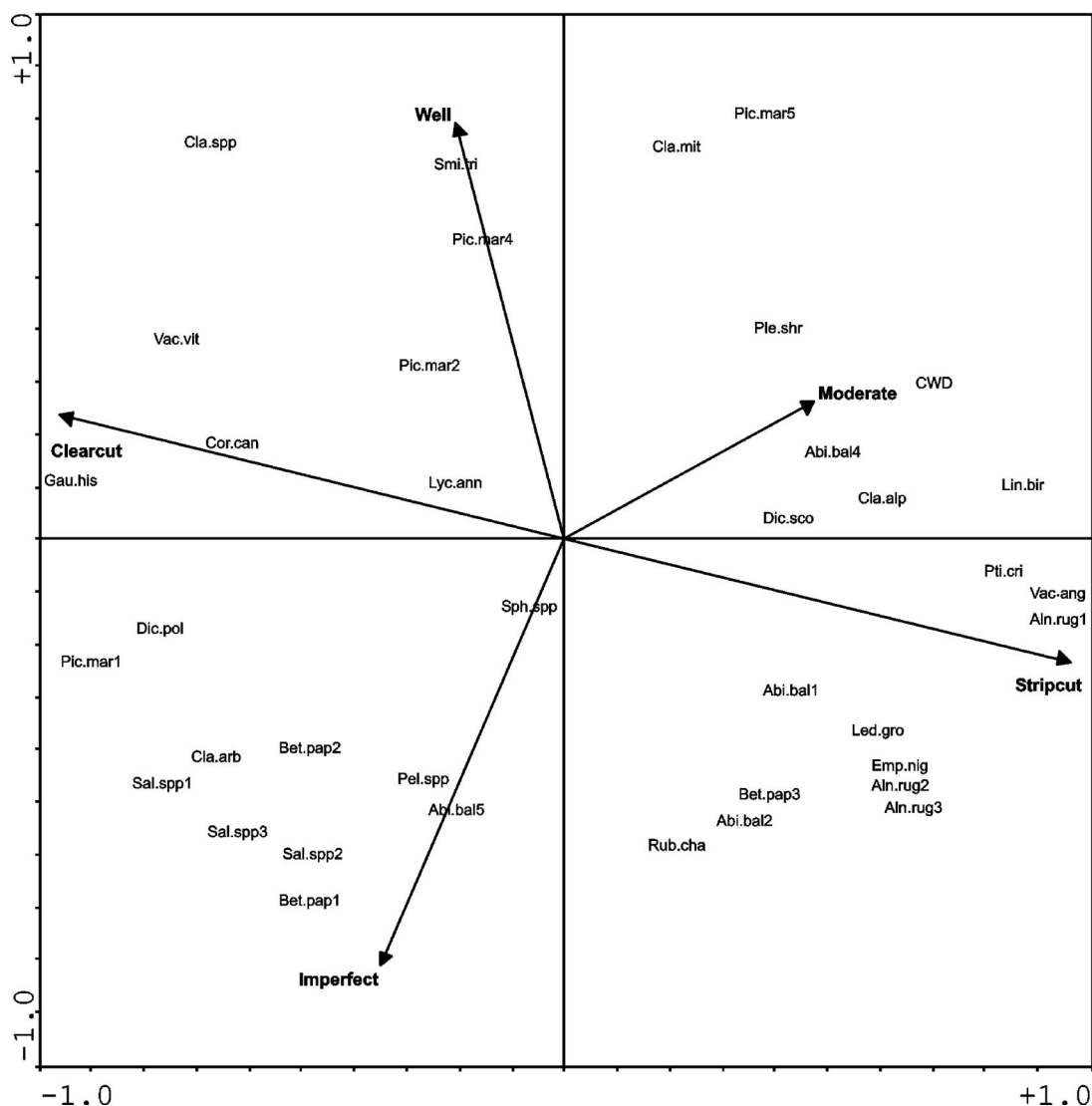
Figure 3. RDA biplot for 1990s logging relating plant species abundance with environmental variables. Environmental codes are given in Table 1 and vegetation codes given are in Table 2.

proximity of seed trees (van Nostrand 1971, Pothier 2000). Conversely, our only RDA that found logging method important was the 1990s logging data, and it showed *P. mariana* associated with clearcuts and *A. balsamea* associated with stripcuts. Our plots of mean *P. mariana* density for 1990s logging support the RDA, and our plots of mean *A. balsamea* density show weak association with stripcuts. We expected that our clearcuts would have abundant *P. mariana* regeneration because of proximate seed sources. Clearcut shapes are restricted such that maximum distance between forest canopies is 300 m or less (Forest Management District [FMD]) 19A Planning Team 2003), suggesting the maximum distance required for seed travel is 150 m or less. Limits placed on cutting caused by topography, noncommercial stands, buffers around riparian, and other sensitive areas usually ensure that the distance to seed sources for most clearcuts is much less. The effective *P. mariana* seed dispersal distance is 75–100 m (Vincent 1965, Viereck and Johnston 1990, Greene et al. 1999), suggesting that most areas within our clearcuts should receive adequate seed. In contrast, clearcut sizes in Pothier (2000) ranged from 9 to 200 ha, suggesting a greater likelihood of seed limitation. In addition, advanced regeneration also

may significantly contribute to regenerating *P. mariana* stems. Although this explains abundant *P. mariana* regeneration on clearcuts, it does not explain why there was less on stripcuts. We speculate that reduced light levels in our narrow strips (less than 30 m wide) could reduce *P. mariana* seedling survival (Viereck and Johnston 1990) and increase *A. balsamea* regeneration because it responds well to partial canopy openings (McLaren and Janke 1996, Prévost and Pothier 2003). *A. balsamea* has effective seed dispersal distances between 25 and 60 m (Frank 1990) and poorly disperses into clearcuts (Hughes and Bechtel 1997), further explaining its lower abundances on our clearcuts.

Our results indicate logging method affects regeneration for the short-term only because our RDA using all years, and the 1970s only, found logging method unimportant in determining plant communities. The effect of logging year on our RDA may be explained by different successional stages between 1970s and 1990s logging. The size distribution of trees, with the exception of *A. rugosa*, increased with stand age. This was expected because the 1970s plots had more time to regenerate. The positive association between coarse woody debris (CWD) and 1990s logging is because
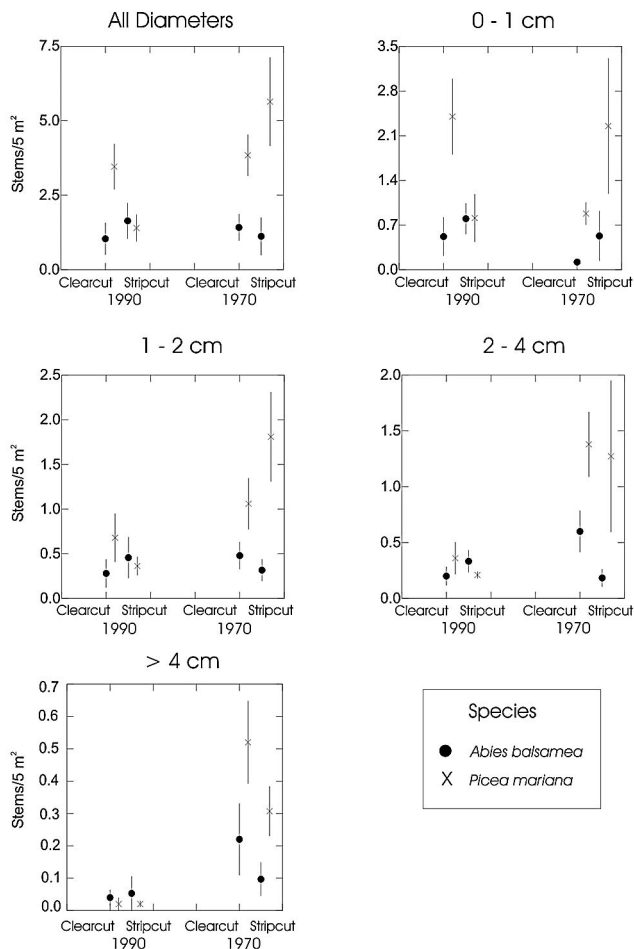
Figure 4. Mean and standard error of the number of stems/5 m² by basal diameter class for *A. balsamea* and *P. mariana* in 1990s and 1970s clearcuts and stripcuts.

the CWD is mostly logging residue, which had less time to decompose than within the 1970s logging. The distribution of most understory species appeared to be affected mainly by edaphic factors.

Our RDA of the combined years found *P. schreberi* associated with moderate drainage, similar to Foster (1984) who reported *P. schreberi* in dry, well-drained sites. Our association of *Sphagnum* spp. with imperfect drainage appears to conflict with Foster (1984) who found *Sphagnum* in poorly drained sites. We also found *Sphagnum* positively associated with pH on our combined RDA, which was unusual because it usually is associated with more acidic soils when compared woth other wetland species (Vitt and Bayley 1984, Glaser et al. 1990, Haraguchi and Matsui 1990). This association may be because all of our soil pH values were acidic and encompassed a small range (Table 1). A negative relationship with pH would be more likely if a broader range of pH values were included. In addition, our data were not species specific for *Sphagnum* and individual *Sphagnum* species can show different responses to pH (Austin and Wieder 1987). Abundances of *P. schreberi* and *Sphagnum* spp. tend to increase in shade (Hannerz and Hånell 1997, Jalonen and Vanha-Majamaa 2001), so it was reasonable to expect their abundances to be greater on stripcuts than clearcuts. However, our RDA of the combined years found logging method to be unimportant and our RDA of 1990s showed only moderate association of *P. schreberi* with stripcuts and no association with *Sphagnum*.

Previous studies in Labrador have found that slope determined vegetation abundance (Wilton 1959, 1964; Foster 1984). Slope causes the continual movement of water through the soil, which enhances aeration and nutrient availability (Foster 1984). However, we did not find slope contributed to vegetation abundance. This may not have been detected because most of the logged sites were on similar slopes (Table 1).

Our results found differences in plant abundances between clearcutting and stripcutting, but only for 1990s logging, and *P. mariana* was most abundant on clearcuts. Vegetation abundances in our study were most influenced by year of logging, pH, and imperfect drainage. Higher costs and ecological problems associated with roads (Johnson and Smyth 1987, Simon et al. 1999, Trombulak and Frissell 2000, Haeussler and Kneeshaw 2003) suggest that stripcutting should not be implemented in central Labrador to increase *P. mariana* regeneration but perhaps only where aesthetics are critical.

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